agROBOfood final report

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Summary

For centuries, farmers learned from each other when This final report describes the overall objectives, strategy and main achievements of the agROBOfood project. After an introduction of the concept of Digital Innovation Hubs, its stakeholders, and the relevance of robotics for the agri-food sector, the establishment and growth of the network of DIHs is explained. Success factors were the adoption of the regional approach with seven regional cluster coordinators and the opportunity to work with attractive open calls for innovation experiments. The network has been supported by using the following tools: website and portal, social media on Facebook, Twitter, LinkedIn and YouTube, organising events, newsletter, Github for technology mapping and access to funding information. Services are the main product the DIHs deliver. The development in the categorisation of services and how it is represented in a service catalogue and on the website is clarified. The lessons learned of the service delivery in the context of the agROBOfood project are also described. Finally, the future of the sustained agROBOfood network after the end of the project is explained. Not only are the mission, vision, added value, main products, government and initial business model described, attention is also paid to the changing environment in robotics and DIHs to illustrate the role the agROBOfood network is expected to play.

To demonstrate a variety of innovative robotic solutions and to test service delivery of the agROBOfood network eleven innovation experiments and nine industrial challenges are reported on. These experiments were all selected as part of an open call process. Included are four experiments with robotic solutions in the post-harvest food production chain, three in harvesting and thinning, one in livestock and a vast majority of twelve experiments focused on crop care management. Lessons learned from these experiments are also described.

Acknowledgement

This report is the result of agROBOfood's journey to create a pan-European network of DIHs for people working on robotics in the agri-food environment and to show a variety of robotic solutions to support agricultural processes. The results presented were possible only thanks to the hard and dedicated work of all 37 partners in the project, the 20 innovation experiments and industrial challenges, and the support and advice from the project reviewers, project officers and industrial advisory board. I also appreciated the cooperation with the other Innovation Action projects joined under the RODIN umbrella, the organisers of several events, like the yearly FIRA, were we could present agROBOfood, and Topontwerper for their support in creating this version of the final report. I strongly believe that in the coming decade there will continue to be a need for a specialised network on robotics for the agrifood sector. It is therefore encouraging to see that the journey will be continued by the agROBOfood network.

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Project Coordinator agROBOfood project.

More information: www.agrobofood.eu

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1. Objectives and concepts

Agri-food

For centuries, farmers learned from each other when it came to improving their farming systems. They created their own inventions and tested them on their family farms. Agriculture became part of the industrial revolution in the 20th century, and education and knowledge became important drivers of innovation. Knowledge was developed on plant and animal breeding, specialised feed stuff, protection against diseases and production efficiency. The 21st century has, so far, seen a shift from a central position of the farm in agri-food, to a cooperative chain of organisations, support companies and advisers working together. The digital revolution, that started late in the 20th century, is now in its hype phase. This is bringing further changes to the agri-food sector.

Now, imagine you are a small or medium-sized enterprise (SME), a start-up, or a farmer and you want to be part of an agri-food system that is future-proof. Predictions indicate that such a food system consists of production networks that will be flexible, responsive, and transparent, that it provides sufficient high-quality and healthy products and services for everyone at a reasonable cost and that it preserves resources, biodiversity, climate, environment, and cultural differences[1].

This ambition of competitive sustainability has become Europe's guiding principle for the future and is reflected in the European Green Deal. Only a thriving community of SMEs using digital technologies and data intensively, can position Europe as a world leader with a globally competitive green digital economy. The impact of digitalisation depends on the country or region you work in. If implemented properly, digitalisation has the potential to reduce disparities between EU regions and member states. This may sound very ambitious. So let's bring it back to this question: What we can do today to improve our current agri-food system or to design parts of a new agri-food system by integrating solutions based on digital technologies and robotics? The agROBOfood project revolves around this question. In this report we present the main results of the agROBOfood project and the lessons learned.

Digital revolution

Digital technologies are increasingly changing our lives, the way we work, shop, socialise, communicate, educate and entertain ourselves. Digitalisation has a proven impact on economy and society by improving productivity, quality of life and boosting access to knowledge and public services. New business models and employment patterns are emerging thanks to digital transformation. Digital technologies have the potential to reshape entire industries and value chains and to enable smaller, innovative and dynamic businesses to develop. These can bring innovative products and services to market faster, increasing their competitiveness. Predictions on the developments in ICT are made on a regular basis by Gartner (www.gartner.com) and used by many organisations for strategic investments. Conolly[2] (2022) indicates that drones, robots, sensors, 3D printing, Internet of Things, Artificial Intelligence, Virtual Reality, Augmented Reality and Blockchain will find their way in the smart farming domain and might have the power to transform agriculture. Professionals in the agri-food sectors must be aware of these upcoming technologies and decide on their usability. In the coming years, the digital uptake is expected to expand further. Societies and economies will - more than ever – be in need of policy initiatives that help them accelerate their digital capacities in order to overcome the societal challenges and the recently experienced negative economic consequences of the COVID19 crisis. SMEs, the backbone of the EU economy, will need to introduce new innovative ways of working, new business models and more innovative products.

Definitions

In this report a number of terms and concepts are used that may not be ubiquitous. The following definitions and concepts are used.

Innovation

Based on experience and looking at important innovations in the past, Lokhorst[3] identified developments in labour, technology, society, market, legislation and science as the key drivers for innovation in the livestock sector. He also described the theory of innovation as follows: According to the business dictionary[4], innovation is the process of translating an idea or invention into a good or service that creates value for which customers will pay. To be called an innovation, an idea must be replicable at an economical cost and must satisfy a specific need. Innovation involves deliberate application of information, imagination and initiative in deriving greater or different values from resources, and includes all processes by which new ideas are generated and converted into useful products. In business, innovation often results from ideas that are applied by the company in order to further satisfy the needs and expectations of the customers. In a social context, innovation helps create new methods for alliance creation, joint venturing, flexible work hours, and creation of buyers' purchasing power. There are several types of innovation, such as product, service, process, and system innovations. It is also essential that the market is addressed. Innovation is not finished before the successful introduction and application of the changed product, service, process or system in the market. Innovations can be directed at an existing or a new market. There is no strict definition or rule that can be applied to define that we are dealing with an innovation. Still, it is useful to understand that both innovation type and market play a part.

Hub

What precisely constitutes a 'hub', is subject to different interpretations. A hub is the centre around which other things revolve, or from which they radiate. A hub focusses on for instance a specific activity or authority on commerce or on transportation. In a hub things come together and are redistributed. A hub in the context of agROBOfood is a one-stop-shop for customers and stakeholders who need support. A portal where they will be helped, where people speak their language and understand their markets and business. A place where they can find the proper advisors and the knowledge directly or where they will be connected to people who can help them. This brokerage function makes it important for hubs to be part of a network of hubs.

Robotics

Robotics is a branch of engineering that involves the conception, design, manufacture and operation of robots. The objective of the robotics field is to create intelligent machines that can assist humans in a variety of ways. To better understand what 'robotics' might be, we are inspired by two quotes of Zillner and colleagues[5].

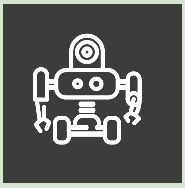
To be called an innovation, an idea must be replicable at an economical cost and must satisfy a specific need.

‘Robots create value by performing physical tasks that people cannot, should not, or will not do’.

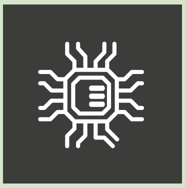
‘A robot is a programmable machine capable of carrying out a physical task or a complex series of actions automatically’.

These practical definitions for robots leave a lot of room for scientific and practical disputes of what exactly constitutes robotics, but given the common drudgery and time pressure involved in many agricultural tasks, it is not difficult to see potential applications of robotics in agri-food. The main reasons to use robots in agricultural environments are: a lack of (qualified) labour, ageing populations and the increasing harshness of production circumstances. Also, working with living material means a high variability in products, diverse quality, seasonality and high volumes. All these challenges might be managed more easily by applying robotics.

Basic modules or components of robots
To describe the basic components of a robot, we can use analogies with human anatomy.



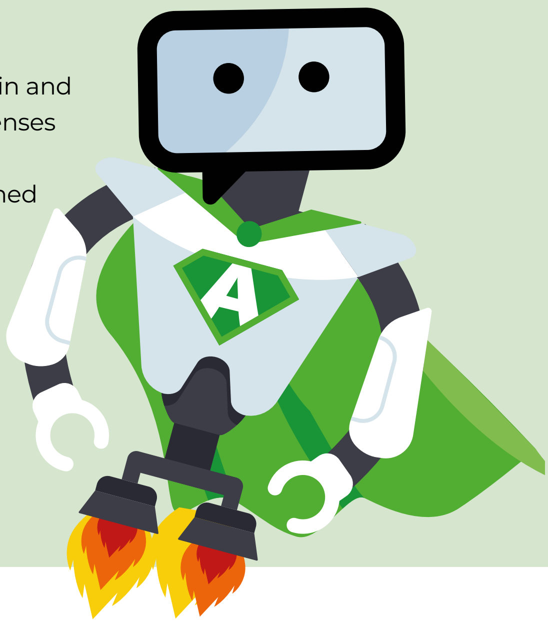
Platform: represents the body and the legs to carry the other components and that can be fixed or move in the environment the robot has to its work.



Sensors: represent the sensing capabilities to see, hear and feel to get the right picture of the world in which the robot is operating and to approach the target that is to be manipulated.

Robot arm with actuator: represents the integrated arm and hand coordination to perform the needed manipulation. Robot arms and actuators have different dimensions of freedom to operate.

Control and communication system: represents the brain and nervous system. Interpretation of information from the senses in combination with tasks expected to perform alone or together, and actual situation of the world, will be combined into actions and instructions to perform these actions. Intelligence is built into the robot itself or in overarching systems for the fleet management of robots.



The overall objective of the agROBOfood project was to establish and expand a network of mature, agri-food robotics DIHs to make the European agri-food sector more efficient and competitive.

Applying digital solutions to agri-food

Robots need to be integrated in business processes to be useful to an organisation. Increasing capacity is usually the goal. In general, there are four choices available when increasing capacity. A vast majority of European farms and companies delivering products and services, are family businesses. To increase capacity, the first choice is usually to ask more family and friends to help. If this is not sufficient, or in case the organisation is not a family business, there are three other main choices. The first is to employ people. The second choice lies in contracting or servitisation. This means signing service delivery agreements with specialised organisations. For instance a contractor who is also able to invest in high capacity and modern machinery. The third choice is to work with robots that can perform specific tasks. The most successful instance so far, is the development of robots that milk cows on a daily basis and dairy farmers learning to work with these robots.

Hubs for robotics in agri-food

A network of Digital Innovation Hubs (DIHs) has become available for robotics in the agri-food domain. Digital Innovation Hubs are one-stop-shops that help companies become more competitive with regard to their business and production processes, products or services, using digital technologies. DIHs do this by providing access to technical expertise and experimentation, so that companies can 'test before they invest'. DIHs also provide innovation services, such as business and financial advice, training and skills development for a successful digital transformation[6]. Proximity and language is considered crucial because DIHs act as a first regional point of contact, a doorway, and a way to strengthen the innovation ecosystem.
A DIH is a regional multi-partner cooperation (including organizations like RTOs, universities, industry associations, incubator/accelerators, regional development agencies and even governments)[7] and when suitable local partners may not be found, the hubs can network with other DIHs to find a matching partner elsewhere in Europe. Hubs can only become good brokers if they engage in regular technology scouting, in order to map the innovation ecosystem, and understand needs and opportunities. Structured relationships with regional authorities, industrial clusters, SME associations, business development agencies, incubators, accelerators, European Enterprise Network, European Innovation Technology Centres and chambers of commerce will greatly help the brokering function. No company can innovate alone. It will help companies greatly if they are brought into contact with other companies from their value chain, with innovators, or with early clients who want to test solutions. DIHs could for instance bring end-users and potential suppliers of technological solutions together for experimentation and testing. Or, for example, public administrations and technology companies to promote co-creation. The non-profit objective of DIHs is important in this respect, and they might encourage local companies to improve the overall economic strength of their local economy.
It is expected that in the coming years, digital and robotic uptake will further expand. The agri-food community and local economies will - more than ever - be in need of (policy) initiatives that help them accelerate their digital and robotic capacities in order to overcome the negative economic consequences of the COVID19 crisis and to become more future-proof. SMEs and family farms, the backbone of the EU economy, will need new innovative ways of working, new business models and more innovative products. DIHs by definition support SMEs in benefiting from advanced digital technologies, including robotics, Artificial Intelligence, cybersecurity and digital skills. This makes DIHs very powerful policy tools for national and regional policy makers to help support the recovery of their economies.

It is also important that people can learn from others. Awareness of others who are already experimenting with robotic solutions and being able to see and discuss these examples, is key. In part 2 we therefore show the results and lessons learned from a variety of innovation experiments that are working on robotic solutions for the agrifood sector.

Objectives of the agROBOfood project

The agROBOfood EU funded project started in 2019 as one of the five Innovation Actions. The overall objective of the agROBOfood project was to establish and expand a network of mature, agri-food robotics DIHs to make the European agri-food sector more efficient and competitive. The overall aim of a sustainable ecosystem of agri-food and robotics DIHs, has been achieved by accomplishing the following specific objectives:

ONE-STOP SHOPS: create a network of DIHs, which offer a complete service portfolio to local or regional companies. Additionally, a web portal is used as a location-independent doorway and gives each DIH access to both the local facility and the entire network of robotics agri-food hubs, covering all key European regions. A one-stop shop DIH provides access to technological, business and brokerage services.

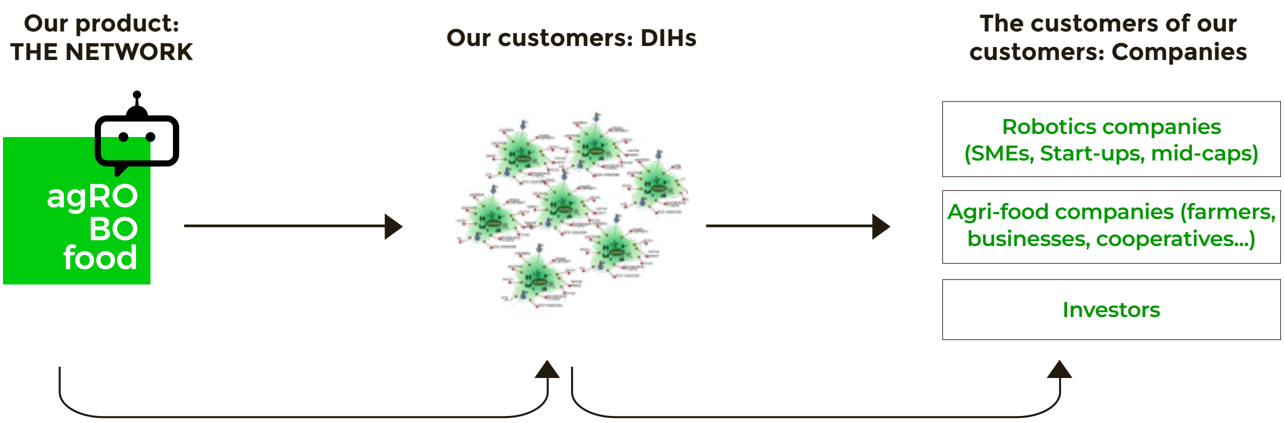
SERVICES: support agri-food industry's digitisation and robotisation through: 1. showing end-users how robots can help them and promoting their deployment and use, 2. supporting smaller organisations developing new robot products through technical, business and educational support and 3. contributing to common system platforms and industry-led standards.

VALUE DEMONSTRATION: demonstrate the value of agri-food robotics applications by 1. advertising how a system can be tailored to unique agri-food business needs, 2. let end users build hands-on experience by participating in highly-innovative cross-border experiments, 3. show the added value of DIH services.

GROWTH of the ECOSYSTEM: stimulate growth of the eco-system by attracting and fostering new DIHs in the network, collaborating within the broader ecosystem, engaging end-users across the value chain and by stimulating business growth.

SUSTAINABILITY of the NETWORK: ensure the long-term sustainability of the agROBOfood network, through developing business models that generate sufficient income to safeguard the network's viability after project completion. The legacy of the project, the agROBOfood network, will continue to thrive in the coming years.

agROBOfood network Business Model



OFFERING: European-wide contacts, best practice and training that help them to be more competitive (e.g. by offering better and more advanced services to their clients)

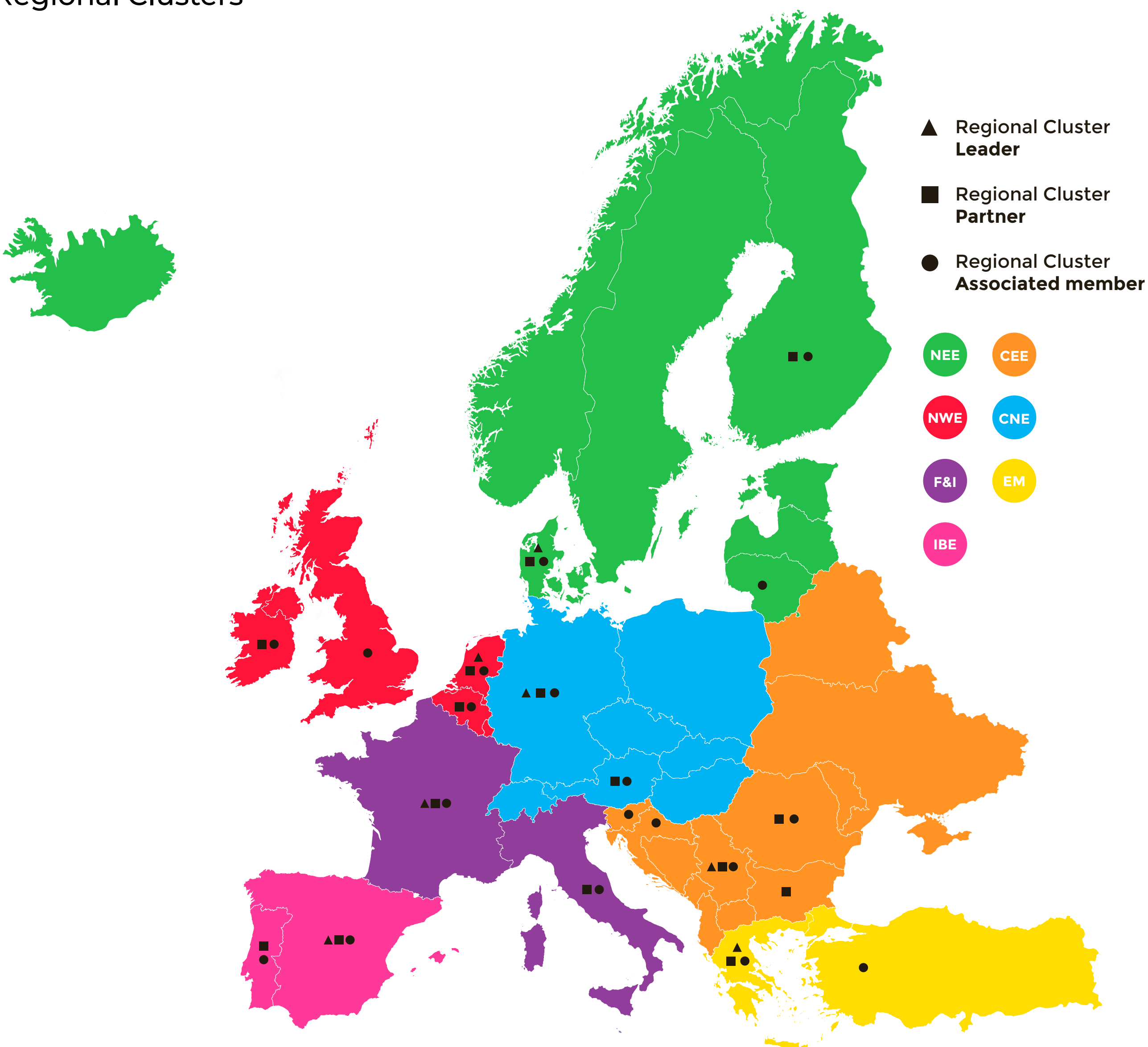
OFFERING: one-stop-shops that provide advanced specialized expertise and infrastructure to companies within their local region

2. Regional approach and network strategy for agROBOfood

At the centre of the agROBOfood network are the local DIHs. These DIHS are a one-stop-shop and give local support to all kinds of stakeholders. Their expertise is quite broad and not limited to technology. They can also advise on business, ecosystem and training services. Local DIHs should have good insights into the existing and future market for robotic solutions in the agri-food sector and be able to apply that knowledge to the specific local situation.

No single DIH can be excellent in all fields. That's where the strength of a network comes into play. Local DIHs align their activities with other DIHs in the same country, with one DIH acting as the national contact point and representative in the pan-European network. The number of one-stop-shop DIHs depends on the size of the country and the variety of agricultural and food subdomains present there. Working together nationally and specialising locally, promotes excellence and avoids

Regional Clusters



Region	Total	DIH members	Business members
North East Europe	24	17	7
North West Europe	63	35	28
France, Italy	23	8	15
Iberia	36	14	22
Central Eastern Europe	27	13	14
Central North Europe	28	15	13
East Mediterranean Europe	28	11	17
TOTAL	**229**	**113**	**116**

every region or DIH needing to invest in all competences necessary for the digital transition. This structure also entails that DIHs are expected to offer their services not only in their specific region, but also to the other regions that are part of the agROBOfood network. All current DIH members of the agROBOfood network can be found on the website and in the members portal. They can be identified by country and by sector.

The same principle applies to the pan-European network of DIHs. On the one hand, DIHs are meant to be one-stop-shops for their customers, on the other, they are part of a network and share expertise to be stronger together. To be able to deal with the large differences between European countries and to make the whole network more manageable, we have divided Europe into seven regions. Each region has a Regional Cluster Leader, whose role is 1) to connect regions, 2) to stimulate further development and professionality of the network of DIHs by identifying where coverage is lacking and 3) to organize market information and insights that can be used in the region itself, but also at the European level. These regional clusters are the 'eyes and ears' of the agROBOfood network. One of the regional cluster leaders has the role of agROBOfood network coordinator.

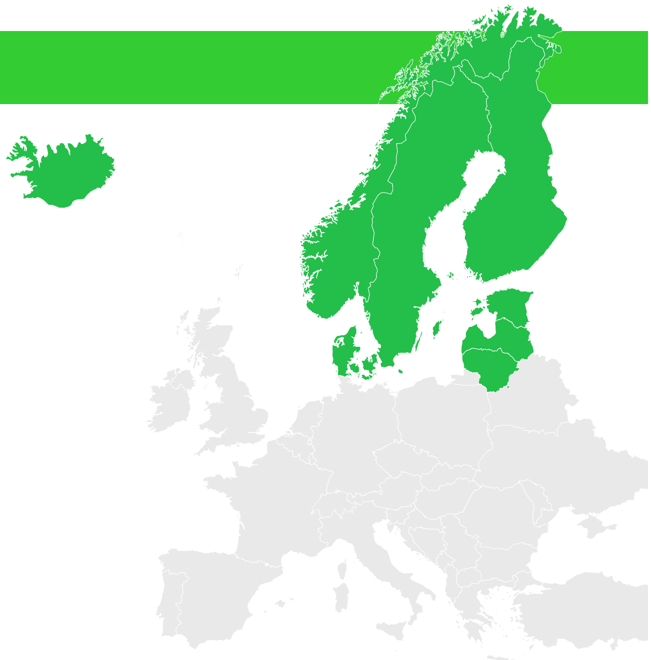
In the following sections, we describe and specify the challenges and needs of the seven regional clusters in the agROBOfood ecosystem. The following table reflects the number of organisations the DIH members (DIHs and CCs) and Business members (SMEs, Start-ups, LSEs, others) are involved with, as of April 2023. More current information can be found on the agROBOfood website.

Currently, there are 113 registered DIH members (DIHs and CCs). Since 2021 we no longer distinguish between DIHs and CCs in our membership application procedure. In general, DIH members in the agROBOfood network are aware that they are expected to support their members not only on technical issues, but also on business, ecosystem and training issues. Our catalogue includes 116 business members, of which 78 are SMEs and 45 are other types of businesses and organisations. We prefer to also register business members, in addition to our DIH's, as they can provide direct contacts and possibilities in brokerage activities. Being part of the network provides benefits from the 'members only' information that is provided in the agROBOfood portal (D6.12). Between 2019 and 2023 the number of members in the agROBOfood network has grown continually.

To illustrate the regional differences within the agROBOfood network, each strategically chosen region is presented below, with a focus on agri-food and robotic developments.

Regions of the agROBOfood network

North Eastern Europe



Countries in this region

North Eastern Europe[8] is a large and diverse region, consisting of: Denmark, Iceland, Norway, Sweden, Finland, Estonia, Latvia and Lithuania.

Agri-food characteristics

In this region, agricultural production ranges from growing cereals to forestry and from dairy cattle to meat production and fishery. The Northern countries in this region rely more heavily on fishery and forestry, whereas the countries to the south and east of the Baltic sea have more land devoted to intensive agriculture and animal rearing. The agri-food infrastructure is characterized by a highly-educated workforce and much emphasis on innovation and technology. There are many start-ups and established companies developing robotics, also for use in agriculture and fisheries.

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Developments in robotics

Robotics are important to the economy of this region. Governments are generally investing in the development of AI and support technological innovations. Denmark is a global hotspot for new and aspiring robotics companies and has more than 300 companies focussed on robotics, automation, or drones, that employ a total of approximately 8,500 people[9]. In Norway, agritech companies are booming, many with a global market focus[10]. Potential revenue is expected to grow by 6.31% annually[11]. Sweden has a very high rate of robot adoption with 80% of Swedes welcoming robotics and AI. The Swedish trade unions openly embrace this new transition and the country spends 3% of the country's gross domestic product on research and development. Finland is known for its excellent education system and the country ranks top 10 worldwide, for using industrial robots. The number of robotic innovation companies is increasing rapidly and Finnish universities and research institutes are investing heavily in engineering and testing[12]. Agricultural robotics are expected to help overcome the challenges of labour shortage in the agriculture industry across Scandinavia. In Iceland, the fish processing industry plays a key role in the adoption of robotics: they are the country's second largest export product. Estonia's government is leading the way in AI implementation and creating a model for other countries to follow[13]. It could still improve support for research and development in order to enhance its competitiveness and ensure sustainable development[14]. The Latvian government released a national AI strategy, focussing on teaching expert-level and management-level specialists to help support digital transformation[15]. The Lithuanian robotics sector is still in the early development face. Labour is still relatively cheap here, but as robots become cheaper and more available, and wages rise, innovation will pay off. Robotics can be more efficient in terms of costs, waste and energy[16].

Perspective

In North Eastern Europe the perspective for robotics and digitization in the agri-food sector is excellent. Most governments and societies are well-prepared and invested in these developments. Companies in robotics and AI will continue to grow both in numbers and in turnover and output. The need for knowledge on the implementation of technical solutions is evident, however. The sector is also under governmental pressure to take greater responsibility regarding the green agenda. Robotics and automation are just two of a wide range of (costly) initiatives that farmers are supposed to prioritise.

North Western Europe

Countries in this region

North Western Europe[17] onsists of: The Netherlands, Belgium, Luxemburg, United Kingdom and Ireland.

Agri-food characteristics

In this region, agricultural production revolves around horticulture, vegetables, granivores, and other permanent crops[18]. Plant breeding is a specialisation of this region and agri-food products are exported worldwide. The livestock sector is highly specialised in dairy, sheep, pig and poultry production systems. Wine production and insect farming are upcoming. The agri-food infrastructure is characterised by its highly specialised and optimised production methods and organisation of production chains. Many agri-food markets in these countries are dominated by retailers and food companies. However, a transition to more organic and sustainable farming systems is ongoing.

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Developments in robotics

Achievements in this region include increasing awareness in the engineering and technology community of value sensitive design methods and ethical, legal and social aspects related to robotic innovations in agri-food. The relatively highly-developed robotics competence in North Western Europe makes it possible to organise well-attended webinars on a range of topics including post-harvest design, strategies to promote regional strengths, and live online robot demonstrations. In addition to supporting the open calls in the agROBOfood project, DIHs in this region support businesses in the region to attract financing through the Pitch Your Robot events, Venture Capital funds and Business Angels programmes. Furthermore, the region extends the network beyond the borders of the EU, by fostering collaboration with the UK-based Agri-EPI Centre.

Perspective

Challenges in the region include a wide diversity in user-acceptance of robotics. For example, while dairy milking robots are well-established and automation is well-integrated in greenhouse horticulture, user-readiness for the application of outdoor robots in arable crops is much lower. Building trust with end-users will be key for adoption of these innovative technologies to succeed. Incorporating value sensitive design at initial stages of product development is also very important.

France & Italy

Agri-food characteristics[19]

More than 30% of agricultural output in Europe in 2020 was attributed to production in France and Italy. France's largest agricultural sector is animal rearing, followed by cereal production and wine. Vegetables, horticulture and fruit growing are also significant. Italy's farming is mainly related to crops, both permanent (such as vineyards, orchards and olive groves) and non-permanent (cereals and seed crops). Livestock rearing plays a smaller but significant role in Italy.

Developments in robotics

Relative to other agROBOfood regions, the growth rate of agROBOfood membership in this region has unfortunately been weak. This is a bit odd, considering the characteristics of Italy and France. A review of all sectors (excluding the financial sector) in 2022[20] shows that the percentage of enterprises using industrial and service robots are quite uniformly distributed across Europe, with Denmark and Finland leading the way. The mean percentage of uptake of robotics is 5.26%, with Italy at 6.1% and France at 5.6%.

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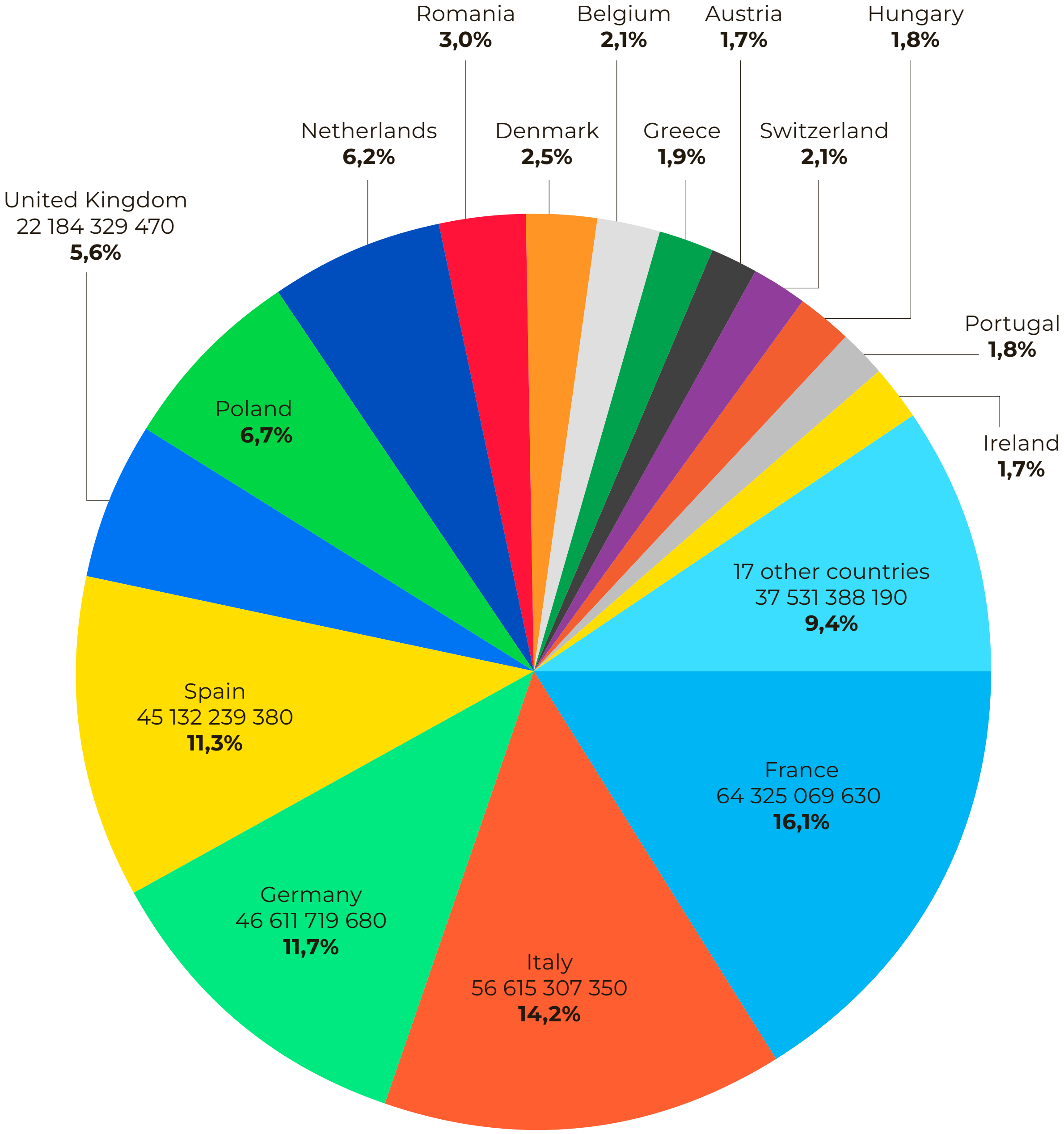
Perspective

Considering the characteristics of this region, the perspective for the use of robotics and digital technology in France and Italy should be good. However, despite several attempts to demonstrate the unique positioning of agROBOfood as a European platform to create synergy and added value, we could not yet generate enough active interest for the network from relevant stakeholders in Italy and France. For example, our proposal for a block membership to agROBOfood of all members of RobAgri[21] association has not been supported yet. RobAgri has 80 members and is very active in France. The association includes manufacturers, start-ups, equipment suppliers, research, technical and educational institutes, competitive clusters and agricultural users. A similar situation was found in Italy, where FEDERUNACOMA[22] (The Italian Agricultural Machinery Manufacturers Association) is an example. We were successful in France with a two-day event jointly organised with INRAE and the CNRS-2RM network in Toulouse. In Italy our Innovation Experiments were presented at the EIMA fair held in Bologna Italy in November 2022. There are several reasons for the low rate of participation in the agROBOfood network in this region. The effectiveness of the regional orchestrators played a role, as did the availability of national funding and other opportunities. It is however encouraging to see the growth of the FIRA events in Toulouse. These are becoming the 'place to be' when you are interested in the use of robotics in agriculture.

France & Italy

Farm Indicators - 2020



Agricultural output in Europe in € and in percentage of total.

Iberia

Countries in this region

Spain and Portugal

Agri-food characteristics[23]

Spain is the fourth largest exporter of agricultural goods in the EU and the seventh in the world. The main products exported from Spain are cereals, citrus fruits, olive oil and wine. Portugal produces mainly wine, olives and grains and has an upcoming almond sector. Thanks to Iberia's mild climate and extensive irrigation, many crops can be produced early in the season, giving the regional agricultural sector an advantage over European countries further to the north. In Spain, the number of farms is decreasing and there is a tendency towards farm specialisation. In Portugal, the sector is still dominated by smallholders, mostly ageing farmers, with low education levels. Portugal has a relatively low agricultural productivity compared to its European counterparts: the average production per hectare is 1,400 euros in Portugal, compared to 2,400 for the Euro zone and 1,700 euros for Spain.

Developments in robotics

Agricultural production is growing in this region, as is the productivity of agricultural land per hectare. Although there are no large-scale enterprises that operate in the European agri-food robotics market, we do see a lot of energy in start-ups and SME companies. This was also apparent in the open calls of agROBOfood. These robotic companies mainly focus on replacing labour in plant production systems, either in open fields for vineyards and fruits or in the Almeria region for horticulture. The investment climate for these companies has improved substantially.

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Perspective

Considering the characteristics of this region, the activity of start-ups and SMEs and the investment climate, the perspective for the use of robotics and digital technology in Spain and Portugal is very good. The biggest challenge will be to demonstrate that there are also good business models and experiences with robotic solution in the agri-food sector for the home market.

Central Eastern Europe

Countries in this region

Central Eastern Europe[24] includes the following countries: Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Romania, Moldova, Ukraine, Bulgaria, North Macedonia, Albania and Montenegro.

Agri-food characteristics

Extension-type agriculture is significant in most of Central and Eastern Europe. While it has contributed to meeting food demands and driving economic growth, challenges related to environmental sustainability and social inclusivity persist. By leveraging EU funds and adopting innovative approaches, countries can navigate towards a more sustainable and resilient agricultural sector that ensures long-term food security while addressing environmental concerns and supporting the livelihoods of small-scale farmers. In contrast, there are also very large scale farms in Central and Eastern Europe, specialised in the production of grains. Ukraine for instance, is known as 'the grain shelter of the world'.

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Developments in robotics

Central and Eastern Europe show a large variety in terms of technical development of robotics and their application in the agri-food sector. However, a set of common challenges exists for the countries in this region. The start-up ecosystem has grown and developed significantly in recent years, thanks to various institutions and organisations dedicated to supporting start-ups in the region. Incubators and accelerators like Techstars, Startup Wise Guys, and Startupbootcamp have emerged to provide early-stage start-ups with mentorship, resources, and networking opportunities. Co-working spaces such as HubHub, TechHub, and Impact Hub have become popular, offering collaborative environments for start-ups to work and connect with like-minded individuals. Venture capital firms, including Earlybird, Speedinvest, and Credo Ventures, have played a crucial role in funding and supporting start-ups at different stages of growth. Governments in the region have implemented initiatives such as start-up grants, tax incentives, and public-private partnerships to foster entrepreneurship and create favourable conditions for start-ups to thrive. Additionally, vibrant entrepreneurship networks and communities such as Startup Grind, European Startup Network, and Global Entrepreneurship

Network facilitate knowledge sharing, mentorship and collaboration among start-ups, investors, and industry experts.

Perspective

Developed countries in Europe have more abundant funding opportunities and a more mature start-up ecosystem than countries in Central and Eastern Europe. Venture capital investments are higher in Western and Northern Europe, with established tech hubs attracting significant investment. Investor confidence and risk appetite may be higher, too. While government support programs exist in both regions, Western Europe tends to have more comprehensive initiatives. However, the start-up landscape is evolving in Central and Eastern Europe. Venture capital activity is increasing, as are efforts to foster entrepreneurship.

Ukraine war

In the war-torn state of Ukraine, the development of drones and robots in agriculture has taken on added significance. With disruptions in traditional farming practices and a shortage of manual labour due to the conflict, there is a growing need for innovative solutions to maintain agricultural productivity. Drones and robots offer the potential to automate tasks such as planting, harvesting, and monitoring crops, reducing the dependency on human labour and mitigating the risks associated with working in conflict zones. These technologies can help farmers continue agricultural operations despite the challenging circumstances, contributing to food security and economic stability in war-affected regions. The ongoing conflict has likely accelerated the exploration and implementation of drone and robot technologies in Ukrainian agriculture.

Central Northern Europe

Countries

Central Northern Europe[25] consists of: Germany, Switzerland, Austria, Czechia, Poland, Slovakia and Hungary.

Agri-food characteristics

This region is located in the centre of Europe. It contains an interesting variability and mix of central and eastern European countries and supports the cross-fertilisation of ideas and technologies to produce better products and services. With around 22% of EU farms and more than 30% of the EU's agri-food labour force, the region constitutes an important part of the European agri-food market. For example, over half of Germany's territory (51%) is used for farming purposes, while the surface area of agricultural land in Poland is 15.4 million ha, which constitutes nearly 50% of the total area of the country. The agri-food sector is well-established and diversified, ranging from large-scale commercial farming to tiny family-owned farms. On average, the total output per farm in this region was around €85K with the granivores (pigs and poultry) farms accounting for the largest output per farm.

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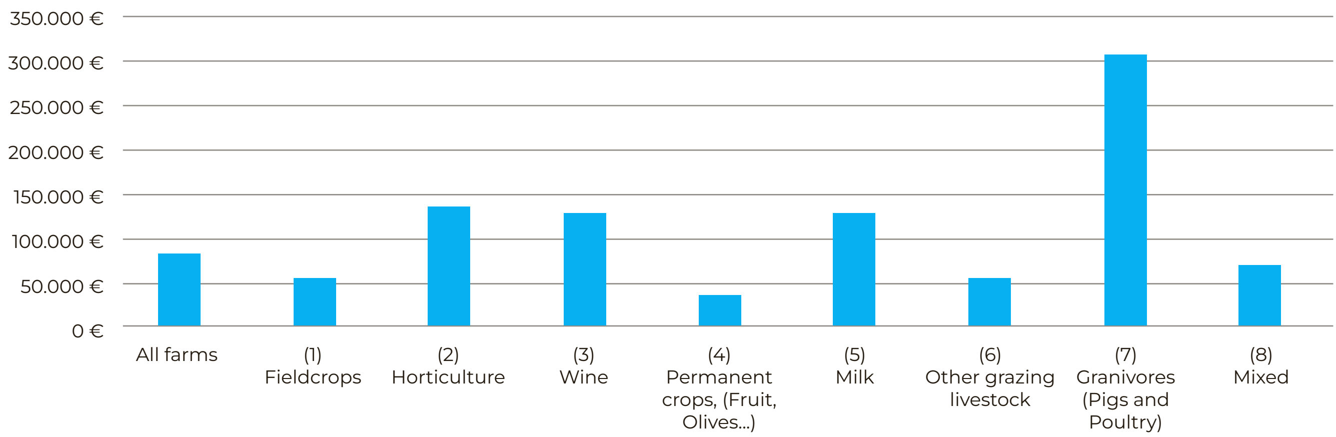
Total output / Farm (€)



Total output per farm in the Central Northern European region

Developments in robotics

The strong agricultural industry along with the adoption of sustainable agriculture in this region is driving demand for the robotics solutions to support both agriculture and livestock farmers, in order to boost efficiency, production, and competitiveness. This region boasts strong research and innovation centres for robotics technologies. They have been working on developing robotics solutions for decades, ranging from manufacturing and healthcare to agriculture and livestock industries. These centres revolve around innovation and collaboration with both industry and end-users. For example, a world-famous company that specialises in seeds for sugar beet has established a collaboration with two research institutes in order to compare the performance of innovative robotic systems (developed to combat weeds in sugar beet farming) with conventional methods in field trials. Another characteristic of the region is that technical expertise meets willing-to-collaborate end-users (farmers) here. This is particularly true in areas such as livestock, where many farmers rely on robot-supported systems. This ranges from automated cleaning and milking to quality control of milk. Robotics have become integral to the livestock industry in the region.

Perspective

In Central Northern Europe the perspective for the use of robotics and digitisation in agri-food is good. Many initiatives are already well under way. The region is home to some of the world's leading manufacturers of agricultural engineering equipment, such as CLAAS and a big number of agriculture machinery manufacturers like Pottinger and GEA Farm Technologies. This environment provides opportunities for robotics technology developers to collaborate with established manufacturers in order to bring their technologies to market. In addition, the region is home to the Agricultural Industry Electronics Foundation (AEF), which is an independent organisation founded to improve cross-manufacturer compatibility of electronic and electric components in agricultural equipment.

Eastern Mediterranean Europe

Countries

Eastern Mediterranean Europe[26] of Europe includes Greece, Türkiye, Cyprus and Israel. Türkiye and Israel are not members of the European Union, but beneficiaries of several EC funding programmes.

Agri-food characteristics

The Eastern Mediterranean Regional Cluster is defined by great variability. Countries in this region mainly focus on open field agriculture and animal production and less on industrialised agriculture. Strong points of the region are the production of vegetables in the winter, high-quality olive oil, a very professional sheep meat and milk sector, high-value crops for export, and an abundance of biodiversity.

Developments in robotics

The Eastern Mediterranean Region has unique needs, as robotic solutions are not very prevalent. The Technology Readiness Levels (TRL) have largely not been sufficient to occupy the market. This in contrast to developments in Northern European regions, where industrial robotics are fairly commonplace. This means farmers and start-ups are very keen on finding solutions that will help them work more profitably and efficiently. The real challenge is to find and develop tools that are appropriate for the needs of these countries, but also align with the standards set by the EU and the Green Deal for the preservation of the environment. National funding has so far been very limited in this region and mainly focuses on other sectors than agriculture.

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Perspective

By taking part in the agROBOfood network, organisations that originate from the Eastern Mediterranean Region benefit greatly. They can create new collaborations, develop new products and reach new markets. The socio-economic profiles of the countries in this region are drastically different from each other. There are three different currencies and each country has its specific set of laws and common practices. Because Israel and Türkiye are not members of the EU, participating in a network such as agROBOfood greatly benefits their access to new markets, such as robotics in agri-food. This can happen through the adoption of cross-regional services and best practices from other successful parties within the vast diversity of the agROBOfood network.

3. agROBOfood network services

agROBOfood network services

The agROBOfood network aspires to function as both catalyst and glue for all members of its ecosystem. Every stakeholder - from farmer and agribusiness to robotic SME and investor - has access to the services of a DIH. Each DIH is a one-stop-shop, connected to other DIHs within the pan-European agROBOfood network. This way, they can provide any agri-food company with up-to-date information, expert support, and access to technologies. All with the aim of applying digital innovations to products, processes, and business models. The hubs use business principles and a consolidated service model to help interested clients address tasks and provide services that would otherwise not be readily or easily accessible. Cross-border collaborative services between EU-providers, for example. Or access to cutting edge infrastructure or technologies. Moreover, DIHs act as intermediaries for investor relations, facilitate access to funds for digital transformation, and bring digital innovation users and suppliers together in the value chain. DIHs also play an important role in assessing private sector needs for robotic skills and their application. The agROBOfood network provides services aimed at significant changes in the European agri-food sector. Companies in the network can increase both their competitiveness and the added value of their products and services.

More detailed insights in the services provided in the agROBOfood network can be found in the 'Updated plan and results for service delivery'[27] and on the agROBOfood website and portal.

Historically, we have had a number of discussions on categorisation of services and the need for standardisation. Within the agROBOfood network we adopted a categorisation used by RODIN and the Innovation Action projects for maintenance and inspection, and healthcare. This categorisation describes services related to ecosystem, technology, business and skills and training for one-stop shop DIHs and a network of DIHs. However, recent developments and the creation of European Digital Innovation Hubs have inspired us to start using a different model as well. This is the 'Test Before Invest' categorisation model. This model is explained extensively in 'Digital Innovation Hubs as policy instruments to boost digitalisation of SMEs'[28], and agROBOfood has now adopted this categorisation for promoting services on its website.

Overview of services provided by DIHs and the agROBOfood network

Skills and training

DIHS help SMEs move their businesses forward by providing the resources to make the most of digital/robotic innovations.

- Business mentoring and start- up support
- Business model innovation booster
- Business plan development support
- Defining your digitalisation strategy

Ecosystem and Networking...

SMEs can connect, through a DIH, with other companies to explore growth opportunities and robotic solutions.

- Market assessment
- Dissemination activities
- Matchmaking & brokerage
- Access to specialist expertise
- Joint pre competitive R&D
- Project management for R&D&I projects

Test before invest

DIHS provide the testbed for SMES for their software, hardware and business models. Testing is necessary to take a solution from the lab to the field.

- Access to laboratory facilities
- Provision of tech infrastructure
- Prototyping
- Concept validation
- Benchmarking analysis
- Functional safety assessment

Support to find investments

By contacting a local DIH, SMES can find support in conducting feasibility studies, develop business plans & participate in acceleration programmes.

- Finding public and/or private funding opportunities
- Supporting in creating consortia for follow-up projects
- Support in IPR management

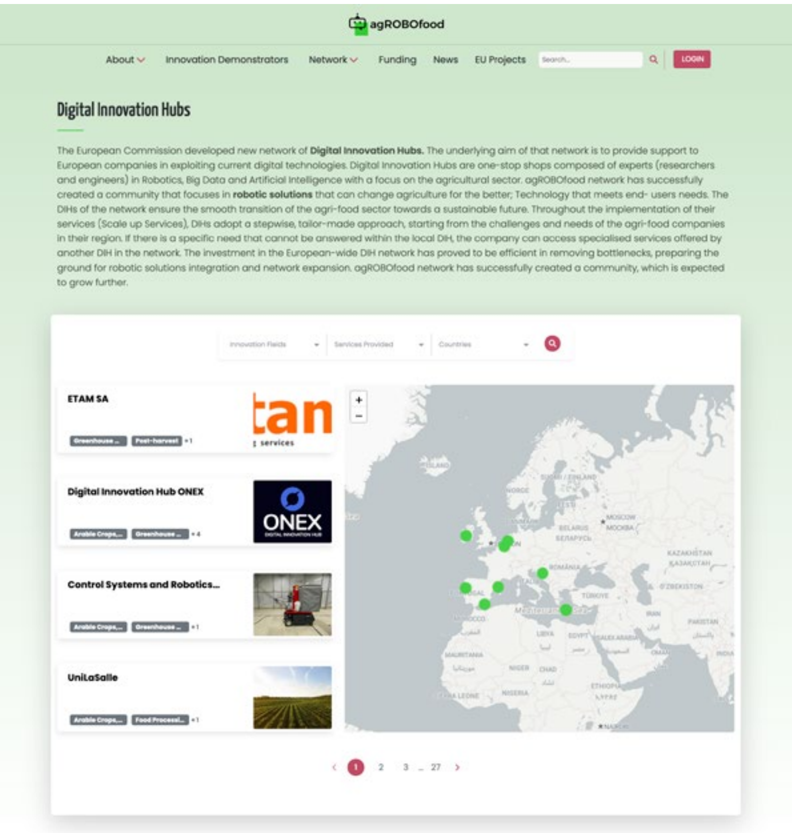
The website supports search facilities and it is expected that people can find the services on offer more easily. Of course there is always interaction needed to bring offer and demand of services together and to discuss the specifics of the service.

The content of the services is linked to a catalogue database. It is possible to search this database using six different innovation fields, four types of services (corresponding to the four TBI categories) and country location of the service provider. Search results appear on a map on the right-hand side while on the left-hand side summarised details of the DIHs matching the search criteria are visible. It will also become possible to click on the DIH summary, which will bring the viewer to a more detailed page. All agROBOfood members will also have access to contact details of business development managers and experts at the DIH, for instance. The content and contact details of the DIH can be managed by the member DIH from the portal, or via the webmaster.

Service delivery lessons learned

The agROBOfood project has been able to increase transparency in the network of DIHs, with their business, ecosystem and technical services becoming clearer to all stakeholders. The service catalogue and service coordinators were key in this. Mentoring and support for companies that are designing and developing robotic solutions, proved the added value of the DIHs. The main focus was on companies who will sell or service robotic solutions to end-users. Impact to end-users was indirect, but valuable and they were involved in the innovation experiments.

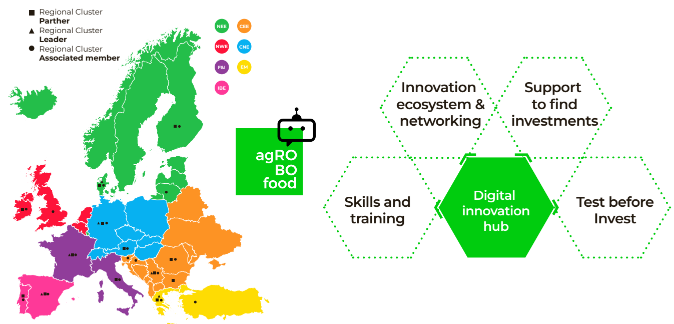
In the network there are dedicated DIHs who are engaged in standardisation and platform activities.
It was very positive that a wide range of services and robot technologies could be offered in the catalogue. With a total of 105 DIHs offered their services (technical, ecosystem, business) in the agROBOfood catalogue. The mentors and the service contact point both played important roles for the SME's involved. They could also bring good insights into current market developments to the innovation experiment partners. The services used in the experiments were appreciated greatly.



Pan-European network of agROBOfood DIHS

Skills Services (DIH-DIH)	Activities
Joint skills development	Mentoring programme, EU-skills strategy development, EU-skills summer school

Ecosystem Services DIH-DIH)	Activities
EU market place	EU website providing information to European expertise, translated to regional websites
EU awareness creation	EU events, repository good practices, common communication materials, ambassadors
EU strategy development	EU tech foresight, initiation discussions on common topics, aligned regional strategies
Representation on EU level	International business visits, informative visits to governments/industry/research
EU widening and sharing expertise	Mapping of activities, mentored DIH initiation, peer visits, background guides/manuals



Technology Services (DIH-DIH)	Activities
Creating common approaches	Standard templates/approaches on activities (testing, assessment, etc)
Pan-EU collaborative research	Initiation of joined RDI projects, programmes: facilitating exchange of researchers
Standardization	NDR/IPR approaches, tech standards, services standardisation
Smart(er) specialization	(Initiation) discussion on aligning regional investments and strategies

Business Services (DIH-DIH)	Activities
Pan-EU value chain creation	Support finding and activation of horizontal/vertical value chain part or RDI projects
EU industry market assessment	Macro/meso leverket assessment of specific innovations, including benchmarking
Pan-EU innovation fund	Development/coordination fund for trans-regional collaboration (loans & venture capital)
Organizing trans-regional collaboration	Pan-EU project development, creating import/export opportunities implementation

Experimenting with the process of service delivery in the agROBOfood project also resulted in a number of points to be improved. The service catalogue is large and was not immediately available for the SMEs participating in the Innovation Experiments. They were provided with a more simple and reduced version. We have since improved the catalogue and search options were added to the new website and portal environment. Regardless, we still advice all members to contact a DIH in person to discuss the potential needs for services. This type of intake conversations works much better than just searching online. It provides the contact person from the DIH all necessary information to find the appropriate services.

We also experienced that working in a project with partners and allocated budgets did not always resulted in quick response for service delivery. It might have been a mistake to allocate the budget to DIH partners in advance, without knowing at the start which experiments and service needs would be needed during the execution of the experiments. DIHs should be actively looking at the market developments and the agROBOfood network will provide them with many opportunities to be active outside of their own regions as well.

LEVEL 01

ECOSYSTEM SUPPORT

Offered to the Digital Innovation Hubs (DIHS) of the network, to help them optimize the process of delivering value to the market.

LEVEL 02

SCALE UP SERVICES

DIHS can help SMEs achieve business growth through the provision of specialized services.

LEVEL 03

DIGITAL AGRONOMY

Guide & support farmers in implementing agricultural robotic solutions.

4. Communication with stakeholders

When communicating with and about agROBOfood, we need to take into account whom we are talking to. Our communications are focused on a number of different types of stakeholders, each requiring a different communication strategy. Communication with our core customers and with the partners of the network is thorough and frequent. The agROBOfood network builds on an active pan-European network of DIH members, Business members (SMEs, Start-ups and LSPs with interest in robotics for agri-food) and euRobotic members. There is a big community of interested organisations (followers) and we are aware of their needs and anticipate on these needs by building and maintaining connections with e.g. investors, machine representative bodies CEMA, and AEF, (Global) network and information partner like GOFAR or Future Farming, peer projects or similar EU bodies (EDIHS, DTA, TEF, RI4EU, AIoD, JRC, etc), public authorities at EU, national and regional level, academia and the research community, and farmers' representative bodies. Additionally, agROBOfood members - especially the DIHs - can interact with cooperatives of farmers, agri-food processing companies and communities of start-ups.

The agROBOfood network has developed a specific communication strategy for each group, based on so-called customer journeys. Detailed descriptions can be found on the agROBOfood website[29].

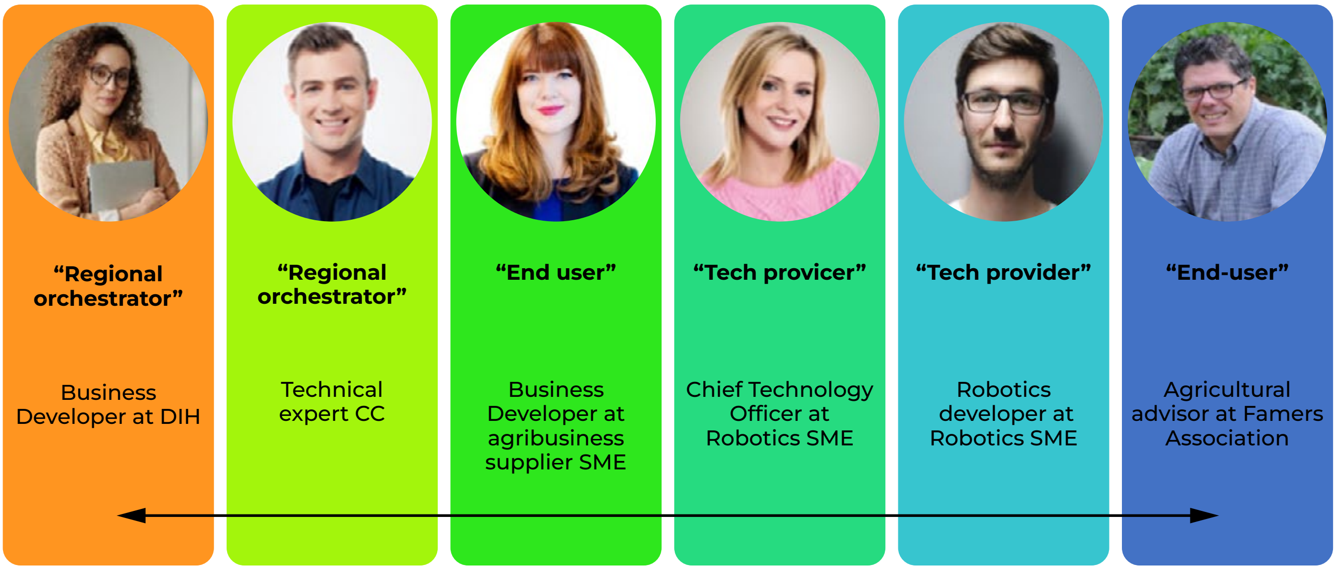
Defining customer personas

For the customer journeys six key customer personas were identified within the agROBOfood network ecosystem:

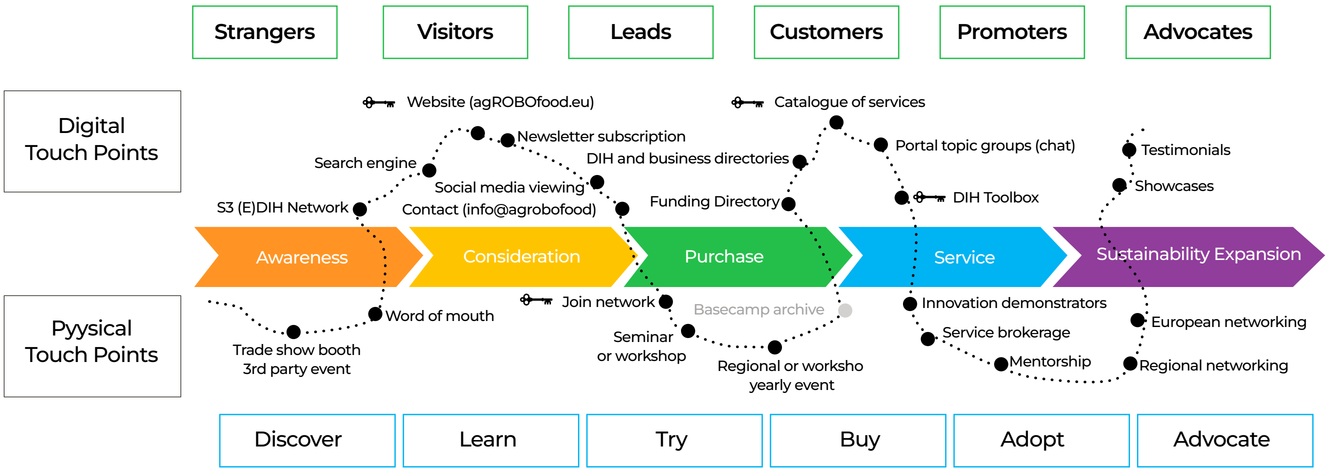
- Business Developers at a Digital Innovation Hub;
- Technical Experts in a Competence Centre;
- Business Developers at an SME;
- Technical Experts at an SME;
- Robotics Developers
- Agricultural Advisors.

All of these six personas are either DIHs and CCs (our primary target group), or management and experts from agribusiness SMEs, robotics SMEs, and farmers associations. The latter are the customers of the DIHs and CCs (our secondary target group). Services from the agROBOfood network must be of relevance to both groups. DIHs and CCs need relevant information to help them serve their customers well. With a clear view of the agROBOfood ecosystem and customer personas, we have constructed customer persona journeys. We used a model geared towards (digital) services[30] to develop these personas.

Using the model, we mapped the agROBOfood ecosystem and the customer's journey. The customer's journey can be explained at different levels. Starting from awareness, and moving sequentially to consideration, purchase (or buy-in), service and finally sustainability/



Six key customer personas in the agROBOfood network ecosystem



Map of the customer's journey across the agROBOfood ecosystem.
The dotted line is an example of an individual customer's journey through the various stages and developments.

expansion. The customer development stages are shown at the top of the graphic, from stranger to advocate; and along the bottom we see the type of behaviour the (potential) customers show at each stage of development and each stage in their journey. The development stages and their corresponding behaviours are aligned with the journey stages. As strangers, the (potential) customer gains awareness and discovers what the network has to offer; whereas at the final stage, the customer is motivated to act as an advocate of the network and contribute to the sustainability and expansion of the organisation.

At each stage of their journey, the customer has the opportunity to engage with the agROBOfood ecosystem through digital and physical 'connection points', which are tuned to the needs of the customer at that particular stage. A total of 24 touch points were identified for the agROBOfood ecosystem. The following were identified as key points:

1. joining and becoming an active member of the agROBOfood network,
2. connecting to the website, its portal environment and events,
3. becoming acquainted with the catalogue of services.

It is obvious that there are many stages in the customers' journeys and many services that may be provided at different stages. It is useful for DIHs to have insight into these different stages and needs, to be able to tailor their services to the needs of their clients. The early stages of engagement are crucial to later uptake of services.

5. Network support tools

The agROBOfood network revolves around people being able to exchange information and contacts. To support these interactions, a variety of communication tools is available. A quick overview.

Website and portal

The agROBOfood website[31] has been running since November 2019. It is a key instrument in supporting the ecosystem at both DIH, regional and pan-European level. It is the main channel for promoting the project and network. The public website showcases agROBOfood to a wider audience, promotes the Innovation Experiments and shows how technology can be adopted or adjusted to suit relevant applications and sectors. It also aims to inform people about relevant project/network events, new technology, business and sector specific developments in regard to robotics and many other topics. The website and the portal, which is only available for registered members, are maintained and updated regularly. In May 2023 the website counted 39.705 users monthly, located in 140 different countries around the globe.

Social media

Social media are used to actively post messages, invite reactions and guide people to the website. Facebook, Twitter, LinkedIn and YouTube are actively used by the agROBOfood network. Posts vary, they can be updates related to the project's progress, events organised by project partners (webinars, pitch events), videos promoting the project's activities such as open calls, events, the monthly newsletter, and the latest news and upcoming third party events of interest to the agROBOfood community. All channels have seen significant growth in the amount of users and interactions during the agROBOfood project development. Growth in engagement has flattened somewhat after 2022.

Events

The agROBOfood project has organised a number of events so far. Two main events each year were organised by the network itself. One was a yearly event with workshops, project information, presentations of practical information and round table discussions with the intention to inspire and learn from each other. Due to COVID19 we were forced to organise most of these events online or in hybrid form. Even though physical events are preferable to enable networking, it is clear that online meetings can be used effectively for information exchange. People from all over Europe participated. Also, webinars on specific topics were organised. The second yearly event we introduced was the Pitch your Robot event. Start-ups and SMEs

were challenged to pitch their robotic solution to representatives of different funding organisations. The companies participating were supported in producing their pitch deck and/or video. Over 44 companies have already been able to pitch their robotics solution. Prize winners received additional support and money to invest in their ideas. The agROBOfood network also participated in events organised by others. The yearly FIRA for instance, which is in Toulouse and attracts a mixed target audience of farmers, solution providers and researchers interested in robotics for agriculture. The organisation strives to create similar events in other parts of the world. The agROBOfood project also takes part in the FIRA scientific committee, stimulating their business members to present their robotic solution, and taking part in round table discussions. Another important yearly event is the European Robotic Forum organized by euRobotics. The audience at this event has a scientific or policy background. AgROBOfood participated in a number of ERF workshops, notably the ones on building DIH networks and exchanging best practices of developing and testing robotic solutions.

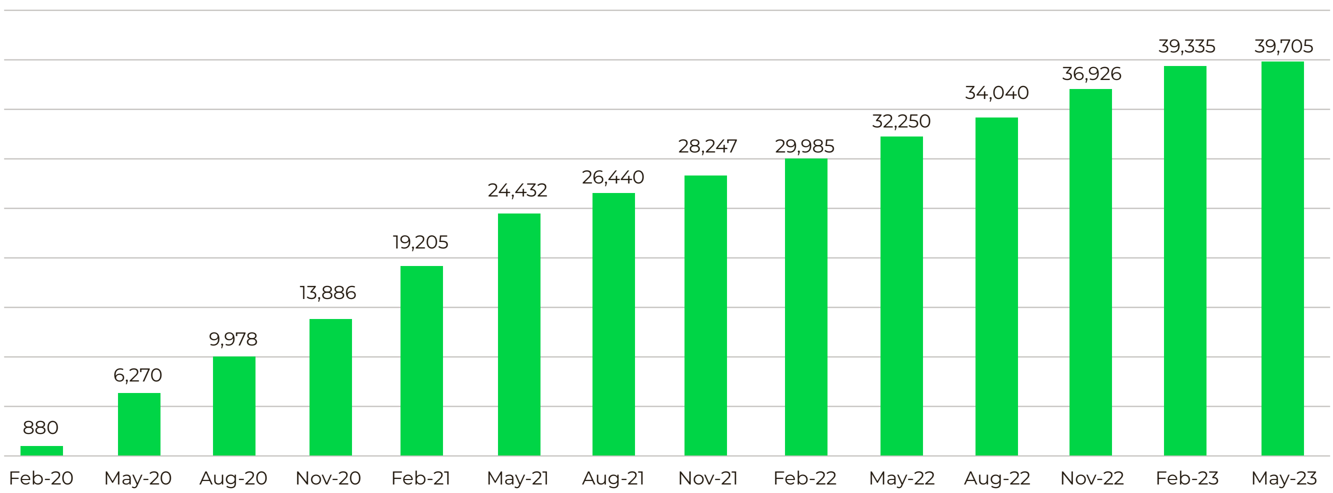
Newsletter

The agROBOfood newsletter was first released in March 2020 and has since been published monthly. Every issue is sent by email to the agROBOfood network and subscribers' mailing list. The newsletter includes a number of returning features, for instance an editorial, project news, on our radar, tv, forthcoming events, quiz, become an insider, interested in getting involved. Additionally, items such as interviews and publications focusing on current subjects and news relevant to the project are included in the newsletters. In May 2021, a new standard feature about funding opportunities was introduced.

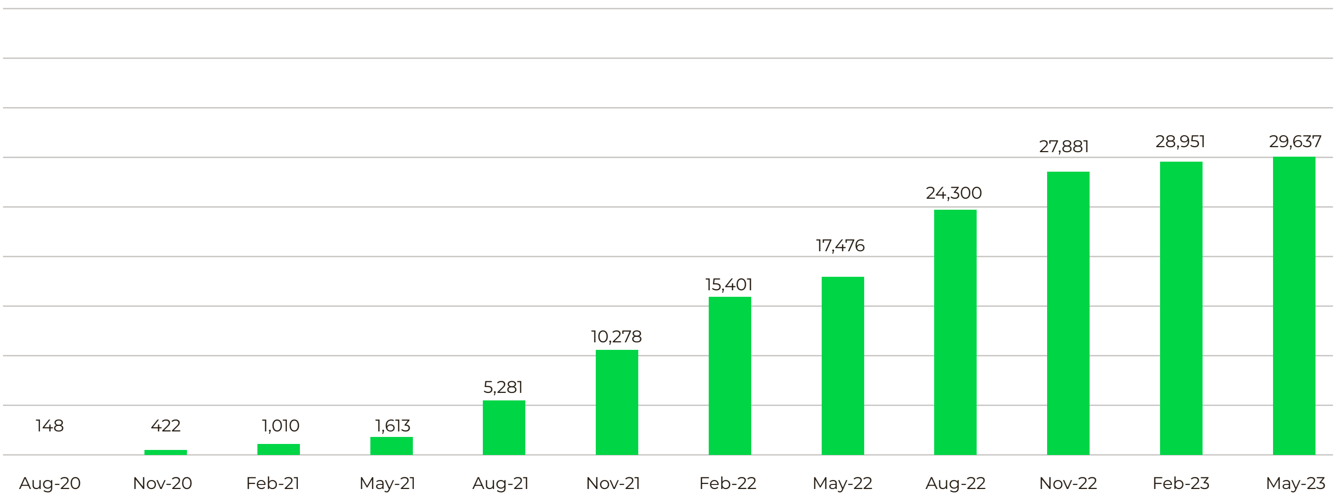
Github and technology mapping

A Github[32] page 'agROBOfood Case Studies' was also created. This page presents a number of different case studies and is aimed at people who are interested in the technical intricacies of robotic solutions in agri-food. The platform also provides background and training information on robot software platforms like ROS(2), YARP, ROCK and OROCOS, development of ROS2 components, and interfacing between ROS2 and field busses like CANopen, EtherCAT and ISOBUS. Robot security issues are discussed, focusing on attack targets and attack vectors and some common countermeasures to take. Examples of relevant standards on communication protocols, food safety, robot modularity, safety and security are also given. To support developers, best practices of open standards are also included for field busses, low-level communication, manipulation, navigation and robotics middleware. The Github is completed by some recommendations on open source licensing.

Website visits

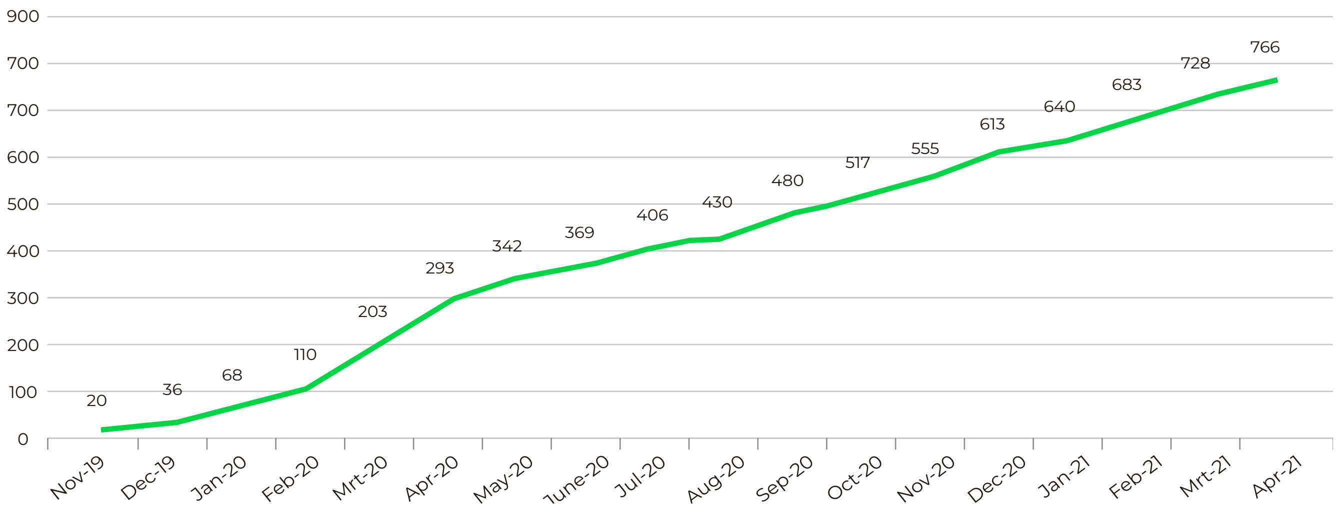


YouTube views



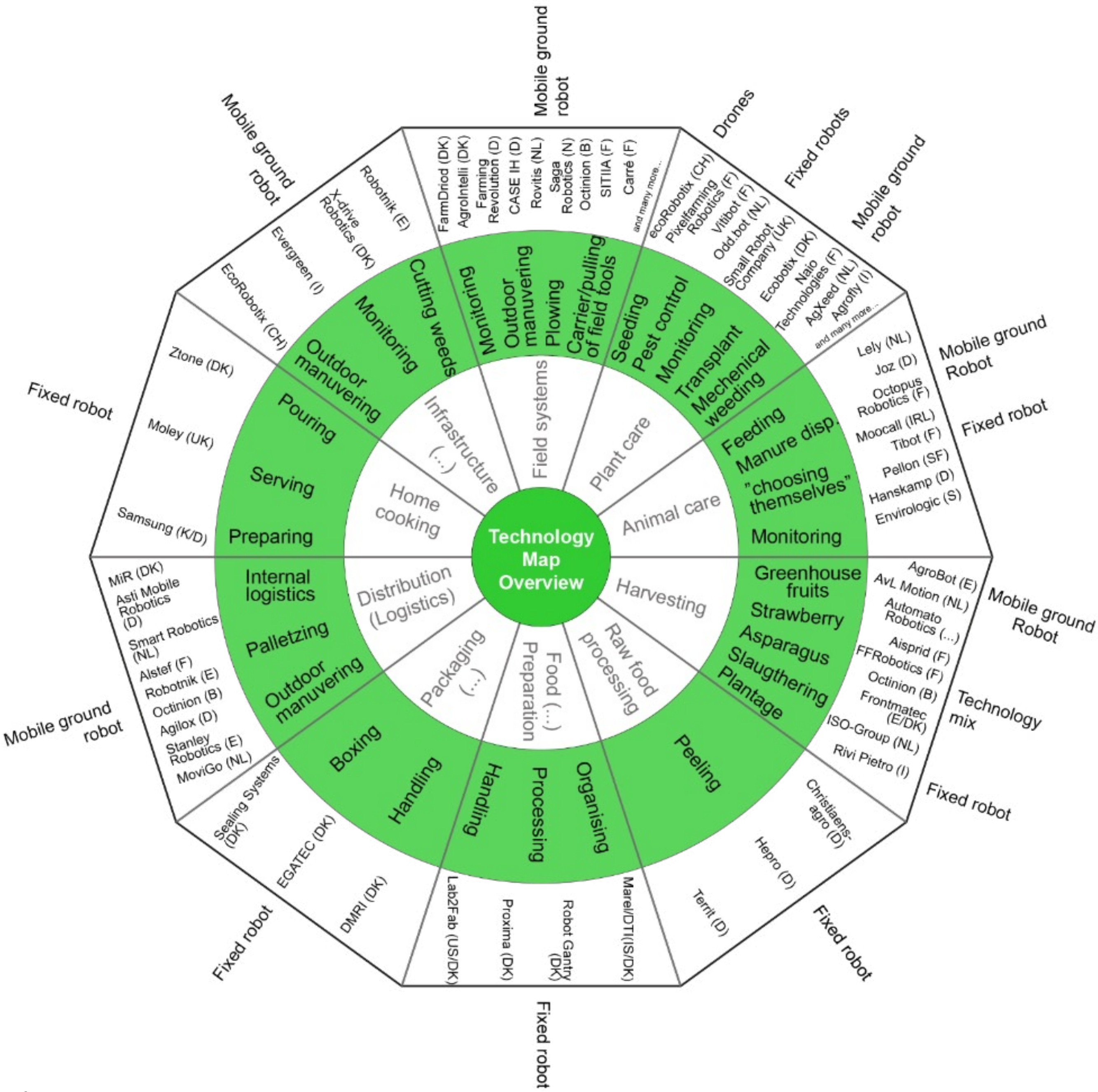
Development of YouTube views as an example of social media engagement during the agROBOfood project.

Newletter subscribers' growth



Development of newsletter subscriptions during the agROBOfood project.

In 2021, a technology map was created for robotic solutions in the agri-food domain[33]. The idea behind mapping available technologies in the agri-food sector, is to promote robot deployment and ultimately create better solutions with improved flexibility and effectiveness, better interfacing, standardisation, etc. for a lower purchase price. The scope of the technology map includes robot solutions for all aspects of agri-food. From planning and production through processing, packaging, and transportation up to the food being served at the table. It includes technologies that are already commercially available and those expected to become market-ready over the next two years. A total of 126 robotic technologies and systems were identified for the map. This map is not meant to be exhaustive, but can be used for inspiration. The map summarises our findings and shows the main applications, sub-application categorizes, companies and technology types.



Other:

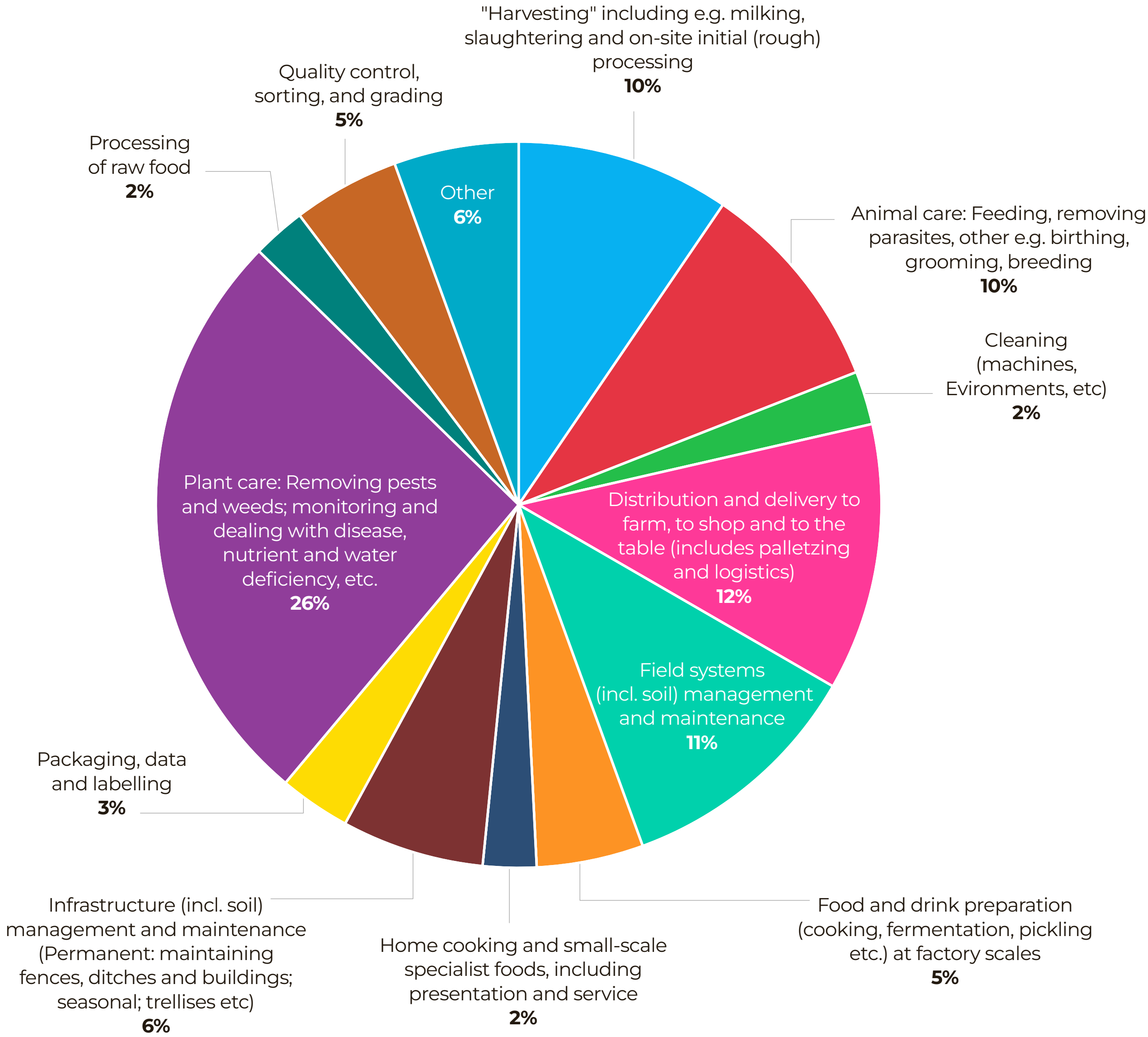
Cleaning of production facilities; Zenzoe(D)	*Support to manual labour; Comau (1)*
Multi application AGV; Acrobat (P)	*Chicken picker; Farm Robotics and Automation (E)*
Autonomous monitoring of sea; Martime Robotics (S)	*Automation for vertical farming; Codema (NL)*

When looking at the map, it is clear that a higher percentage of robots is used for plant care, logistics, and fieldwork than for other activities in agri-food. At the same time, our data suggest that robots have been implemented or will soon be implemented across the entire agricultural supply chain.

Funding information

SMEs are at the heart of the European economy. They are a key driver for economic growth, innovation, and employment. For this reason there is a wide array of European funding available to SMEs. By understanding the diverse funding sources available to them, European SMEs will be able to grow and create employment.

Main Application areas for agri-food robotics

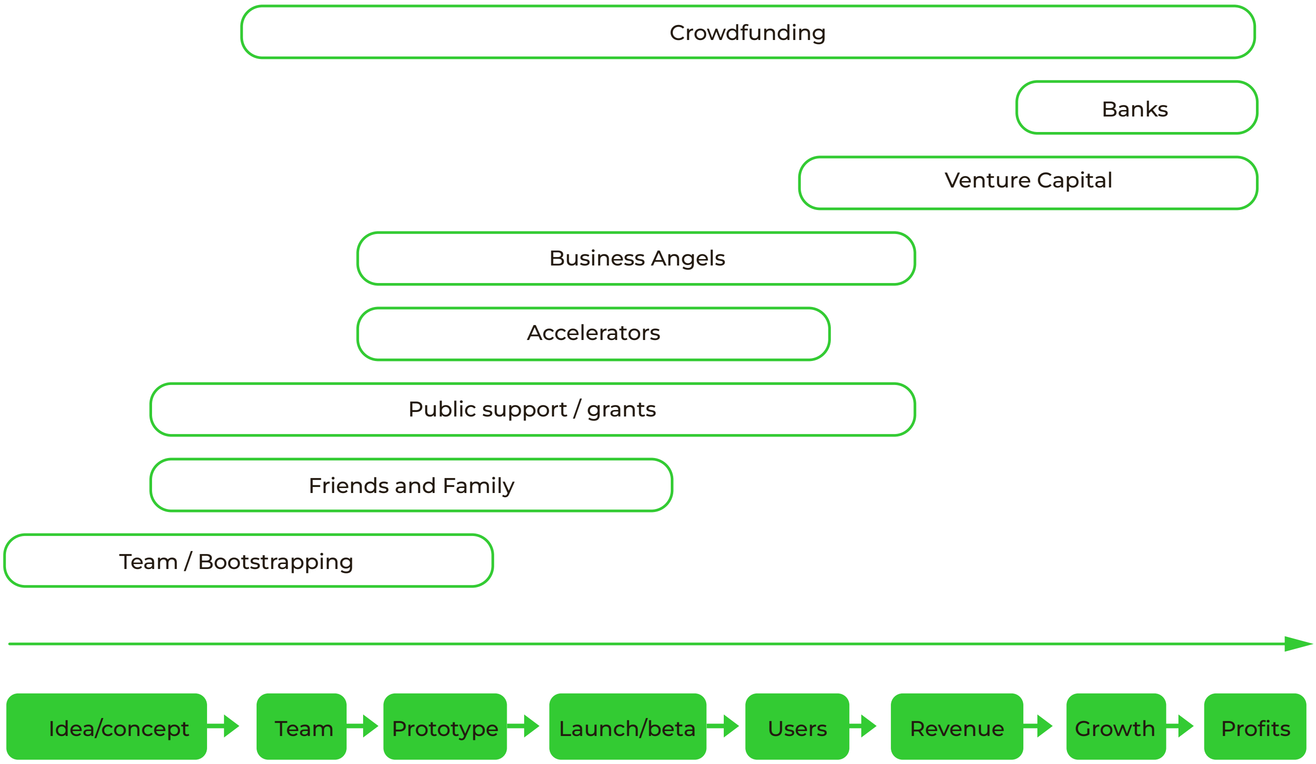


Application areas for identified robotic systems in the European catalogue

To help SMEs, DIHs, Venture Capital (VC) Firms and other EU-and regional funding agencies involved in agROBOfood ecosystem make educated choices about the type of funding they need and to help them improve their chances in grant applications and other kinds of fundraising, agROBOfood's deliverable 'General guide on potential funding opportunities'[34] was created. It provides a comprehensive overview of the financing options available to agROBOfood beneficiaries, including practical tips on where and how to access these funding opportunities.

The deliverable explains funding opportunities to SME's at the different financing stages of a company. Funding methods - such as Bootstrapping, Public support/grants, Accelerators, Business Angels and Venture Capital – are

Funding opportunities across development stages of a company



Different funding opportunities arise at different stages of development.

related to the stage of development of a company or experiment.

The deliverable 'General guide on potential funding opportunities'[35] includes:

- A detailed and exhaustive presentation of Public Funding opportunities including the fundamentals of EU Funds and Grants from Horizon Europe, Single Market Programme, LIFE and Digital Europe Programme, which are relevant in the context of agROBOfood.
- EU Financial Instruments and ways to obtain loans, guarantees and equity. Accelerator and Incubator Programmes and Horizon Prizes.
- Regional Funds analysis, including voucher opportunities (covering most of the EU Public Funding Opportunities).
- National Funding, covering in detail the geographical area of agROBOfood partners. With useful links and resources for the rest of Europe.
- The bulk of private investment opportunities, incorporating short but comprehensive guides on how to acquire funding. Angel Investment, Venture Capital, Private Equity and Debt Finance are included.
- Finally, analysis of the differences between public and private funding.

We also address funders' reasons to invest in the ag-tech sector. Insights and predictions from worldwide investors have been gathered and shared in order to understand what new investment opportunities investors are looking for. A lot of value to be 'harvested' in the agricultural robotics market, especially as seasonal field labour is becoming harder to find and increasingly expensive. One enormous challenge is that limited growing seasons mean t the robotic machinery has a lot of downtime Another big challenge is that working in muddy or dusty fields is very tough on hardware and electronics.

Our open calls for innovation experiments (which are detailed in Part 2) attracted many companies with good ideas. The innovation experiments focus on a specific part of the long journey from an idea to a product or service that is operating in the market. It turned out that all experiments were looking for additional funding for their specific next steps.

Feedback from agROBOfood Open Calls' participants showed us that EU initiatives implemented through projects such as agROBOfood, are very helpful for start-ups and SMEs, especially the ones operating in agricultural robotics sector, because companies can get money according to their technology, innovation, and not according to investors decision. We've also discovered great differences in the public funding landscape for the ag-tech sector across different EU countries. For example, there are more public funding opportunities for the ag-tech sector in France, Netherlands and Germany, while the situation in Spain is much more difficult.

It became clear during the project that DIHs can also become confused when it comes to the financing options available to them. As DIHs serve multiple purposes and provide services that are mixes of public and private nature, a common way to organize the funding of DIHs could be to use hybrid business models that combine public and private financing sources. They can also use different public and private funding sources. Public funding sources for DIHs include public local, regional or national funds, as well as European funds such as the European Regional Development Fund (ERDF), the European Social Fund (ESF) and Digital Europe Programme (DEP). Private funding sources that DIHs could use are membership fees, usage fees, or sponsorship from private actors.

In conclusion: funds play an important role in stimulating research, development and implementation of robotic solutions in agri-food. It might seem like there are ample possibilities, but it can be difficult to find the best fits. The agROBOfood network of DIHs has a large role in supporting SMEs at finding appropriate funds in their region.

6. The future of the agROBOfood network

Robotics in a changing environment

In 2019, when the agROBOfood project was started, the European robotic industry had a strong and prominent position. In industrial robotics the market share was 32% of the world market. In the smaller market for professional service robots, European manufacturers produced 63% of non-military robots. The EU agri-food sector however, was not taking full advantage of robotic technology. Robotics technology can enhance most activities in the agri-food sector using different application solutions. The technology has the potential to positively transform lives and work practices, raise efficiency and safety levels and provide enhanced levels of service. Robotics in agri-food should be welcomed in this era of digital transformation. Within the agROBOfood project, the market study 'Robotic markets in EU-landscape[36] was carried out. The key conclusions of this study are discussed below.

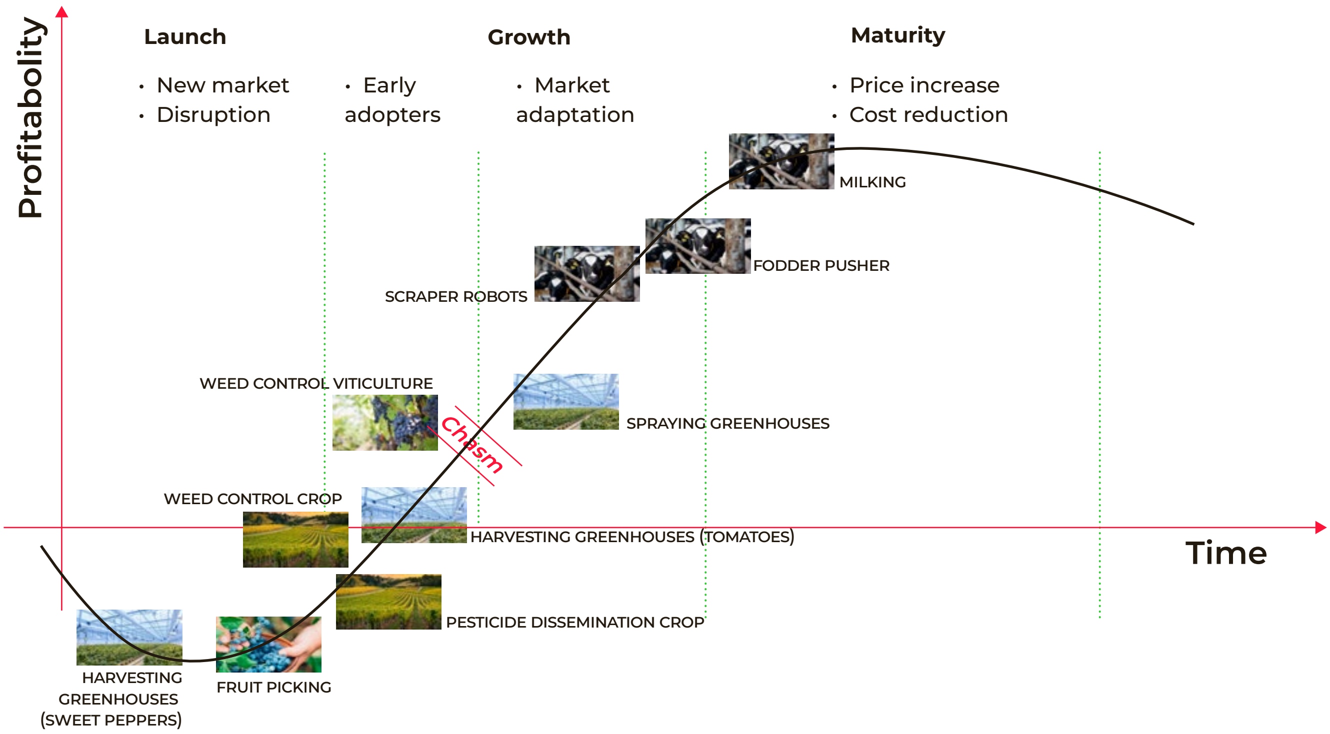
The market for robotics is complex and fragmented, characterised by great disparities. It is very difficult to accurately establish market size as studies publish varying numbers. It is also a very diverse market, with some major manufacturers of machines who are now entering the market but also a large number of small start-ups. It is very difficult for young companies to find and access their market.

Robotics for agriculture and food processing comprise a small market compared to other robotics sectors. The agROBOfood network basically comprises two distinct markets, namely food & beverages and agriculture. The market for robotics in food and beverages is a very small, worth USD 2 billion worldwide. The market for robotics in agriculture is estimated at around USD 500 million worldwide, but still very fragmented. Robots have found their place in the agriculture and food processing sectors for quite a number of tasks: material handling, palletizing, packaging and milking. Major players in the segments with the highest revenues are positioned in robot tractors (Deere & Company (US), CNH Industrial NV (UK)) or the milk sector (DeLaval (Sweden), GEA Farm Technologies (Germany), BouMatic Robotics (USA) with former SAC from Denmark, and Lely (The Netherlands)). Also the well-known company Husqvarna is collaborating with ABB to use robots in the production of agriculture, forestry and horticulture equipment in order to reduce the stress and workload on human labour.

For the other sectors, including crop farming, the main players are start-ups such as Deepfield Robotics (Germany), ecoRobotix (Switzerland) and Naïo Technologies (France). The largest category of field robots is used for weed control, which includes both mechanical hoeing robots and chemical spot spraying robots. Many initiatives aim to automate other tasks (fruit picking, planting) but the large variety of robots and the relatively small penetration indeed teaches us that the development of business cases prior to investment are key.

The driver for change and development of robotics, is usually the cost of labour. It also depends on the size of the agri-food activity, as the ROI is not always obvious for small size farms. Field crops or large-volume production (like milk or meat) are largely located in Western Europe. Market observations show an imbalance between robotic applications in Western countries as opposed to Eastern countries, where companies are smaller, which results in a very low adoption of automation.

It comes as no surprise that high-wage countries are the early adopters of robotics for agriculture. These nations feel the need to implement technologies that can save resources. Israel is also very advanced in the use of robotics. The role of research centres is also key to development and adaptation of robotics. For instance, Wageningen University and Research in the Netherlands seems to drive the adoption of robotic solutions in the country. The Netherlands is very advanced in the use of robots for many tasks and across sectors. The country also leads in terms of net added value for a large number of products. In France, investments and initiatives to support automation and robotics are on the rise, thanks to prompting by public policy. Eastern and Southern countries in Europe show a growing interest in technology that would reduce the pressure on their workforces. The robotic adoption there is driven by big farming companies, younger generations, and the pressures of climate change.



Profitability and market stages of different types of agri-food robotics. There is a chasm between robotics that are on their way to maturity and robotics still in the early stages of market development.

The feedback from most agROBOfood cluster coordinators is that organic farming is a segment that should favour robotisation. The labour cost for the sector is the highest and the added value of the products is also higher. This sector is also supported by public policy, notably in Eastern Europe, where many countries encourage the development of organic farming.

The market study discovered many initiatives for robotics in agri-food. A few of them have a national scope. But there is no real trend, nor are common goals defined among European countries. Innovation projects are scattered and relate to all agricultural sectors worldwide. Legislation is also often an impediment to the development of robotic technologies for agriculture in the European market. This holds especially true for autonomous vehicles.

Despite this lack of focus and coordination, automation and robotics could well solve challenges faced by the European agricultural sectors. For instance in mitigating the impacts of climate change. Arable crop farming is bound to be impacted the most, but vineyards will also suffer. Yields in these sectors should be supported by a focus on innovation including enhanced farming practices, crop rotation systems, improved soil management and increased usage of decision support tools with open data accessibility. This is especially important in the case of organic farming.

The use of robotics differs greatly between sectors. The dairy sector, for instance, already uses many robots. Milking robots were introduced some 30 years ago. Nowadays, more tasks are being robotised, including: animal feeding, manure scraping, and cleaning. Saving time was the initial driver for the use of milking robots. These days, the benefits of robots are generally related to performance. Feeding robots, for instance, optimise the quantity of food given to the animals. Up to 25% of farms in Denmark and the Netherlands are now equipped with milking robots. Market penetration in this sector is high. Robots for dairy farming are already in place, the market is organised and mature. In the greenhouse sector, the market for spraying robots is also making its way towards maturity.

In most sectors, however, robots are not mature. Both crop farming and fruit farming are examples. For crop farming, the main constraints lay in the regulation of robots in open terrain and the lack of an obvious return on investment. For fruit picking, the barriers are more technical. There seem to be more opportunities in the viticulture, organic and greenhouses sectors. There, the regulation for pesticide restriction is a real driver. But

Robotics for agri-food Production	
Use Case Themes (sectoral)	Key Challenges

1. Innovative/Disruptive novel agri-food systems enabled by robotics.
2. Robotics, AI, and data science for breeding.
3. Complex handling and manipulation in primary production.
4. Complex handling and manipulation in post-harvest.
5. Realizing full autonomy of already mechanized tasks.
6. AI and robotics for livestock farming.
7. AI and robotics for precision agriculture.
8. Cleaning in agri-food.
9. Connectivity, distributed intelligence, and pervasive technology.
10. Logistics and transport.
11. Ocean farming and agri-food.
12. Food preparation and presentation.

Technology

1. World modelling, simulation, and benchmarking.
2. Robot-to-X interaction.
3. 24/7 level 5 cooperative systems and fleet and swarm management.
4. Perception in robotics.
5. Multi-dimensional manipulation.
6. Interactive design of trustful, safe, and ethical robotic system.

Ecosystem

7. Sustainable pan-European agROBOfood network.

Business

8. Push-to-market for agricultural robots and systems, support, education, and training.
9. Specialized robots to be used by seasonal unskilled labor.

Training and Human Capital Development

10. Infrastructure for practical training with access to robotics.
11. Lifelong learning: connecting people from agri-food with people from robotics and analytics.

even for those sectors, the robotics market remains one of early adopters. The need to enlarge these markets is very high.

Strategic agenda for robotics in agri-food

Not only did we look at market developments for agri-food robotics, we also investigated the technological developments and challenges. The agROBOfood team - together with euRobotics representatives - produced a strategic agenda 'European Robotics in agri-food Production: Opportunities and Challenges37'. The purpose of this Strategic Agenda Document was to contribute to the development of the Strategic Research and Innovation and Deployment Agenda (SRIDA) of the AI, Data and Robotics PPP, give a broad and coherent view of the needs, applications, and key challenges for robotics for the agri-food production domain in combination with data and AI, provide a 360o stakeholder view addressing both technology, business, and ecosystem development, and give a basis for the vision, alignment, and development of programs, projects, groups, and consortia that aim to contribute to the development and deployment of robotics, AI, and data in the agri-food production network.

Reflecting on this report, it is obvious that robotics are now fully embedded in the European strategy of bringing AI, Big Data and Robotics together. EuRobotics, which is specialized in Robotics, in 2021 created a partnership with BDVA, CLAIRE, ELLIS, and EurAI and founded Adra (AI, Data and Robotics Association, asbl). Adra is the private side of the AI, Data and Robotics Partnership in Horizon Europe[38]. A second observation is that robotics' challenges are no longer fully driven by technology. There are also challenges in terms of business, market ecosystems and training. The agROBOfood project played a major role in this development, and will continue to have its impact in the coming decade.

Technology has been instrumental in the very successful development of agriculture throughout the centuries and will play a crucial role in the European Green Deal that addresses the transition to a more sustainable agri-food production in the years that lay ahead of us. It is expected that Artificial Intelligence, data technologies, and robotics will be leading in this transition. It is critically important to support agri-food production with novel technologies during the transition. Across the entire value chain - from breeding, through on-farm production, post-harvest storage, logistics, packaging, and food processing - the agri-food production network is an ecosystem providing agri-food products and services. Other off-farm production types should also be taken into consideration, such as : harvesting of wild food, fisheries, indoor farming, home growing, forestry, and, urban landscaping and maintenance. Robot technologies can and will be applied for all of these uses as well.

The strategic agenda mainly focuses on the food production part of the equation. As it is a working document, the authors express the hope that it will serve as a basis for further elaboration to encompass the whole agri-food domain in its full width and depth. With an emphasis on robotics and to a lesser extent on AI and data, this report provides a vision and mission on what robotics should contribute and how to facilitate the transition to a more sustainable agri-food production. In the report, key challenges in terms of technology, ecosystem, and market are derived from twelve use-case themes within the agri-food production domain. Use-case themes represent classes of functionality (of technology) that go beyond specific individual applications and application domains. They indicate a direction and can be useful to make longer-term investment decisions. Key takeaways of the strategic agenda are listed in the following table.

DIHs in a changing environment

The concept of Digital Innovation Hubs was introduced quite some time ago. DIHs started as Competence Centers that were specialised in technology issues on robotics. In general, these CCs were based at universities and research organisations. CCs were the core of the DIHs, which initially had a more local orientation. However, over time, a much broader service package was developed and partners became involved. Based on the need to cooperate and benefit from each other, networks of DIHs were created on regional and European levels. Based on the SPARC partnership between the European Commission and euRobotics, five pan-European Digital Innovation Hub Networks have been created as a Horizon2020 project. The agROBOfood project is one of these. It started in June 2020 and ends in February 2024.

The European environment around agROBOfood and its partners is subject to constant change. The DIHs are part of the new Digital Europe Programme (DEP), but in the meanwhile the European Commission established new European Digital Innovation Hubs (EDIHs) as legal entities with a non-for-profit objective. DEP envisions that EDIHs can support the broad uptake of AI, HPC and cybersecurity, in both commercial and public sector organizations. EDIHs are to provide services in the fields of test before invest, skills and training, support to find investments, and Innovation ecosystem and networking. At the beginning of 2023 the first EDIHs started operations. They are expected to directly provide, or ensure access to, technological expertise and experimentation facilities, such as equipment and software tools to enable the digital transformation of the industry, as well as facilitate access to finance. EDIHs shall be open to businesses of all forms and sizes, in particular SMEs, midcaps, scale-ups and public administrations across the European Union. The network of agROBOfood focusses on robotics in agri-food and can be an important network partner for some EDIHs. To prepare for this role, we adapted our service categories and reviewed which members of the agROBOfood network were already active in the EDIH network at the start of 2023. It appeared that 24 of our agROBOfood DIHs are involved in 14 different EDIH networks. It is expected that these DIHs can acts as bridges between the two network environments.

Another development has been the call to set up world-class reference sites for testing and experimentation (TEFs). In early 2023 the agrifoodTEF[39] project started, with support from the EU and co-funding from the countries involved. Four of the agROBOfood partners are also partners in this new activity. The agrifoodTEF will focus on testing and experimenting with robotic and AI solutions in a physical and digital environment. The broader context of conformity testing and ethical, legal and societal aspects will also be covered by this TEF. The agrifoodTEF will work closely with the robotics specialists of the agROBOfood network.

What is TEF?

- World class reference sites for experimentation ans testing AI
- Real setting
- Essential sectors: Agri-Food, healthcare, Manufacturing and Smart Cities, & Communities
- Connected to the Network of Digital Innovation Hubs
- Equipped with infrastucture & latest AI + Access to Cloud/Data/HPC...

Explanation of TEF: Reference Site for Testing and Experimentation

From agROBOfood project to agROBOfood network

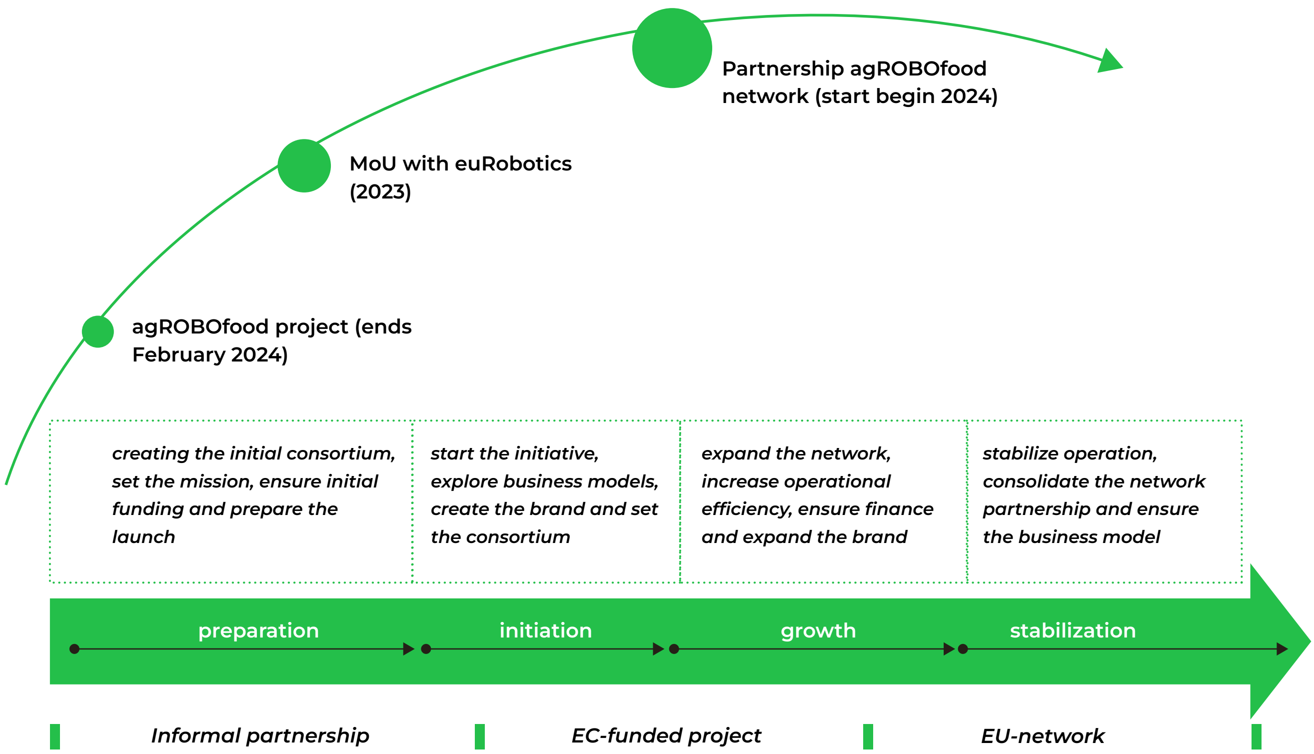
An agROBOfood working group was started in 2021 to ensure the sustainability of the agROBOfood network. The working group has been using a step-by-step approach to make use of insights coming from the agROBOfood project. The working group looked at the position of our network in the ever changing environments of DIH ecosystems and robotics in Europe. Potential scenarios for a sustainable agROBOfood network of DIHs were developed. The future of agROBOfood could either be a network completely dedicated to robotics for the agri-food sector, or it could become a multisectoral network specialized on AI-Data-Robotics. We also faced the choice of whether to create a completely new organisation or connect to an existing one. The working group concluded, based on all experiences, that agROBOfood should preferably remain a network of experts on robotics in agri-food that is part of an existing organisation. Early 2022, a number of scenarios were presented in the document 'Initial scenarios for sustainability of the agROBOfood network[40]'. The preferred scenarios were discussed with GOFAR, CEMA and the executive board and regional cluster leaders of the agROBOfood project. In November 2022 an offer was made by euRobotics to team up with them and with the other Innovation Actions.

EuRobotics declared:

"The five Digital Innovation Hub Networks created through the SPARC partnership between the European Commission and euRobotics (agROBOfood among them – ed) are now becoming ready to sustain themselves beyond the funding provided through Horizon 2020.These DIH Networks represent a significant outcome from the collaboration with euRobotics and the sectors they occupy and continue to be prime areas of focus for euRobotics into the future. Having assisted in setting the focus and direction of these networks, it is now appropriate that euRobotics wants to see these networks continue to thrive by supporting their long term sustainability. To achieve this euRobotics is offering a package of support to each network and thereby provides a common access point within its communication and digital assets to host the networks."

This offer of support from euRobotics, has been seriously considered by the agROBOfood network. As a result, a Memorandum of Understanding with euRobotics was signed. It is the explicit wish that the agROBOfood network will integrate or closely be connected to the existing euRobotics network that already has a legal entity. This integration needs time and proper discussion. To be able to function as agROBOfood network after the end of the project we created a partnership between founding partners. The partnership is not a new legal entity, but it is based on the D2.10 advice to have a small, centralised governance with strong regional coordinators and having connections in almost all EU-countries. The main principles of this partnership will be explained below.

From EU project to agROBOfood netwotk



agROBOfood Value Proposition

The agROBOfood project established a pan-European network of Digital Innovation Hubs (DIHs) focused on robotics in the agri-food domain. It has transformed from a project to a network. This offers added value. The value proposition of the pan-European agROBOfood network is:

- The agROBOfood network facilitates easy access to vital information and experts in agri-food robotics
- The agROBOfood network facilitates leading-edge robotic technologies, skills and expertise that can be applied in the European agri-food context to accelerate a digital transformation.
- The agROBOfood network supports and identifies new business opportunities and policy recommendations by providing market insights from and to its community.
- The agROBOfood network stimulates and supports services to find investments.

The agROBOfood network has a strong foundation in over 30 countries in Europe. The benefits to SME's and other partners of being part of that European network is having:

- easier access to European markets,
- economics of scale in organising (cross border) collaboration and events,
- increased visibility for public and private funders,
- increased visibility of best practices and robotic solutions,
- easier access to expertise and experiences in robotics for agri-food, and
- easier access to European networks for policy, industry and research.

The mission of the agROBOfood network of DIHs is to support DIHs and their customers and promote the development and integration of innovative robotic solutions for the agri-food domain, to increase their collaboration in the community and engagement with funders, industry and government as well as producers and consumers to stimulate the uptake of robotics in the European agri-food sector. The agROBOfood network will be the driver of sustainable change in agriculture, acting as the place to be in the European innovation ecosystem when it comes to agri-food robotics.

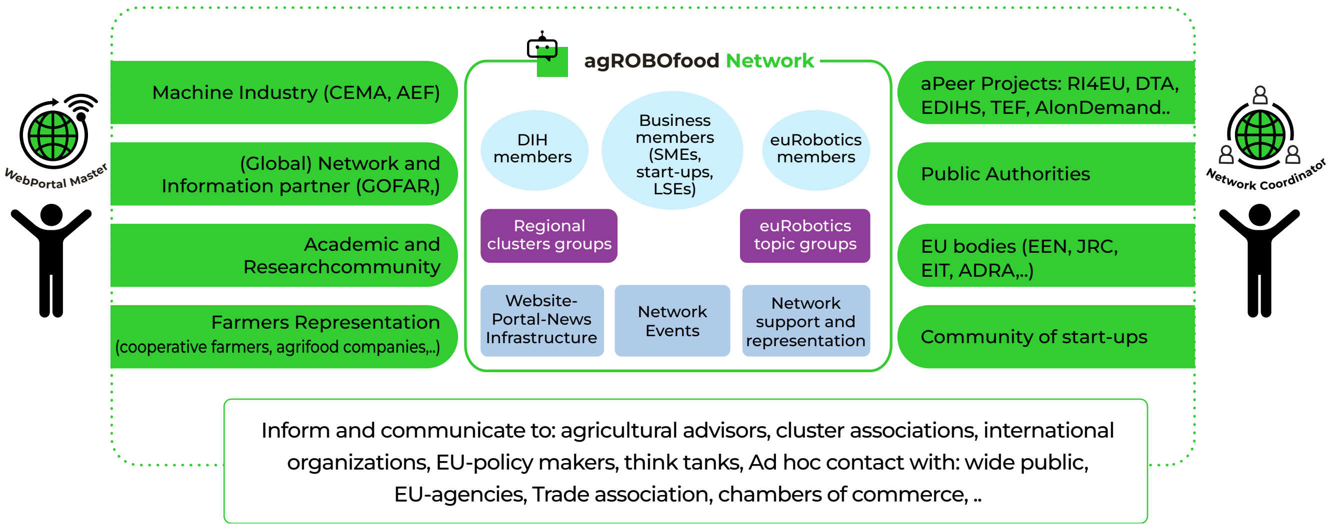
agROBOfood network products and services

The main agROBOfood network 'products' will be:

- A network with DIH, Business and euRobotics members active in robotics for agri-food
- A website-portal, knowledge-base and news portal to provide information and contacts and to support network activities
- Events organized by active and dedicated regional clusters and topic groups
- Active network partner for a variety of CONNECTED stakeholders.

The following matrix shows what products and services the agROBOfood network provides to its three customer segments, in the categories of services 'Test before invest', 'Ecosystem building', 'Access to finance' and 'Skills and training'.

Members are expected to be active in the network. This includes supporting the organisation of events, attending events, delivering content and using the website-portal-newsletter environment, supporting members in the network and promoting and developing robotic solutions in the agri-food sector. Regional cluster and topic group leaders initiate the organisation of specific events. The network also participates in the yearly euRobotics and FIRA events. The regional clusters and topic groups publish a yearly update on market and sociotechnical developments, discuss these within their groups and extract best practices from their findings. More specific market studies and information can be sourced from dedicated business services in the network. To grow the visibility of the network, at least two fulltime professionals might be needed to staff the network: a network coordinator and a webmaster.



	Test before Invest	Ecosystem Building	Acces to Finance	Skills and Training
Ecosystem Support (CS: DIH&CC)	· showcase your latest innovation demonstrators through our website · collaborate through our pan-European network of DIHS to offer cross-border services seamlessly · gain access to industrial experts affiliated with our network	· cross border and cross sectoral insights (reports, webinars) in market developments for policy making and strategic investments · matchmaking with SMEs and Startups looking for support · matchmaking with farmers looking for support in their digitalization journey · listing of your organization in our DIH directory	· access listings of public and privatefunding opportunities through our website	· advertise your listings of trainings provided through our DIH catalogue · Access to DIH specific training through our DIH service box
Scale-up Services (CS: SMEs and Startups, LSEs)	· find independent innovation mentoring through our network of DIHS and CCs · connect to EU level testing and experimentation facilities (TEFs)	· matchmaking for specific market and business model analysis though our network of DIHS and CCs · a local one-stop-shop in your region to get introduced to farming organisations, co-operatives and farmers interested in digital agri-food solutions · Listing of your organization in our Business directory	· participate in our Pitch Your Robot Find Your Investor Event, including pitch training · access listings of public and private funding opportunities through our website	· access listings of trainings provided by DIHS and CCs in our network
Digital Agronomy (CS: farmers and farming organisations, funding companies)	· visit demonstration days to experience the latest innovations tested in real-world conditions · explore the latest technology solutions in our Business directory and Innovation Demonstrators on the website	· a local one-stop-shop in your region to get introduced to agricultural robotics innovators and digital innovation hubs to help you find the best solutions	· access listings of public and private funding opportunities through our website	· access listings of trainings to learn the terms and concepts of digital agriculture

The network coordinator:

- Promotes, builds, maintains and manages the agROBOfood network.
  - Works together with the webmaster
  - Works together with the dynamic topic and regional cluster group coordinators.
- Manages and sets up the activities needed to actively stay connected to strategic partners.
- Maintains the daily operation of the agROBOfood network

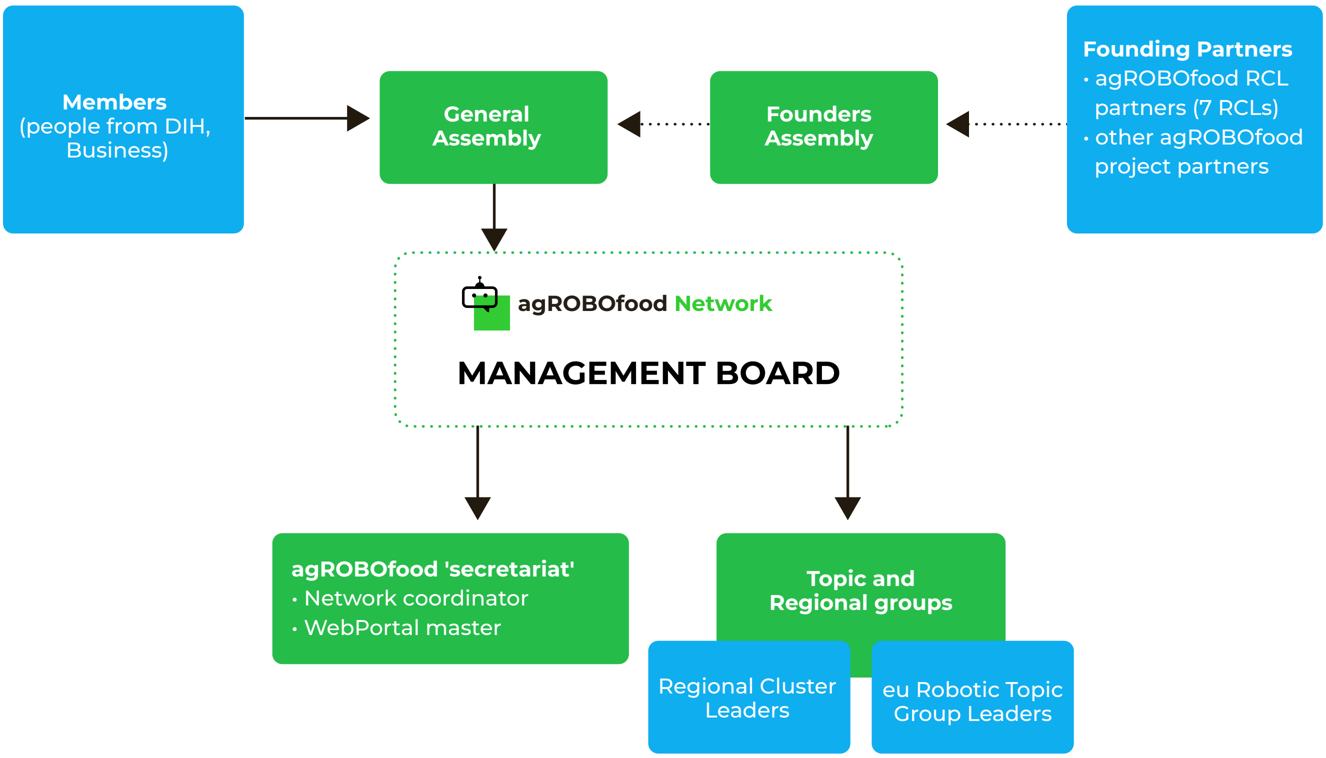
The webmaster:

Is responsible for further development and maintenance of the website, portal functionality and the newsletter. The website is public access, and the portal is for members only. Information should be easy to add, easy to change, informative and searchable.

Structure and business plan

Based on our experiences, best practices and the need for alignment with other Innovation Action networks and euRobotics, we propose the following structure for the agROBOfood network, going forward. The network is built upon memberships by people and organisations of DIHs and Business members. By joining, members are helping to create the future of the European Robotic in agri-food industry. Membership enables them to join activities with other experts to accelerate R&I, and to drive the kind of transformational change that individual companies struggle to achieve on their own. During registration basic information from the member will be gathered and regularly maintained. The agROBOfood network will be a non-profit lightweight network that is expected to join the euRobotics topic group Agriculture that will rely on its members.

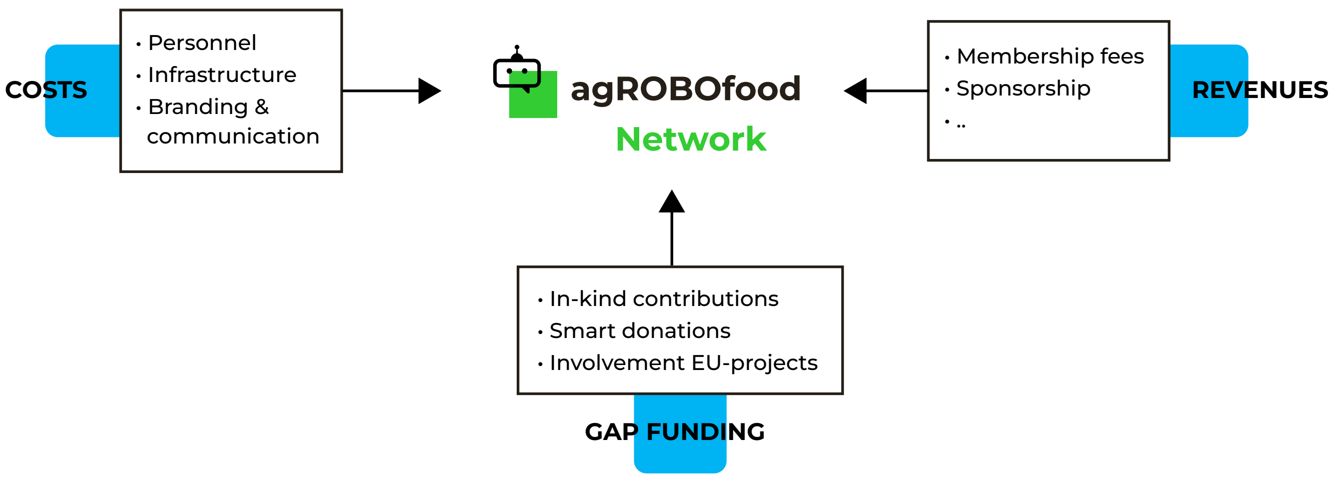
The legal entity for the agROBOfood network will be a Partnership, at least for the first three to five years. Also, we have identified a successful example in the Welfare Quality Network European Research Group. This network also created a partnership at the end of their successful EU project and still have a very active and influential ecosystem. The organisations that coordinate the regional groups have all become founding partners. This partnership will be the 'owner' of the agROBOfood network.



The RODIN green paper on sustainability of DIH network states:

"It is likely that continuous public funding might be needed for many networks to strengthen the long-term position of the network (either through participation in projects or co-funding). As the activities of a DIH network address 'market failures', it is to be expected that public funding will be needed[41]. The transition from a fully public funded to sustainable network with balanced public/private funding could be challenging. Key is establishing a wide network, prepared to contribute (e.g. via memberships). However, the authors believe that establishing a sound business model for the DIH network is complex and not intrinsically incorporated in the aim of the IA-approach. But without serious attention and an efficient and effective approach, it might lead to suboptimal use of public resources. (RODIN work group sustainability)."

We recognise that it might be difficult to transform the agROBOfood network from a publicly funded EU project into a public-private partnership for a pan-European network. Gap-funding will be needed for the transition into a self-sustaining network. This will be particularly challenging at the beginning, as the value offered is still not clear to all stakeholders. At the same time, many activities of the network need to be developed further. This explains our choice for a partnership structure and the euRobotics connection.



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40 D2.10 Initial scenarios for sustainability of the agROBOfood network by Kees Lokhorst, Luca Maini, Ahmad Issa, Manolis Tsantakis, Christoph Hellmann Santos, Erik Pekkeriet, and Natalie Hotrum

41 The mission of DIH networks (European collaboration) experiences issues like network externalities, public good, initial costs and other "market failures". See https://en.wikipedia.org/wiki/Market_failure

2

Development and demonstration of Robotic solutions

1. Introduction

A total of eleven Innovation Experiments and nine Industrial Challenges were selected for the agROBOfood project after the open calls. All of these will be described in this chapter.

The aim of the open calls was to support industry, in particular SMEs and start-ups in the agri-food sector, in their robotic transformation. Through demonstrations, platform development, technology transfer experiments and other services European agricultural machine industry could benefit from the opportunities of guiding, supporting and teaming up with start-ups and SMEs from the robotics sector. Also, private matching funds were mobilised, that will support the scale-up of robotic technologies and accelerate the digital transformation of the agri-food sector. Private matching funds could be acquisitions by big industrial players, corporate Venture Capitalist (VC) and investments, for instance. Also, the agROBOfood network of DIHs could be tested, as they supported these initiatives with their services.

There were two types of open calls, and a total of three rounds of calls. – Two open calls were directed at Innovation Experiments and one open call was for Industrial Challenges.

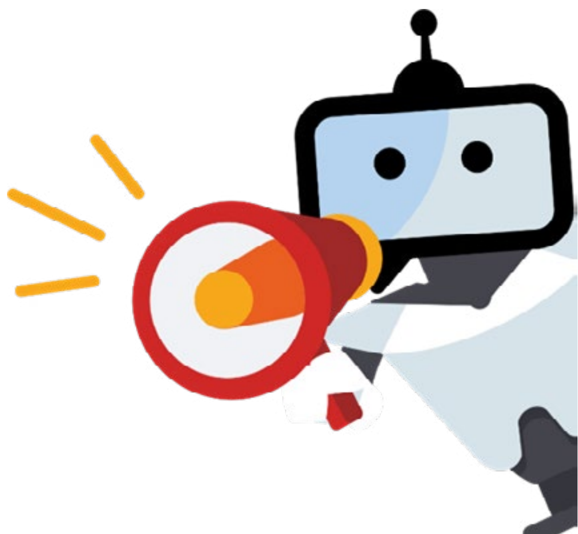
In the Innovation Experiments (IEs), small consortia of three to five organizations work together. These experiments target small consortia consisting of one SME as end-user and another SME or industrial partner as technology provider. The IEs aim to stimulate collaboration between European countries, therefore at least two eligible European countries are represented in each consortium. SMEs from all over Europe had the opportunity to further develop and showcase innovative solutions for the application of robotic technologies in the agri-food industry. At the same time, they are utilizing DIHs services, thus reaching a two-fold objective.

Each Innovation Experiment met the following criteria:

- they tackle a commercial need within agri-food,
- the solution is based around robot technologies,
- they use a local partner DIH as the primary contact point,
- they agree to use network cross-border services,
- they provide feedback on each service that they use,
- they agree to videotape non-commercially-sensitive parts of their work for agROBOfood dissemination, and they agree to promote the agROBOfood network.

Innovation Experiments were supported through a variety of technological, ecosystem and business services. These experiments demonstrate the usefulness of the technology from an end-user perspective.

The overall concept of the Industrial Challenges is that real industry problems, need real tech solutions. The agROBOfood consortium partnered with the Industrial Advisory Board (IAB) and defined real industry challenges or problems from their portfolio through a consultation process. We then invited agile small players (start-ups/SMEs) to solve these challenges through the open call. The Industrial Challenge is based upon the principle that the interaction between start-ups or SMEs and big corporations can yield mutually beneficial value-for-money innovation. The larger corporation has the opportunity to coach the solution or invest in the SMEs that are working on it. On the other hand, the SMEs gain access to funding through the call, utilize and test DIHs services and have the opportunity to mobilize private resources either in the form of contracts with big customers (a crucial factor for the growth of a start-up) or in the form of equity investment or takeover. Not only the key robotics and technical challenges were important, the IAB members also highly valued the challenges related to environmental, ethical and social aspects. Because of this, it was decided that each proposed challenge had to be divided in two components. Each industrial challenge topic was composed of a technical component and a complementary component. The technical component demanded the development or improvement of (existing) robotic technology-based solutions.



The complementary component required a socio-economic analysis or assessments of complementary social, economic, environmental, or ethical aspects of the newly designed solution. The topics for the industrial challenges were:

Challenge	Received applicants per challenge
Can optimized spraying lead to improved environmental conditions?	34
Can robots improve working conditions in the labour force in the fresh and processed food industry?	12
Are robots in the livestock industry posing ethical challenges by replacing human labour with machines?	1
What added value can harvesting robots bring compared to existing machinery solutions?	9
What new business opportunities do robots for cleaning livestock farms bring?	5

It was interesting to see that most applicants wanted to work on robotised (spot) spraying and some are interested in the food processing industry. This interest in plant production was also apparent in the Innovation Experiments.

The calls were promoted successfully in a decentral way, based on regional contacts. The Regional Cluster Leaders and Digital Innovation Hubs promoted the calls, organised dedicated webinars and events, communicated with potential SMEs and supported them. The DIHs acted as the centres of gravity where various stakeholders such as developers, users, consultants and investors could interact and ensure synergy and cross-pollination of ideas. Matchmaking was in great demand and many inquiries were received from the SMEs looking for potential partners. Regional cluster leaders and DIH representatives took action to connect interested SMEs and introduced them to potential partners. The applicants were curious and showed interest in the agROBOfood service provision, which were left open-ended in the first call. In the two other calls a more detailed table of services was introduced as an example. There were also quite a few technical questions related to robotics, which is why the agROBOfood team formed a small committee of robotics and technology experts to support the applicants.

In summary the open calls attracted 605 organisations. As can be seen below, the Innovation Experiments attracted much more participants than the Industrial Challenges. This was due to the fact that Innovation Experiments needed consortia of three to five organisations and that the choice for robotic solutions was free. It is also clear that there is much interest in the East Mediterranean, France-Italy and Iberian region. This might be explained by the fact that the local climate for funding projects differs from the other regions, where more alternatives for support and funding might be available. Most applicants came from Spain (88), Italy (77), The Netherlands (43), Greece (42) and France (30).

Since not all applicants could be supported, the idea of a yearly Pitch your Robot event came up. In these events SMEs and start-ups can pitch their robotic solution to

	IE1	IC	IE2	Total
North East Europe	26	3	19	48
North West Europe	47	7	34	88
France, Italy	53	15	39	107
Iberia	53	17	38	108
Central Eastern Europe	58	5	55	118
Central North Europe	35	6	27	68
East Mediterranean Europe	37	8	23	68
Total	**309**	**61**	**235**	**605**

funding organisations. During the three recent Pitch your Robot events we already attracted 44 organisations to pitch their solutions and we supported them with preparing their pitches and some follow-up actions.

As mentioned, a total of eleven Innovation Experiments and nine Industrial Challenges were directly supported with a variety of technical, business and ecosystem services. These experiments demonstrated the benefits of robotics applications in the agri-food sector and helped raise end-user awareness. All of them contributed to understanding how the agROBOfood network adds value for their members. Each experiment was mentored by a DIH and participants were expected to work on both the design, development and market orientation of their solutions. This was done deliberately, to inspire them into looking at the broader picture, and not just the technological issues they were trying to solve.

We are aware that bringing a robotic solution to the market is a much longer and bigger road than can be supported by the grants from agROBOfood. However, we provided a substantial amount of money (between 300 and 500 k€ for a period of 18 months) and the feedback we received, was that it really speeded up product development. In general the support these experiments received from the agROBOfood project was also beneficial to them.

To paint a picture of the variety of the experiments that were carried out, we present all eleven Innovation Experiments and all nine Industrial Challenge experiments that resulted from the open calls, below. The information is based on the documentation of the development phase and the final reporting on the market phase of these experiments.

2. Robotic solutions in the post-harvest food production chain

Honey-AI

Country

Spain, Norway, Cyprus and Romania

VIDEO

Technology Fields

Data Processing & Infrastructure
Data Interpretation & Visualisation

A pollen analysis of honey is almost mandatory for honey producers, to confirm honey provenance, provide a quantitative measure of its purity, ensure authenticity, and confirm that the pollen concentration meets the labelling regulations of the specific floral source (eucalyptus, rosemary, etc.). A pollen analysis consists of the identification and quantification of pollen grains in the honey sediment. This is a widely used reference method to verify the botanical and even geographical (origin of honey samples. The analysis of the pollen content in honey (called Melissopalynology) is carried out by an expert specialist with a light microscope at x400 to detect, identify and count every pollen grain present in the sample. Unfortunately, this method has several shortcomings; it is complex (requires a highly-trained expert with adequate skills and experience to identify different pollen morphologies), time-consuming (an analysis requires around 1 to 1.5 hours per sample), poorly reproducible results (depending on the technician's skills and experience), expensive (analysis is often done by accredited laboratories at a price ranging from 40 to 120€ per analysis) , and takes a long time (results are received in 4 to 5 days).

Honey.AI aims to automatise the tedious work of pollen analysis using artificial intelligence and robotised low-cost microscopy. This solution standardises the pollen counting measurement, reduces time, allows on-site real-time results with a five to 15 times lower price, increases reproducibility of results and immensely reduces human dependency (and chances of human error). In addition, Honey.AI will help reduce counterfeit honey commercialization. The Honey.AI project is carried out by a skilled and experienced consortium composed of one technology provider from the food industry (www.sonicat-systems.com) and three different end-users from North, West and South Europe (www.apisrom.ro; www.honeymell.com; www.honning.no). These partners actively collaborate to train the robotic solution, and to test and validate the system. Honey.AI is externally accredited by Polytechnical University of Valencia, which contains one of the global reference research groups in honey quality matters.

During the design stage, we optimised the first version, which was developed before starting the agROBOfood project. We manufactured three units of Honey.AI V1.0. The units were sent to three demo sites, who started the installation, training and bug-solving phase. In the development phase, Sonicat was very busy training the neural networks, improving the hardware, and designing the new version of Honey.AI. The demo sites were using the device and provided their feedback to Sonicat. At this time, Eurecat acted as a technical mentor while Sonicat provided them with ideas to improve the artificial intelligence module. The technical team of Sonicat and Eurecat met twice each month to discuss technical challenges and future work, and brainstorm on ways to improve results. The demonstration showed good precision in most of the pollen species and helped the team

to identify usability problems, to improve the design, to improve the sample preparation protocol, to test the yeast counting functionality, to test the crystallization measurement software and also to train the platform with additional species. Sonicat tried to train the models with real pollen from flowers, but this turned out to be impossible. The reason for this was that the morphological properties of pollen are not equal and the precision decreased. Currently, the system has been trained with over 40 species of pollen, using more than 4,000 images per specie. Different AI models have been tested during the project, including Yolov4, Yolov5, MaskRCNN, EfficientDent and EfficientNet. The mechatronic design of Honey.AI has been improved considerably during the experiment, between Honey.AI V1,0 and Honey.AI V2.0.

A public website and a specific user platform for clients were developed in the cloud with GPU computing on AWS (www.honey-ai.com). This currently includes the e-commerce module for purchasing credits and consumables. Different architectures and clouds hosting were evaluated before this set-up was selected. During the marketing phase, the team has manufactured a first version of Honey.AI V2.0. The initial Arduino on the first device was also traded for a custom control board (self-designed and mounted). The second version includes a Jetson Nano and a touchable display. The cost of goods were kept below the budget. Also, thanks to another nationally funded project, EURECAT has designed an automated sample dispensers with 24-units autonomy, together with the help and assistance of Sonicat. This prototype is currently being validated. The team went to ten different fairs, events and webinars, applied for five accelerators and was selected by EIT FAN and TEST FARMS. We also received a prize, and are already in talks with many different stakeholders with the purpose of reaching a number of collaboration agreements. Also two additional grants (DIGIFED and VEDLIOT) were obtained, private funds were raised and a loan for R&D in Spain was requested. One patent was filled and one trademark was registered. Civitta has helped the team with a pitch deck preparation, a financial plan, and a detailed list of potential VCs and other programs to apply to, specifically of Agtech.

We faced a number of problems during the project. It was difficult to obtain good accuracy of the AI models as the creation of a dataset proved much more difficult than initially expected. Reasons were: too many different pollen types, different enlargements, dirt, bubbles, different species. It has been complicated to obtain good accuracy and reproducibility. We expected the datasets could be created with pollen from the flowers. The team started working on this, but then realised that the morphology of the pollen was not uniform. That is why it has taken much more time to develop the datasets. Due to Covid19 the consortium could not meet for training and installation. The sample preparation specifically, required correct training. It proved difficult to work remotely. But the relationship and collaboration has been extremely smooth during this project and collaboration between partners went well. The technical development has been much more challenging than initially expected, Sonicat has spent much more money than initially forecasted in the proposal stage. The consortium asked for less than 400.000 euros in the proposal, much less than the allowed lumpsum, and now, after the project, the team regret this decision. The personnel effort was much larger than initially estimated. The business model and pricing strategy has been difficult to work out. When clients to pay for a device upfront, they don't want to pay for testing. And the other way around. The team is evaluating this problem and looking at using a rental agreement for the devices.

HyFlexyBot

Country
Italy

Technology Fields
Robotic Manipulation &
Handling Food Processing

VIDEO

The HyFlexyBot project aims to design, implement, and demonstrate the effectiveness of a pioneering concept of fully integrated Autonomous Mobile Manipulation Robot (AMMR), combining an autonomous robotic arm with an autonomous mobile robot (AMR), that guarantees hygiene (protection from bacterial/viral/allergen contaminants), scalability thanks to proprietary joints, real-time and full kinematic and AI implementation, state of the art safety and the highest grade in collaborative certification (ISO 10218), low power consumption, and cost-effectiveness making t it more affordable for SMEs. The HyFlexyBot experiment is led by Automationware from Italy, and they are supported by the CRIT research institute and CNR as DIH, also from Italy.

The purpose of the HyFlexyBot Industrial Challenge Experiment is to design, implement and demonstrate the effectiveness of a full non-contaminating production and palletization food process based on a fully integrated, reasonable cost and a collaborative robotic system. The experiment opens a new management perspective for implementing upstreaming and downstreaming in the food production lines to enslave the production line or unload the end of the production line for palletizing or logistic distribution of small production items. Mobility determines an innovative definition of logistics for food applications, which is in great demand at the moment, for anti-contamination precautions and to compensate for any absence or shortage of personnel.

The HyFlexyBot concept consists of a series of robotic systems composed with scalable modalities to obtain the maximum modularity of the system according to the applications. The fundamental components are robotics joints (J-Actuators), robotic arms, a mobile AGV/AMR, and AI to be applied. In this project we worked on a Mobile Cobot Architecture. HyFlexyBot is the anthropomorphic element that defines the picking structure on board of the Mobile robot. The robot was designed in a collaborative way, thanks to the technologies included in the robotic joint. The overall system is driven by a new ROS platform composed by a PC embedded on the Mobile Robot (AGV). The board is connected via Wi-Fi to the master control system based in ROS and defined by a new middleware platform that incorporates the navigation for the AGV and the robotic arm control. Safety is provided by an additional Wi-Fi system (TUV certified) and controlled by a flexisoft SICK network system certified TUV as well.

Thanks to agROBOfood, support was received from the Fraunhofer IPA on issues related to ROS latencies in the generation of robotic trajectories, sporadically interspersed with jitter due to Kernel activity. The problem does not have an impact on the application in progress, but small fluctuations are highlighted due to this instability of determinism on the data transmitted by the ROS PC. The problem is being solved thanks to the use of an interface between PC and Ethercat bus equipped with FPGA with separate management of the real-time control of the field bus connected to the robotic joints, which with this technique will bring the Jitter level to values lower than 5 us[1]. This new technique is applied for the first time in an industrial robot with ROS 2 control. It will allow a behaviour of the robot to be obtained in real time, avoiding latencies and keeping the trajectories clean from any disturbances caused by high jitter with consequent loss of kinematic information of movement. Furthermore, this will allow Cobot to follow behaviours in a deterministic way and therefore connect artificial intelligence systems for behavioural variations of the robot in real time. The program in question will be protected by a license and applicable to any robotic configuration. This includes robots of other brands and with the possibility

1 https://www.xilinx.com/products/silicon-devices/soc/zynq-ultrascale-mpsoc.html#productTable

of controlling machines integrated in the process thanks to a ROS-Codesys interface.

Most of the electronic components used for the prototyping of HyFlexyBot were actually used for the prototype phase. The experiment also involved the construction of two new HyFlexyBots to progress from the TRL6 phase to the more industrial TRL8. Many of the components were unavailable on the market. In many cases we were able to solve the problems thanks to stock or supply from Chinese brokers (for example for a part of the SICK safety components). This way, we were able to complete the construction of the systems with only 8 weeks of delay with respect to the supply times of the electronic components (on average 26-52 weeks). HyFlexyBot is also in the process of certification for ISO 10218 and 15066 with UL. This phase has already started in 2021, but has suffered a series of delays because of staffing issues due to Covid19.

The experiment started on a specific application for the palletizing of gluten free foods. However, thanks to the omnidirectionality and the extension of the robotic arm and payload up to 20 kg, unprecedented possibilities opened up. A series of new applications are possible, all in great demand in the agROBOfood and pharma sector. In fact, the experiment has already experienced new POCs in addition to the original project. The visibility of the project (web / media) also influenced other customers in the same agROBOfood segment.

SCaFo
- Implementation of a fleet of human-aware robots for the food processing industry

VIDEO

Country
Spain

Technology Fields
Robot Navigation & Co-operation

Automated Guided Vehicles (AGV) and Autonomous Mobile Robots (AMR) have traditionally filled a single role in industrial applications use, and are mainly deployed in warehouses and distribution centers. But during the last decade, the application of Automatic Guided Vehicles has broadened. As AGVs/AMRs can deliver efficient, cost-effective and automated movement of materials, they reduce the workload of workers when performing these tasks. AGVs/AMRs can be applied to various industries and different usages including: pharmaceutical, chemical, manufacturing, automotive, paper and print, food and beverage, hospital and warehousing. The main difference between AGVs and AMRs is that the former operate through fixed routes and require adapting the environment to add an external guiding system for the vehicles. AMRs, on the other hand, are more flexible as they can adapt to dynamic changes and do not require adapting the environment. They can navigate autonomously, avoiding obstacles, by using onboard sensors. The AGV and AMR market consists of the total revenues generated by the sales of the most dynamic solutions in the field of material handling equipment.

The entire food industry would benefit from having a complete AMR platform available for their operations at an affordable price. This would contribute to making robotic technologies more accessible, and also lower the barriers for deployment of robots in their daily work.

- The SCaFo Industrial Challenge experiment focuses on the following objectives: To improve the existing TIAGo Base design to ensure robust and long-term operation in the fresh food industry where there are typically environmental conditions that can pose problems to AMRs, such as low temperatures (i.e. 4°C), high humidity, slipping floor due to sporadic puddles, and areas with thin layers of water.
- To design and implement an appropriate trans-port-ation structure for TIAGo Base that better adapts to the transportation of the processed food, exploring a combination of the most effective interfacing modalities for the food industry lines.
- To optimise the current design of the platform in terms of ergonomics and connectivity. Together with the creation of a visual programming of tasks, this will allow programming of generalizable food industry tasks, contribute to the overall goal of creating a better user-experience.
- To optimise, refine and extend the current navigation software, making it more reliable in the perspective of a semi- or unstructured dynamic environment with the presence of human workers.
- To define a fleet management strategy and a task scheduler system that allow the robots cooperation in large-scale environments like factory floors or warehouses. Given the size of these plants and the amount of required tasks to complete, a single robot approach is highly limiting in many factors. In most cases, a better solution is to employ a group of robots to tackle the workload in a more efficient way.
- To further demonstrate the technology involving real food industry partners to better show the benefits and the impact of their solutions in the field of food logistics.
- To refine the Business Model, with the aim of generating revenues from the commercialisation of the platforms and the use of the results obtained to create a better connection with the DIH-agROBOfood community and the food industry in general.
- To analyse the robots' transportation process, making use of AI tools for the evaluation of the collected data in the real food industry to optimise labour force workflow and workload.

The SCaFO experiment is led by PAL Robotics form Spain. PAL collaborates with (potential) end-users like the General Càrnia's factory, Casa Tarradellas, the Food Service Cluster in Catalonia, and interest groups for the technology. PAL Robotics is also supported by the DIH Eurecat from Spain.

The PAL Robotics products are platforms that could easily be customised thanks to the modular architecture, both in terms of hardware and software. The SCaFo Innovation Experiment's specific achievements for the HW redesign have been mainly related to: 1. the design of the base is in accordance with current regulations, 2) the steel structure and machining is made of stainless steel to avoid having to paint these parts, 3) new suspension concept for the wheels in order to prevent slippage, 4) cushioned caster wheels are used and the lower plane of the base is raised compared to its predecessor to be able to climb higher irregular steps in the field, like cables, etc., 5) the cover is designed with a future rotational moulding in mind, although in the prototype it is made with 3D printing to verify geometry and validate the concept, avoidance of all kinds of paint (both on the internal structure and on the covers) to avoid chipping, 6) electronic components are commercial and homologated, and 7) materials are compatible with the agri-food industry. The development of the robot SW capabilities focused on the optimisation of the current navigation capabilities and 'human-aware' navigation, the fleet management and task scheduler development, the visual programming of tasks development and the integration and testing. Pilot tests were performed in the General Càrnia company, based in the Barcelona area (Spain), that works in livestock farming and the processing, sale and distribution of lamb, beef and other kinds of meat.

Overall, there were some minor deviations in the planning of the SCaFo experiment that delayed the execution of some tasks. This was mainly due to both the global shortage of electronic components and the longer delivery time for the machined parts, caused by a shortage of raw materials. There were also some unexpected situations related to the outbreak of the Omicron variant of COVID-19 which imposed some challenges in the organisation of the system pilots. In addition, some of the developments required more time or had different outcomes than expected. Some changes in the responsible people involved in the project affected the testing activities as well.

Technically speaking there were some challenges related to human-aware implementation: this proved time consuming to develop. To mitigate these delays, the following approach was used. We started from dynamic obstacle detection, avoidance and prediction advance to human detection and awareness. Issues and points for improvement detected during testing concerned a low density of laser features in the main room, presence of high reflective objects (stainless steel), integration with the building's elevators and doors, the laser can detect the water drops in the air, the payload above the base can be outside our current FOV and can cause possible collisions, if a robot gets disconnected the program needs to be re-launched to connect it back to the fleet computer, and sometimes it takes time to connect to the fleet manager and the program needs to be launched again at the robot level.

The SCaFo project has been a big milestone for PAL Robotics and the company will follow up the develop-ments on the service robot after the SCaFo experiment, improving the robot so it has future potential in the food industry.

CROVER

Country
United Kingdom, Italy

Technology Fields
Data Interpretation & Visualisation

VIDEO

Cereal grains are the basis of many staple foods, yet post-harvest losses during long-term storage are exceptionally high, above 20% in Europe and worldwide. Pests are to blame, with grain moisture content and temperature being the most significant factors. Cereal storage sites such as farms, grain merchants, millers and breweries, all experience these challenges, which have high-cost implications in terms of lost revenue and cost to rectify.

This Innovation Experiment aims to use the CROVER, the world's first 'underground drone', to scan and sample grains in bulk storage (in bins and sheds), to provide early detection of potential spoilage. This will allow grain storage operators to reduce losses and maintain quality, while improving the health and safety of grain storage operators, who will no longer be required to actually walk on dangerous grain bulks.

The main objectives of this project are to demonstrate and qualify the ability of the complete CROVER Grain Storage Management system to operate in an industrial scale grain storage environment, to enable the end-users who are part of the experiment to become the first grain storage operators in the world to be able to employ accurate Integrated Pest Management (IPM) practices for grain storage, and to evaluate the use of the CROVER Grain Storage Management system on a variety of seeds and pulses (whole wheat, whole barley, paddy rice).

This Innovation Experiment is coordinated by Crover Ltd. from Scotland, working together with Simbiosi s.r.l and Istituto Cooperativo di Ricerca who are end-users in Italy. Test farms were Upper Nisbet Farm (Scotland), Stratton Farm (SE England), Az. Agricola Bargiggia (NE Italy) and Coop Ag. Riviera Molisana (SW Italy). The experiment was mentored by the DIH Agri-EPI from the United Kingdom and a specific business model service was provided by specialists from Wageningen Research.

In early 2022, the team executed an extensive tour, with relative tests and an initial experiments, of all the potential storage sites in both the UK and Italy. We collected crucial data and information and had fruitful discussions with grain storage operators at each site, to understand their processes and priorities even better. These introductory visits and preliminary tests aided and directed the extensive improvement and modification to the system. A roof-mounted system was developed, so as to have a reliable system ready to be deployed and used when needed, without interfering with non-monitoring storage operations, adapting it to the diverse storage infrastructures we encountered. We improved the reliability and robustness of all parts of the system, by applying and integrating industrial standards, making the system more ready for (small-scale) manufacturing. Automation workflows were implemented and embedded in the system in order to enhance the convenience of use of the system for their future customers, ('set-and-forget'). Improvements, in both front-end and back–end, have been made to the web-based app, as this will be the main point of contact between the customers, the CROVER system's data, and the company. We carefully selected four storage sites for installations (including what has been the main test-bed for almost two years, Upper Nisbet Farm), which allowed us to cover and monitor, for the next storage cycle, the main global cereal grains: wheat, durum barley, and paddy rice.

During the development and testing phases we learned that this sector is very heterogenous, both in terms of size, nature of the operations and infrastructure. Various strategies were used to account for this, in particular a modular approach where modification of one part of the system does not necessarily reverberate to other components (i.e., robot version can be attached to the same roof mounted cable management system). None of the storage sites in this project were ATEX certified, which makes the experimentation easier, while the sites are working towards certification. Installation of this system usually must be done when the storage facility is empty and can take up to two days, depending on the specifics of the storage site and its configuration. Proper planning is needed to streamline these operations and we are currently working to simplify this process, in order to reduce customer inconvenience and costs. Different crops can have different impacts on the robot's movement and performance. For example paddy rice has been somewhat difficult to work with, due to its quite abrasive husk, while soybeans and peas have been surprisingly workable, opening the perspective of wider markets in terms of crops covered. During the development and market phases the partners put considerable effort into refining their market intelligence, leading to a more sophisticated and detailed segmentation and evaluation of the market. We are now able to prioritise the aspects of the system that can add the most value in a short timeframe.

To overcome the challenges the small but significant infrastructure differences between sites presented, we initially designed a quite versatile roof mounting system, installable in all the flat storage solutions around Europe. This system could manage the cable and assist the movement of the surface device.

Unfortunately, continuous use and feedback from test partners and end-users proved that the chosen design route posed issues in terms of the scalability of the system. Also the performance and intended use of the robot and the installation cost and effort were compromised. To overcome these technical challenges, we decided on a drastic change in the design. A modular approach was chosen, where the granular robot is split into two parts: a larger surface 'mothership' robot which carries the majority of the load, and is able to carry over 50 meters of cable through grain hills, and a sub-surface penetration robot/module, the size of which is kept to a minimum. This latter module is optimized for penetrating through granular bulks and carrying a sensor (or other small modules). The project was also confronted with supply chain delays and disruption, especially in the manufacturing of PCB boards, which caused a few issues with the overall reliability of the system. From the operational side, one of the major hurdles encountered was the organisation of both the test and the demo events, due to the distance between the test sites.

This Innovation Experiment has been crucial for the development of the robotic grain management system and its progress toward a commercially ready and available Minimal Viable Product (MVP).

3. Robotic solutions for crop care management

ACROCrop

VIDEO

Country

Spain

Technology Fields

Sensing, Data Processing & Infrastructure, Data Interpretation & Visualisation

Frost losses are one of the major causes of crop loss for open-air permanent crop farms. ACROCrop created, for a real-world environment, a robotics-based solution for the protection of crops. Frosts are generally considered to be unavoidable accidents in farming operations. They occur in varying degrees in most growing seasons, leading to considerable crop losses. Methods for frost control exist. One of them is to fly helicopters over the crops to mix the air into different layers, but this is not environmentally and economically viable for farms in Europe. ACROCrop uses gasoline-powered, autonomous helicopter drones in combination with IoT sensors and complete software service support, to provide a revolutionary technological solution for frost protection. This includes a general crop scouting service.

The ACROCrop product line consists of multiple product tiers. These consist of a base module and two add-on modules, which can be added either individually or combined. The base module consists of at least one Alpha UAV (UAV Alpha 800), a software support package, and the special eVineyard software ACROCrop subscription that includes a flight path generator delivered by GeneticAI. The base module offers the key capability of performing anti-frost flights. The intended customers of this module include drone service providers that are interested in providing flight services on request for their customers (in a similar manner as current manned helicopter flights), as well as major vineyard management companies (multinationals and largest grape and wine producers) who have the financial and operational capacity to operate their own drone systems, and already have frost detection systems in place.

The add-on module Augmented Frost Detection and Early Warning Module, consists of a ground-based IoT sensor station that is capable of collecting data about microclimate (air temperature, humidity, wind speed and direction), including some frost-specific data points such as leaf and bud temperature for frost detection. Those sensor stations are plug-and-play compatible with the base module's software system (eVineyard), and the data from the sensor station is analysed in eVineyard to indicate frosting conditions, real-time alerting of frosting conditions, and an overview of all fields that are monitored by the ground-based IoT sensor stations for the end-user. This module is targeted at vineyard management companies that don't have sufficient detection systems for frost conditions in place, and at drone service providers that want not only to provide on-demand frost protection service, but rather a comprehensive frost detection and mitigation service to their customers. Especially in the scenarios with many customers in a wider area, this add-on can help frost detection and mitigation service providers pick the most frost-affected areas, and focus their service delivery on those areas. This effectively allows them to provide a higher-value service to a higher number of customers with the same number of UAVs.

The add-on module – Imagery Collection and AI Image Analysis adds the capability of aerial imagery collection in multiple spectral bands to the UAV, along with powerful geospatial intelligence services, provided by Picterra. The Imagery Collection and AI Analysis module is a perfect addition for both main types of customers (vineyard management companies and drone service providers alike) when they would like to increase the usage spectrum of UAVs throughout the whole growing season and even in the winter, by allowing capabilities such as large-scale growth monitoring in the vineyards, detection of anomalies and flaws, and more.

The consortium of ACROCrop consists of Alpha Unmanned Systems S.L. who is the UAV provider, ELMIBIT who brings the agricultural knowhow and analysis web platform eVineyard to the experiment, GeneticAI who provides a set of AI powered ground IoT sensors that

will help to determine the need of an actuation over the fields (anti-frosting flight, but also irrigation or fertilization), feeding eVineyard with data and responsible for the Flight Plan Generation, Picterra S.A. that brings in its AI image analysis platform, and Finca Zerberos as end-user that integrates the set of technologies into its processes, executes them, validates the system and gathers data about its cost-effectiveness. Their vineyards are placed at different altitudes (between 650 and 950 metres of altitude, presenting a high unevenness) and suffer from frost every year.

Within the experiment a thorough analysis of determining factors has been performed. On the technology side the development of specialised drones for agricultural situations, use of multispectral cameras and the existence of eVineyard were important. For the use of drones it was important that since 2021 the regulations[2] have been synchronized throughout Europe. The new regulation establishes the basic principles to guarantee the protection, safety, privacy and protection of personal data. It also aims to reduce bureaucracy and encourage innovation. On the political and economic side, the shortage in logistics and supply of semiconductors and metal products, and the Ukrainian-Russian conflict influenced energy prices and production costs.

To gain insights from end-users, a frost protection survey was sent to more than 2,000 farmers growing permanent crops all across the globe. The survey was sent via e-mail and shared on several social media profiles of the consortium members. We asked farmers that already had frost threatening their crops, to complete the survey. Despite the huge audience, only 28 farmers responded to the survey – nine from the United States, six from the United Kingdom, two from Australia, and one from each of the following countries: Sweden, Serbia, Italy, Hungary, France, Cyprus, Canada, Bulgaria, and Brazil. Based on the survey, we can conclude that farmers all over the globe are dealing with frost events that threaten their crops. The willingness to invest in drone frost protection depends on the size of the fields. Namely, only two small growers (in the size of up to 4,9 ha) would be willing to invest in the frost protection method using a drone. Most interest in investing in drone technology for frost protection was shown by medium-sized farmers–-5 up to 30 ha of crop area, as well as big growers (3 out of 4). When it comes to owning the drone or using it as a service for frost protection, most farmers would prefer to own a drone (or already own one), which can be correlated with the percentage of growers owning their current frost protection equipment. As farmers prefer to own equipment rather than use it as a service, the product offer should also include the possibility to buy a drone and frost protection feature and not only offer it as a service.

The consortium had a very active approach. Using social media, blogs and a website more than 7,500 contacts were reached. More than 1,400 e-mails were opened and this resulted in more than 260 interactions. The contacts that showed high interest were invited for a webinar or one-on-one discussion. This success in gathering initial interest and visibility was due to the innovativeness of the robotic solution and it resulted in very promising signals for further commercialisation.

2 Consolidated Execution Regulation (EU) 2019/947 includes changes to Execution Regulation (EU) 2020/639 and Execution Regulation (EU) 2020/746. Delegated Regulation (EU) 2019/945 consolidated that includes the changes of Delegated Regulation (EU) 2020/1058.

MIRAGE

Make It Rain And Grow Efficiently

Country
France, Belgium

Technology Fields
Data Interpretation & Visualisation, Sensing

VIDEO

European farmers face increased competition and are currently looking for more economic viability and competitiveness in their production. In some places such as the 'Haut-de-France' region (in the north of France), but also in Belgium, Netherlands, Poland, and Germany, potato and vegetable productions at an industrial scale have become the answer. These cultivations consume a significant amount of water, fertilizers, and chemicals. They are also time-consuming. Current climate change is increasing the size of irrigated areas worldwide, including Europe. At the same time, groundwater recharge decreases. The scarcity of water puts both the financial viability of European farms as well as our food production autonomy at risk. This is a major problem.

Currently, most farmers use reel machines to irrigate, even though these involve time-consuming processes and are far less efficient than micro-irrigation (20 to 50% less). The main reason for continuing with this non-optimal practice is the economic viability and the investments needed to change. A new solution is needed, as drip irrigation for example, typically costs twice as much per hectare as reel machines. Robotics, high-resolution root-zone moisture measurements, and artificial intelligence are parts of the solution to improve the efficiency of water-usage. These techniques could free farmers from manual tasks and allow them to better conceive and plan their agronomical process. The MIRAGE solution is based on the prototype of the OSCAR robot for irrigation and on gprSense. It can assist European agriculture with precise and automated irrigation while ensuring profitability.

The MIRAGE Innovation Experiment works on the development of an economically viable solution for precision-irrigation. The experiment develops an automated solution that allows farmers to irrigate without back-breaking work. Replacing 90% of manual labour with robots means farmers can focus on other important tasks. The sustainable irrigation solution also reduces water and power consumption by at least 10% compared to traditional reel machines and includes a management system and a decision support tool for irrigation. This tool is based, among other things, on advanced ground-penetrating radar (GPR) for real-time soil moisture measurements, and allows for very precise irrigation to increase water usage efficiency. The positive impact of these new irrigation processes and the use of an advanced decision support tool for irrigation are also proven scientifically.

The MIRAGE Innovation Experiment is coordinated by Osiris Agriculture, a robotic manufacturer from France, that works with local suppliers, subcontractors, and engineering offices to redesign OSCAR. They also cooperate with Sensar Consulting from Belgium, a company specialised in soil moisture mapping of agricultural fields and the design of a specific Ground Penetrating Radar, and GITEP which is an end-user advisor from France that is relying on its 100 farmers-subscribers network to find the right environment for field tests. This partner also has knowledge and almost all the equipment needed to operate field tests, since they conduct yearly trials on irrigation and potato growth. The Innovation Experiment is mentored by the DIHs CEA and Robagri from France.

The MIRAGE consortium was able to create the first autonomous robot for irrigation in Europe that can gather data on the fly about water need and could test it in real field conditions during the summer of 2022. These tests highlighted water savings by 10%, energy use reduction of 20% and the ability to automate the vital and back-breaking irrigation tasks (80% of decrease in manpower) plus between 30%-45% of potential water saving

with the GPR soil moisture information, depending on the field variability. Te pre-industrialised version of OSCAR was improved, using parts that for 90% hail from Europe. The first robot-as-a-service with GPR add-in for 2024 has been sold at the time of writing and the consortium has started to develop their distributor network in France, Belgium, Poland and Switzerland. Sensar Consulting developed and analysed a new GPR design for the specific application of root-zone soil moisture mapping in potato fields. For this purpose new software for the gprSense was developed. Also, a scientific article about GPR use on mound-based fields has been published.

The development and testing plan was based on the timing of the potato crop production. The risk of timely delivery of parts was described in the risk management plan. As it turned out, even if we were ready to pay a premium fee for specific parts, suppliers were not always able to deliver in time. As the management team acquires experience, expectations and plans are adapted according to the lessons learned, level of ambitions, and the global context. It was still possible to get a great deal done. The challenge to manage the cost increase of parts and metals and the inability to find private equity funds, was countered by loans. The final cost of the robots is higher than expected, but the industrialisation process is still ahead and will allow us to optimise thei global costs for our machine and offer a viable investment for farmers.

The main technical challenge faced by the MIRAGE team was to manage the water pipe autonomously. The required pipe motion could be managed quite well, even though technical improvement is still needed. It was concluded that this functionality is a key and even critical component of their machine and its success. Another technical challenge is to allow OSCAR to work with existing infrastructure at low cost. The robot needs to handle the communication with the pump perfectly. This poses a challenge as some farmers use pumps with older and unreliable communication protocols. The consortium managed to adapt to the one used by the farmer on their test field and they will address this problem very seriously in the coming years.

The radar calibration was a challenge as in the relatively low frequency range needed for this application, i.e., around 100-200 MHz, the calibration plane, usually a copper plane, should be relatively large (ideally 15 m, although smaller may still work). In order to find a trade-off between calibration cost and calibration accuracy, a series of calibration strategies were tested. Performing real-time GPR data processing was considered a challenge as the electromagnetic model is full-wave (complete electromagnetic model accounting for the radar-antenna and 3D propagation in planar layered media). However, the use of a look up table approach for the inversion, together with the high computing performances of C++ and parallel processing, made real-time processing possible. The challenge for Osiris is to hire the right employees: European 'rockstars', who are even better at these subjects than the current team. Such people should be able to make a huge difference by delivering quickly. The company however is based near Lille (not considered the most appealing city in France), and experiences difficulties presenting the possibilities to the 'rockstars' it is looking for and aligning on wages, due to a lack of funding.

In conclusion: This Innovation Experiment allows the consortium to confirm the usefulness of the GPR as a sensor that can enable very precise irrigation leading to water savings of at least 10% by the OSCAR robotic irrigation system. It will also provide farmers with the capability to use state of the art technologies to automate laborious tasks without compromising their financial viability.

I-Catch

VIDEO

Country

Netherlands, Belgium

Technology Fields

Data Processing & Infrastructure, Data Interpretation & Visualisation

Food in the European horti- and agriculture sector needs to be produced in an increasingly sustainable way without the use of pesticides and their undesirable effects on environment, biodiversity and health. The EU Green Deal's 'Farm to Fork strategy' requires a 50% reduction of pesticides use in 2030. The EU encourages Integrated Pest Management (IPM), a methodology based on economic pest control suppressing pests instead of eradicating them. However, the large-scale transition to IPM is hampered by the fact that each pest requires different countermeasures with contradictory effects, while this tailored approach is both labour and resource intensive.

PATS has developed I-CATCH, a bio-inspired drone system for automated monitoring and mechanical elimination of airborne pest insects in greenhouses. The I-CATCH system consists of a computer vision system that is able to detect, track and distinguish harmful pest insects with AI-based software. The system controls a small, bat-like drone with fast in-crop manoeuvrability for accurate insect elimination by mid-air collision with the drone's propellers. Autonomous and 24/7 operability is secured by a charging platform. With the I-CATCH system PATS provides a solution that helps growers to reduce crop damages as well as the use of pesticides, while automating the laborious process of crop protection.

Consortium partners PATS (technology provider), Hortipower (greenhouse grower) and Proefcentrum Hoogstraten (research centre and greenhouse grower) combined their expertise on drone technology, crop protection and cultivation. I-CATCH has made large strides towards market introduction during the design, develop and market phases of the Innovation Experiment.

During the Innovation Experiment, our solutions were tested and iterated at the sites of Proefcentrum Hoogstraten (PCH, research centre and grower) and Hortipower (grower). We have optimised the identification of *Tuta absoluta* and we showed that we are able to detect this pest insect with high accuracy and that the system is able to detect adult moths 5 weeks earlier than scouting methods that are currently utilised by growers. For identification we have successfully worked together with WUR, who provided facilities (wind tunnel) and conducted research (experiments) to measure flight paths and flight behaviour of *Tuta absoluta*. Our monitoring and control solution together (PATS-X) has reached close to full autonomy in a tomato greenhouse environment. We are now in the final stages of development for this environment. PATS-X is thus already available for a small number of environments - including tomato - and will be available for larger commercial roll-out. We have demonstrated that we are able to eradicate the *Tuta absoluta* moth in tomato production environments, which is the starting point for next steps in high-vine crops (tomato, pepper, cucumber). A market research for application of the technology in tomato greenhouses in Europe was supported by CIVITTA (service). This has resulted in a top-5 country list for roll-out after the Netherlands. These are, in order of preference based on the data: Belgium, Germany, Spain, France and Poland. Media presence was gained through press releases, com-

munication of results and new partnerships that were established as an (in)direct result of the progress made during the I-CATCH project. One of the main pieces for dissemination was written by WUR and shared in the university's network. We have produced promotional videos for the launch of control solution (PATS-X), and for explaining the already launched monitoring solution (PATS-C), complemented with a testimonial video from Hortipower and Proefcentrum Hoogstraten to be used commercially. Demonstration events in tomato (research) greenhouses have been and remain difficult to organise, due to COVID and a challenging virus for tomato. We have been able to provide digital demonstrations for tomato growers individually and to attend and present at a number of industry exhibitions. During the project multiple commercial agreements with market partners and customers were closed and agreements were made with international distributors.

During the Design and Develop Phases, progress was made towards introduction of the technology. The following challenges were encountered: when starting at Proefcentrum Hoogstraten March 2021, we found out that our PATS-X control technology still needed some significant improvements in terms of autonomy and control to conduct effectivity tests in the eradication of *Tuta absoluta*. Both the hard- and software development needed to reach a higher standard. However, we have been able to demonstrate that our drones are capable of eradicating *Tuta absoluta* in this environment, specifically in confined spaces with crops, wires and other obstacles, and we showed that the performance was comparable to existing methods of pest monitoring/ scouting. Seasons and crop cycles make development in this industry relatively hard. You need to be ready in time as small delays can quickly become problematic. This is a challenge most (robotic) developments for agri- and horticulture will encounter. The market phase was obviously obstructed by the COVID pandemic, as physical events were barely possible during the Innovation Experiments period. In addition, tomato growers are challenged by ToBRFV (Tomato Brown Rugose Fruit Virus), not allowing anyone in the greenhouse. However, we have been able to attend a number of industry fairs, like Horticontact (NL), GreenTech Americas (MX), RoboCrops (NL) and GreenTech Amsterdam (NL), which resulted in a substantial number of concrete leads for the PATS-C and PATS-X solutions. Interest was largely shown from growers with tomato and other high-vine crops, and are a direct result of the progress made during the I-CATCH Innovation Experiment. However, we now must also confront the challenge of converting those leads first to the PATS-C solution, while also keeping them waiting for the PATS-X solution, that is still to be launched in high vine crops. The most important learning point from the market phase is that growers are highly interested in new and sustainable solutions developed for the monitoring and control of increasingly challenging pests.

GreenSprayer

VIDEO

Country

Greece

Technology Fields

Data Processing & Infrastructure, Data Interpretation & Visualisation, Robotic Manipulation & Handling

Green Sprayer performs disease detection and 3D spot spraying on plants in greenhouse environments. This system helps reduce pesticide use, protects the soil and aerial environment from chemical contamination and improves production capacity. The goal of the GreenSprayer is to introduce an autonomous, self-navigating ground vehicle with an attached 6-axis robotic manipulator, developed to perform plant recognition, disease detection and targeted 3D spot spraying. In contrast to current practice, where the crops of an entire greenhouse are uniformly sprayed when a disease is detected, this solution will detect early symptoms of the disease and take immediate small-scale action, preventing further spread, as well as minimizing the use of human resources and pesticides and chemicals.

The key objectives of GreenSprayer include constructing:

- A modular and robust robotic platform suitable for operating in semi-outdoor environments such as greenhouses;
- Accurate and real-time algorithms for plant and disease detection;
- Safe and reliable navigation and motion planning algorithms;
- A spraying system attached to the end-effector of the robotic arm;
- A socioeconomic analysis to evaluate the economical, ethical and environmental impacts of this solution for the agricultural sector.

GreenSprayer has used four distinctive approaches to increase solution awareness:

- Networking and presence: include individual attendance at exhibitions, demonstrations, forums and seminars;
- Workshop: organising a workshop related to precise agriculture;
- Promotional materials: includes social media, brochures, leaflets, videos, posts and e-newsletters;
- Sector awareness: communicating directly with candidate end-users to inform them about the GreenSprayer solution and collect feedback for the system by providing them with a questionnaire.

The Greensprayer experiment is coordinated by IKH (I-Know-How) Greece and supported by the Agricultural University of Athens as DIH.

The implementation and demonstration of the Greensprayer solution is based on the integration of separate modules for localising, mapping and state estimation, 2D navigation, robotic manipulator motion control, AI plant and disease detection and a high-level task planner. The architecture is based on the ROS framework. Learning from the provided solution under the support and guidance of agROBOfood community, a few remaining challenges have been identified. These include (1) the provided availability of an fully operational greenhouse with tomato production for extensive and larger-scale testing, (2) battery pack integration to enhance large-scale demonstration, (3) satisfaction guarantees and completeness of the workspace 3D reconstruction (this will be achieved with a fully autonomous procedure), as well as, (4) a better understanding of the optimal spraying setup with respect to type of disease detected.

The GreenSprayer product design is aimed at tackling the most common tomato disease: *tuta absoluta*. During the market analysis phase, research was conducted to identify the market in which the GreenSprayer technology would demonstrate the best value proposition. In this analysis many limitations came up, that pointed towards designing a differentiated product/service market entry strategy. Reasons for this were the greenhouse tomato production characteristics - such as the complexity of multiple disease detection - and the market expectations of a completely integrated solution. In addition, spraying should not account for more than 6,5% of the total variable costs and priority in automation priority is given to harvesting (the most populated market segment). Also, harvesting is a pick-and-place robotic application that usually involves low complex AI implementations.

The analysis points towards a multipurpose/multi-functional robot platform business model which would undertake and precisely perform many other tasks in the greenhouses and the open-field farms. The platform could also be open-ended, providing the tools to the market to develop its own custom applications. The findings of the marketing analysis covering agricultural robotic companies on a global scale, indicate that the most popular or appealing robotic applications are the ones which involve less complexity but contribute mostly to restraining operational costs.

H3O-SpotOn

Country

Spain, Poland, Slovenia, Tunesia

Technology Fields

Data Interpretation & Visualisation

VIDEO

The agricultural machinery manufacturer FEDE has developed technology and an infrastructure that allow for the remote management of sprayers, as well as precise spot spraying. Going forward, this technology and infrastructure will help reduce pesticide use by up to 50%, fully in line with the 'The European Green Deal', and the future Common Agricultural Policy (CAP). These policies aim to ensure a fair income to farmers, increased competitiveness, climate change action, environmental care, preserving biodiversity, developing vibrant rural areas, and protecting food and health quality. The H3O-SpotOn Innovation Experiment contributes to easier management of the fields, while not jeopardizing health and safety of the workforce. It also helps reduce pesticide drift and contamination of surface waters and the environment. H3O-Spoton stands for Healthy Crop, Healthy Environment, Healthy Farmers' Finances through Optimized SpotOn Spraying Robotics.

This Innovation Experiment is led by FEDE, an AG machinery producer from Spain, AGROBARD a dealer from Poland, and the end-user farms PAWLAK, KRAMPAC and CHEMTOU from Poland, Slovenia and Tunisia, respectively. The IE demonstrates successful functioning of H3O-SpotOn Spray Robots on the road towards international market exploitation.

In a predecessor research project FieldCompanion[3] FEDE was able to construct a spot spray prototype at a TRL6 level, that included a zone spray and a plant level spray algorithm to achieve pesticide reductions. In the IE new developments took place. At its core, there is the 3D vision/eyes augmented sprayer control system (SCSe) and the nozzle control circuity (NCC) that includes electric valves through which the spray liquid flows to the nozzles, as well as the electronics driving circuitry that allows to actuate all valves within milliseconds at pressures up to 20 bars, which, on a vehicle with limited on-board electric power, requires quite some innovativeness. H3O-SpotOn sprayers are Wi-Fi connected to a tablet app that is mounted in the tractor's cab.

Bidirectional data communication with the cloud, precisely with the Specialty Crops Platform (SCP), takes place via a cellular modem that is part of the also tractor mounted Specialty Crops Gateway (SCG). As such, SCG is a core element for field job management, as other implements' jobs can be scheduled and monitored at the same time. End-users (farmers, farm-advisors, farm-managers and operators) connect to the SCP via web graphical user interface (GUI) or FEDE's smartphone app 'My FEDE'.

The H3O-SpotOn robots with their corresponding Spraying Control devices were successfully set-up and operated on demo farms in Poland, Slovenia and Tunisia. FEDE assured that H3O-SpotOn equipment passed quality, safety, and demo country specific homologations, and certifications. Documentation and online courses to support swift roll-out were created and provided on the Fede Academy platform. These help dealers and operators to learn how to start up and use both the precision machinery and the services of the digital platform to which it is connected. Documentation is available 24/7 and updated frequently. Remote support was boosted due to the travel restrictions in the COVID period.

An analysis of environmental and economic data obtained from demonstrations in a Slovenian vineyard, a Polish apple farm, and a Tunisian citrus farm proved a sustainable economic benefit for all parties involved. The tech provider, FEDE, as well as the dealer partner AGROBARD have started earning margins on H3O-SpotOn equipment and services, and the end-user farms have started saving agricultural inputs, such as pesticides,

3 Eureka-Eurostars 2, E! 11884, FieldCompanion, youtu.be/rtWS9ii4HJY?si=rvmNK3B_2JuYBCZI and www.sundance.com/sundance-in-eu-projects-programs/fieldcompanion/

spray water, tractor fuel and labour. The, payback period of H3O-SpotOn robotics technology investment ranges from 0.3 year for PAWLAK (Polish 40 ha apple farm), to 1 year for CHEMTOU (Tunisian 10 ha citrus farms) and nearly 6 years for KRAMPAC (Slovenian 10 ha vineyard.

This IE was supported by EURECAT, which provided expertise and service offers for dissemination, matchmaking, benchmarking analysis, and some specific services related to their core business, autonomous navigations systems. ICT/DIH AGRIFOOD from Slovenia was a key partner for language support in the interactions with the end-user KRAMPAC, and in the market adaptation, translation of manuals, market analysis and search for dealers. ICT/DIH AGRIFOOD also significantly contributed to this IE's communication activities, with several publications on H3O-SpotOn performance and updates about the experiment on social networks and in digital newspapers. DIH/CC NOVATION CITY from Tunisia supported this IE with research into the market and dealers, market adaptation and translation of manuals to prepare for distribution of H3O-SpotOn in Tunisia.

qualiSpot

Country

Spain for development and having dealers in Portugal, Hungary, Peru and Poland

Technology Fields

Sensing

VIDEO

Ambimetrics from Spain started in 2014 and produces electronics, fieldware, and App and cloud services for spray robots. These were complemented by image detection and image processing capabilities through the successful execution of the Eurostars-2 FieldCompanion project. This means Ambimetrics is now in the position to offer a complete range of the core components to produce spot spray robots. Ambimetrics has supplied components, which are reliably operating in over 200 Fede® and John Deere® spray robots. These spot spraying systems have greatly improved the problem of 50% of pesticide losses, resulting in pesticide savings far in excess of 30%.

Ambimetrics develops, produces and configures components precisely to clients' specifications. These clients match their product offerings to specific farmers' problems. Having Ambimetrics spray components in operation in four countries (Spain, Portugal, Hungary, Poland) requires extremely high spray robot reliability and does not provide margin for in-field break down caused by electronic hardware or software problems. Especially as some of these operations are in remote areas with poor cellular coverage and high access and repair costs if someone needs to go to the location for repairs. Fede and John Deere both demand all inputs from suppliers like Ambimetrics have to meet very strict quality standards.

The development took place on two levels. Internally, Ambimetrics aimed to build up quality within the company. Externally, the environmental benefits of spot spraying were demonstrated. Ambimetrics is supported on external agronomic expertise by the Valencian Institute for Agriculture (IVIA) researchers and by Biosense, Fraunhofer and Agroapps as DIHs from the agROBOfood network.

The internal group dealing with quality improvement followed the three main development lines related to their precision agriculture project. The App team dealing with the development of the Spray Controller User interface. The Cloud team which develops the web application where the traceability from the sprayers is uploaded and allows users to send work orders to field and the Hardware team which designs, manufactures and programs the sprayer control systems and GPS guidance kits. Attention was also payed to the market and scale phases, looking for opportunities to allow Ambimetrics to grow. New markets for the power-saving electronic driving head were explored and a new GPS guidance kit for non-agriculture environments was designed.

Ambimetrics now has its spray components in operation in 13 countries (Spain, Portugal, Hungary, Poland, Slovenia, Montenegro, Israel, Mexico, South Africa, Argentina, Tunisia and France). Kubota purchased FEDE, which opened new market potential for Ambimetrics. The contact with John Deere has become less intensive. Over 450 Spray controller kits are successfully operating in different countries and over 500 GPS guidance kits have been sold.

During the test experiment together with IVIA, it became clear that existing test methods are insufficiently representative. Improving the testing method became a focus point. The team worked on repeatability and precision and named their testing method the 'Sprayometer'. Apart from not being happy with the existing testing tools, the dependency on the manufacturers of the sprayers (Ambimetrics' clients) was too high. Three limiting factors were identified: The need to borrow tractors, sprayers and drivers, the need to physically go out to fields and finally the technical dependency of their control system to the other systems of the sprayer: nozzle configuration, hydraulic system, electro valves specifications and others. To overcome these drawbacks, an indoor testing system was designed and implemented. This new system can test sprayers and their components without the need for a tractor and driver. This solution might act as the first 'wind tunnel' for sprayers for the agro sector. These testing methods contribute to serious and precise metrology at a cost-effective prize.

MM-ROWER

Multi-row Modular Robotic Weed Remover

Country

Germany

Technology Fields

Sensing, Data Processing & Infrastructure, Data Interpretation & Visualisation

VIDEO

Weeds compete with crops for sunlight and nutrients. In conventional farming, weeds are removed using herbicides, which comes with concerns for the environment, the health of the operators and the food chain. In organic farming, mechanical tools remove the weeds that grow between the crop rows, but are not able to remove intra-row weeds. As a result, manual labour is often required in addition to these mechanical tools. This leads to significant implications on the cost side and the need for organic farmers to source, manage and monitor manual weeding crews.

In the EU, consumer pressure has led to the establishment of regulatory limits on the amount of herbicides that can be used in farming. In addition, minimum wage increases put a downward pressure on organic farmers' margins, reducing the economic attractiveness of growing crops. The vision of this Innovation Experiment is to develop a commercially viable alternative for intra-row weed removal. This solution should be capable of substituting the need for manual labour (in organic farming), and, as economies of scale are developed, for herbicides (in conventional farming).

The robotic solution developed by Dahlia Robotics consists of an autonomous driving frame which hosts separate weeding modules. The image streams from the robot's cameras are segmented on the edge into weeds, crops and background at the pixel level through AI-based ANN technology. On the basis of the information generated by the ANN, the weed removal tools within each weeding module are then actuated in order to remove intra-row weeds. Several modules were worked on during this project, including the development of specific hoes to reach accuracy in sugar beet and salad production systems, optimised power autonomy, industrial design, the user interface and self-diagnoses capabilities, the improvement of the ANN, and the back-end support.

Dahlia Robotics GmbH is the MM-ROWER consortium lead. They work together with the end-users Biotop Oberland eG and Franziska and Johannes Blind GbR, in setting up field test areas and providing feedback on user experiences. This IE received technical support from Fraunhofer IPA in respect to ROS implementation and certification. In all cases the interaction was valuable, concise and directly addressing the issues at hand.

During testing and demonstration the robot had to work in soil rich in humus and organic matter. This created significant strain on some of the electronic components because of the drag this type of soil induced, causing the weed removal system to stop working. A software (self-cleaning procedure) and hardware (different hoe design) solution eventually solved the problem. Construction of new prototypes was hindered by the worldwide shortage of electronic equipment, including components that are crucial for the robots and for which there are no substitutes. A number of fundraising activities have been carried out over the course of this IE. Discussions with several investors were initiated following participation of the Company at dissemination events and conferences. Follow-on discussions with previously known investors, strategic and corporate players, as well as additional fundraising activities (such as regional funding institutions and accelerators) have also been carried out, and some were already successful.

The European Green Deal initiative includes an action

NEWMAN

Non-chEmical Weeding MachiNe

Country

Czech Republic, Austria, Poland, Slovakia

Technology Fields

Robot Navigation & Co-operation

VIDEO

plan with targets for 2030, addressing the challenges of environmental degradation and climate change. Reduction of the overall use of chemical pesticides by 50% and using at least 25% of the EU agricultural land for organic farming are among the targets. At the same time, prices for non-banned agrichemicals are rising, while the manual labour supply is dropping, and labour costs are increasing by about 7 percent each year. This amounts to a complex challenge of maintaining the performance of our agricultural production, while simultaneously decreasing dependency on agrichemicals.

The NEWMAN non-chemical weeding machine is one of the keys to the future of efficient non-chemical agriculture. By combining proprietary AI/ML crop recognition software with a specially developed robotic platform, this Innovation Experiment has created a unique technical solution setting new standards for quick crop recognition and mechanical cultivation. The uptake of NEWMAN technology will reduce the field cultivation and weeding costs for farmers, while completely removing the need for weed-control agrichemicals and drastically lowering the need for manual labour.

The NEWMAN team was coordinated by ULLMANNA s.r.o. from the Czech Republic, working together with four end-users and adopters: Agroland s.r.o from the Czech Republic, Molnár Ernest from Slovakia, GOSPODARSTWO ROLNE PATRYK JEREMIASZ from Poland, and FK Agrar – und Umweltservice GmbH from Austria. The main goal was the public demonstration of the NEWMAN device as well as the presentation and validation of the business model with potential partners and customers.

The original objectives of this IE included:

- Finalisation of the upgraded version of the NEWMAN device including improved dataset, customer-friendly UX, commercial-ready SW, and even more precise AI/ML models.
- Improvement of the NEWMAN hardware including better IoT systems, improved communication, better camera protection, improved quality of the moving parts, and overall NEWMAN production readiness based on best practices.
- Technology validation at TRL 8 including a series of tests with consortium members and independent stakeholders. The NEWMAN device was to be demonstrated cultivating/weeding at least 4 hectares of sugar beet fields.
- Presentation of the NEWMAN value proposition through preparation of descriptive client-oriented materials, participation in agriculture shows, organising private and public pilot trials and DEMO days, and active communication through web-channels (LinkedIn, website).

The NEWMAN robot is a complex system for mechanical cultivation. It combines multiple sensors for position and speed awareness, automatic cameras and LED lights for image collection, AI/ML model operating with the dataset for the crop detection, a software layer for controlling the knives (of each NEWMAN unit independently), and a SW-controlled shifting frame for the NEWMAN unit adjustments to the real field conditions. The carrier of the NEWMAN machine is not controlled by the device, and thus it can be either robotic or manually driven. The cultivation/weeding process itself is fully automatic.

Various tests and demonstrations took place in the Czech Republic, Slovakia, Poland, Austria, Germany, and Belgium. During these tests and the development phase, the developers were supported by the DIHs Moravian-Silesian Innovation Centre Ostrava (MSIC, DIH Ostrava) and ICT Cluster from Sofia in Bulgaria and Fraunhofer from Germany.

A technical challenge that was encountered involved the leaves of mature plants. Initially, the technology worked perfectly with small and young crops, but problems arose when the leaves of larger and more mature plants caused significant inaccuracies in speed detection. This led to wrong position estimations and knife operation. As a result, crops were damaged even though they were correctly detected by the model. The consortium solved this issue by integrating additional depth cameras and new speed detection algorithms using 3D data. NEWMAN is now capable of working with crops at any stage of their growth, whenever weeding is necessary. Another challenge concerned data collection quality issues caused by daylight shadows. Shadows cast by sunlight, reduce the precision of image-based methods in robotics. When part of the image is covered by shadows, the camera and algorithms have trouble detecting crops and details. Many robots use hoods and artificial lights to prevent this issue, but the hood reduces the overall robustness of the unit, and potentially decreases the operational speed. To address this, a unique system was developed, based on powerful stroboscopic LED lights synchronized with the shutter speed of the crop recognition camera. Thanks to this solution, NEWMAN is now capable of receiving sharp and precise images at relatively high speeds up to 15 km/h. This is the fastest precise mechanical cultivator available on the market. It is a major improvement to current state-of-the-art products and can be used not only for their own product, but also for other robotic applications requiring high speed.

The third challenge that was encountered during this Innovation Experiment was also related to speed detection. The problem was that the precision of any one set of sensors sometimes was compromised by the operation conditions. For example, sometimes the image was recorded in low-light conditions (de-synchronization of lights) or dirt on the wheels caused inaccuracies in non-visual odometry. To solve this, a unique solution was implemented, which is efficient and innovative enough to be patented. Like everywhere, challenges related to the microchip market during and after the Covid19 period were faced by this project. This and other spare parts availability issues forced the consortium to develop a modular solution, which is much more universal than earlier prototypes and allows easy and quick customization.

Finally, this project encountered a group of challenges related to market penetration. First, the manufacturing challenge. Second, the challenge of gathering a critical mass of farmers. Third, the limited chances during the pandemic to participate in several offline events. A new business model was developed, based on provision of NEWMAN technology to aggrotech manufacturers and integrating the crop detection units with their machinery. This allows Ullmanna to reach large groups of customers, participate in a variety of private demonstration events, and reduce their internal effort and expenses on manufacturing of the not-know-how parts.

Farmer JoeBot

VIDEO

Country

Israel, Italy

Technology Fields

Robot Navigation & Co-operation

Farming in the European Union is often not profitable. This absurd reality results in the current abandonment of agricultural land in alarming numbers. One promising solution to this problem is the use of autonomous robotics to reduce operational costs. Reducing involvement of operators can reduce labour costs, reduce risk of injuries for farmers and also reduce the cost of expensive machinery.

Autonomous robotics usually means: using electric vehicles. This way the use of fossil fuels and carbon emissions can also be reduced, supporting efforts to reduce global warming. Additionally, the use of advanced robotics is an opportunity to introduce a variety of sensors, produce rich large-scale digital data and stress or crop analysis for more effective crop monitoring and crop management using applications with on-line access. Such improved crop management will further increase yields and farmers' profit and gross margins.

Rich digital data also allow for spot-spray practices, reducing the use of agrochemicals and improving food safety, food quality and health for everyone. The UN estimate 200,000 people die annually from pesticides. The vision of Farmer JoeBot is fully autonomous farming. While that will take time, many autonomous capabilities described above will already be implemented in this Innovation Experiment where we work on a spray robot for vineyard farming. Unlike exiting prototype examples, the Farmer JoeBot platform is designed to be extremely competitive. The goal is to verify the assumption that an autonomous electric vehicle can significantly improve the gross margins and profit margins of farmers, produce rich digital data of the crops for improved crop management and reduce the operational risk for farmers that is involved in practicing agriculture and using chemicals. By doing that, it will improve food safety, food quality and health for the befit of everyone. The IE objectives are:

- Identify spot-spraying requirements and design a relevant solution on the robot.
- Provide an automated robotic solution with precision treatments and monitoring in vineyards.
- Validate the solution in end-user vineyards, with improved profit margins, improved crop yields, improved crop management and reduced effects of agrochemicals
- Formulate a business model for the commercialisation of Farmer JoeBot's platform.

The Farmer JoeBot industrial challenge is coordinated by Robotic Perception from Israel, supported by a specialised agronomist from Israel, an end-user from Italy and the Agricultural University of Athens as DIH.

The IE is focusing on a variety of terrain examples in Israel and Italy. These represent a broad generalised range of terrains and variety types. Interest in this technology has also been noted in Spain and South America, and we are looking to find potential customers in Eastern Europe with the help of agROBOfood services. A highlight of the project is that a patent was filed for a robotic sprayer based on initial results that show that the robotic sprayer can achieve better spray results than standard market sprayers, achieving a reduction of 66% in the amount of chemicals used. For weed cutting, an innovative electric mower was developed in-house, which does not use chemicals. It has a number of significant advantages in that it is fully electric, does not use fossil fuels, can be operated selectively and also reports a power consumption which is equivalent to weed density, and can be reported at sub-meter precision. In the marketing phase the consortium worked with a sales funnel with about 3,000 site visits, 150 leads, 66 Market Qualified Leads, and 2 clients-signed LOIs to buy two vehicles in Italy. The dissemination activities showed a huge interest in the product. Almost everyone who saw the videos

was impressed both because the content of the videos is appealing and innovative, but mostly because the prospects of saving labour costs is considered to save 50% of the production costs. In order to start selling units of the vehicle they need a technical effort to make the robot more robust, meet international standards, and launch a marketing campaign.

Biospray

VIDEO

Country
Switzerland

Technology Fields
Data Processing & Infrastructure, Data Interpretation & Visualisation

The goal of the Biospray Industrial Challenge experiment is to develop and validate the application of organic, non-selective and non-synthetic chemistry in agriculture for key crop care applications. This can be accomplished by adapting and improving an existing, ultra-high precision (UHP) spot spraying and plant recognition technology, enabling the application of compounds in a very precise plant-by-plant way.

The agronomic efficiency is validated with small-scale field tests, and the technique is implemented in two different robotic machines: on the first is ARA, a tractor-towed version used by farmers in medium-size test fields, and the second is AVO, an autonomous robot in small-scale field pilot projects. The main goal is to provide organic crop care techniques for industrial agriculture with reduced chemical residues in food, soil and water for the benefit of human health and environment. The objective of the experiment is to demonstrate that ultra-high resolution spot spraying used with AI-based plant classification can make use of organic pesticides in several main crop protection applications. The experiment is led by Ecorobotix S.A. from Switzerland, supported by the Berner Fachhochschule (HAFL Zollikhofen) as DIH, and with the participation of farmers from Switzerland, France and Germany.

The ambitious objectives of this experiment, are achievable only thanks to the maturity of the existing Ecorobotix spot spraying machines. The experiment mainly adapts and improves existing technology and components. Since the validation of the objectives rely on agronomic seasons and on field tests, the experiment has integrated early field tests in its design phase to have two validation seasons within the rather short experiment of 17 months. The winter period was used for technical improvements.

The design phase focused on the definition of three use cases (applications) of organic pesticides, This included their preliminary validation by means of field tests using the existing (not yet improved) ultra-high precision spot spraying technology of Ecorobotix available on the ARA machines.

The development phase focused on the technical improvement of the spot spraying technology in terms of accuracy and spatial resolution, the adaptation of the algorithms for the targeted applications, the porting of these improvements on one autonomous spraying AVO machine (with a dual resolution spray bar) and several tractor-towed ARA machines (without dual resolution spray bar). These prototypes were used in the tests and demonstrations for the agronomic season 2022. An important feature was added to improve spray accuracy: a 3D depth camera, including every visible camera of the system, that can provide a 3D image of the ground and plants. Depth information is key in improving plant mapping in the 2D spray plan, and in correcting the scaling error of the visual odometry to obtain exact object tracking from detection to spraying. The plant mapping and visual odometry software was adapted accordingly. A doubled precision spray bar was designed and assembled, with 2 cm between each nozzle instead of 4 cm. New nozzles with smaller divergence angles were ordered, but they showed insufficient jet quality and therefore the current nozzles were used, which had sufficient precision for the application.

Several field tests to validate the performance of the applications and the technical improvements have been performed. The first group of tests were performed with the AVO autonomous spraying robot, in collaboration with the DIH HAFL Zollikhofen, and the second group of tests were performed by end-users with the tractor-towed spraying machine ARA, on various crops. Over the three initial applications (all in sugar beet), only the weeding application with organic herbicide could be validated. The two other applications, namely application

of organic insecticide to fight against aphids and flea beetles in sugar beet, could not be validated due to a low population of insects. Regarding the tests with external partners, two partners tested weeding with pelargonic acid in two different crops: string beans in France, and lettuce in Germany. Both obtained satisfactory results. Thanks to the maturity of the technical blocks developed by Ecorobotix before the experiment, these tests did not encounter major problems in terms of modification and adaptation. However, regarding some software functions, and some operational parameters such as machine height, limitations were discovered during the season. These very likely degraded the performance of the applications and came up despite the time spent to verify the good operation of the systems beforehand. The limitations that were discovered included a limited ability to identify crop plants at a very early growth stage, a higher than planned dosage difference between spray spot center and periphery, missed points to spray due to remaining bug in the spray software, and insufficient XY management of the buffer zone. The new software will be uploaded to the more than 140 ARA machines in operation already in 2023 throughout Europe. This means that the technical results of the experiment will be directly available on a large number of machines.

The operational challenges were the most difficult to address, and impacted the experiment most severely in terms of validation of agronomic efficiency of the organic pesticides. Choosing the right chemical mixture (dilution) adapted to the speed and nozzle flow rate was difficult. In some tests, probably a non-optimal dosage was chosen, leading to bad weeding results, and it was too late to correct once the problem was discovered and understood. Also the meteorological field conditions strongly influenced the population of insects. Basically, not enough insects were present and therefore the efficacy of insecticides could not be validated. Also, experimenting under farm conditions was sometimes difficult, especially when they forgot to apply the products on the test plots which meant that the trial was interrupted. A critical point was also to have enough ARA machines for various tests in various locations. The cost of exclusive usage of a single ARA machine for the Biospray experiment was too high and therefore Ecorobotics had to live with the priorities of the ARA end-users, which were not always aligned with the Biospray experiment. Ecorobotics noticed that end-users are often keen to carry out their own trials with the ARA machine. This means that they will be encouraged to try using natural pesticides. Their experiences will be followed up by the commercial team of Ecorobotix and will serve to optimise the operational parameters of the machine. These experiences will also be described in online tutorials to facilitate other (future) users.

ZEROTOXVINE

Country

Spain, Romania, Ukraine, Poland

Technology Fields

Robotic Manipulation & Handling

VIDEO

Zerotoxvine is a robotic solution that aims to demonstrate the feasibility of automating recognition and removal of weeds that are harmful for vineyards, while sparing species that are beneficial to the crops and soil. The robot completely avoids the use of chemicals, toxins and water, and also save costs.

This innovation experiment is of vital importance. The rising demand due to population growth expected by 2050, will lead to 10% of people being affected by severe food insecurity, according to the World Health Organization. Accelerating innovation towards a more sustainable agriculture is therefore urgently needed. Currently, 40% of crops are lost at source. About 60 to 75% of these lost crops are untreated. Also, the efficiency of current crop protection treatment, using chemical herbicides and pesticides, only reaches 25 to 30%. Using a lot of chemicals for crop protection, results in the pollution of air, water and soil, all of which can ultimately undermine agriculture, the food chain and even biological chains. Chemicals used in agriculture globally, are mainly herbicides (50%), followed by insecticides (30%) and fungicides (18%). Thanks to the expansion of irrigation, 70% of global water withdrawals are currently intended for agriculture. The overall objective of the Zerotoxvine Innovation Experiment is to bring to market a SMART ROBOT for farmers of vineyards. This robot is able to distinguish, detect and selectively eliminate pests and weeds, totally avoiding toxins in the food chain, pollution in soil, water and the environment, while saving water and costs. This is achieved by adding a number of functionalities to the Zerotoxvine Robot. These are: detecting weeds and pests thanks to high-tech monitoring of vineyards using sensors and GPS/GIS geo-location; discriminating between species that are harmful or beneficial to vineyards; deciding which species must be eliminated by using artificial intelligence algorithms; dehydrating the selected weeds and pests by application of an electromagnetic field through microwaves. Validation of the operability of Zerotoxvine Robot in vineyards took place, performance was optimised, and the go-to-market strategy of Zerotoxvine Robot in Spain, Poland and Romania has been studied. At a later stage, introduction to the rest of the Europe market is to be achieved by involvement of end-users in dissemination and communication, where they act as ambassadors of the innovation.

The Zerotoxvine Innovation Experiment is coordinated by GreenKillerWeeds S.L., a robotic SME from Spain. They work together with Twist Robotics (TR), a technological partner providing capabilities in artificial intelligence and machine learning from Ukraine, and two vineyard end-users: Winnica Terra Smaku (WTS) from Poland (end-user partner) and Jidvei (JID) from Romania. The experiment was mentored by the DIH Eurecat from Spain.

The Zerotoxvine robot consists of the following main components installed in an agricultural tractor: (1) a sensors' head placed on the front of a tractor, that is able to monitor a comprehensive set of crop-related data, (2) an artificial intelligence (AI) based software module that analyses the big data available from sensors to decide and discriminate target weeds and pests for elimination, (3) a microwaves bar placed on the front of the tractor that automatically eradicates the harmful species, and (4) a power module at the rear of the tractor. As the tractor goes through the vineyard, data about crop status, soil, weather and water are collected by GPS/GIS, video cameras, hyperspectral cameras, LiDAR, NIR camera and MicroNIR sensors. These data are sent to cloud computing platform by IoT communication, where they are analysed in real time. AI algorithms and machine learning techniques are applied to determine which weeds and pests must be eliminated. These are geo-positioned with a centimetre-accurate GPS. Immediately after AI-based software takes the decision, the control system automatically sends an order to the microwaves bar. An electromagnetic field is then generated, which stimulates water molecules in weeds and pests and produces instantaneous dehydration killing the selected living organisms.

This Innovation Experiment was directly influenced by the complicated war situation for the Ukrainian partner, and by difficulties in the supply of electronic components. This meant it took more time to construct the prototype. Consequently, the tests in Poland and Romania had to be carried out in a very short time frame. Intense rains in regions of Romania and Poland then influenced the testing and demonstrations. To compensate, tests in Spain were also carried out, where we could take advantage of the weather to attract the visit of Venture Capitalists . The prototype robot was designed in such a way, that it can be operated by manual activation of the elimination head and in a potential absence of the cameras, sensors or failure of the AI/ML the robot is able to still eliminate the weeds and pests, although in a slower tempo and less efficiently (the robot driver activates this functionality). Sharing information in a technical, detailed and transparent way helps everyone involved to work and move the experiment forward. This was an important lesson learned from this IE.

Oenobotics

Country

Greece, Cyprus, Romania

Technology Fields

Data Interpretation & Visualisation

VIDEO

Oenobotics is developed for wine farmers, especially in hilly terrain. This innovation will provide viticulture farmers with innovative and affordable precision viticulture services. The services rely on the Oenobotics drone platform and consist of early warning and precise spot-spraying for treatment of downy mildew, powdery mildew and water stress and a wireless drone charging via a smart charging dock.

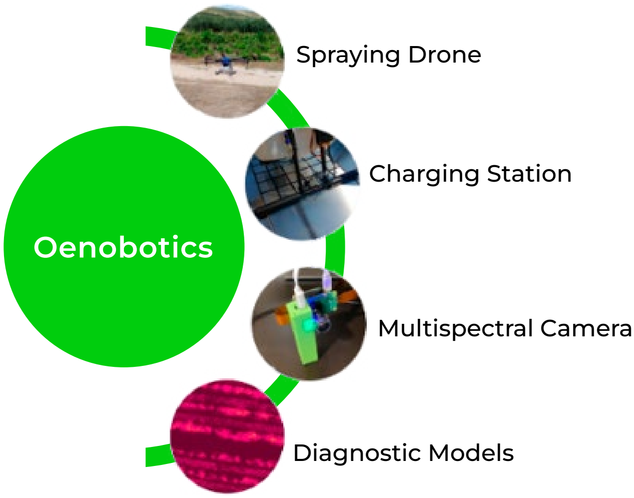
Oenobotics services will be delivered to customers, such as vineyard farmers or associations, via a hardware-as-a-service business model, supporting clients to avoid significant initial investment costs. The Oenobotics hardware and software will also be available to drone companies and interested farmers as an off-the-shelf product. The solution addresses the needs of wine-producing vineyards located in hilly and elevated locations that are hard to reach with machinery. The Oenobotics services will assist vineyard owners in avoiding health impacts of chemicals and heat on vineyard workers, to react much faster to extreme weather changes caused by climate change, and to be more sustainable and profitable by producing yield of better quality, using less pesticides (in case of conventional farming) and producing less CO2 emissions (in case of organic farming).

The objectives of the Innovation Experiment are to demonstrate the accessibility, cost-efficiency, and feasibility of the Oenobotics solution in real application scenarios, to develop diagnostic and actuation models that will enable systematic, efficient, and effective plant monitoring and targeted and selective application of plant protection-therapeutic interventions, to develop a low-cost image processing hardware with multispectral functionality and a machine-vision enabled precision spot-spraying system, and to offer longer flight-time for drones used in precision viticulture via improvement of the charging dock for drones developed by Hellenic Drones.

The Innovation Experiment is coordinated by Hellenic Drones, a SME specialised in drone systems integration in Greece. They work together with the Information & Communication Technologies Laboratory S.R.L., an SME from Romania specialized in machine vision, Future Needs Management Consulting Ltd from Cyprus specialized in business development and market analysis, and Agroecology L.P., an end-user from Greece. The Innovation Experiment is supported by its mentor DIH, the Agricultural University of Athens, and Green Supply Chain Digital Innovation Hub from Greece.

The Oenobotics UAV platform is a hexacopter that carries a 16 liter tank and a multispectral sensor that detects water stress and diseases in vineyards. The cameras' algorithm generates the drone flight plan and the actuators control and command the drone to fly above the infected areas and spray. The flight mission and actuator commands are transmitted to the flight controller by a Robotic Operating System (ROS) framework implemented on a companion computer aboard the drone. The UAV's geo-positioning system relies on the Real Time Kinematics (RTK), which is subject to a position error of less than 2 cm. This way, the UAV can spray the target vines in a very precise manner and land accurately on the charging station. It should be pointed out that during the flight tests it has been observed that wind conditions strongly affect the drone's spraying efficiency. From conducting multiple tests, it was found that by adjusting the flight and spraying parameters accordingly (low altitude and reducing the flow capacity), the drone-based spraying reduces the unnecessary sprayed liquid by at least 50% compared to traditional methods. The diagnostic models for identifying diseases and water stress were based on two pillars. First, suitable camera filters (specific wavelengths) that can effectively support the detection of diseases and water stress and that provide a higher correlation between the spectral bands and the diseases or water stress than satellites. Second, the development (with the help of deep learning pipeline) of data processing techniques for generating results and adjusting to different vine microclimates and lighting conditions. The charging station was assembled with several different components that are waterproof (IP69 rating) and enable the recharging of the UAV's batteries when the UAV lands on top of the charging station. Moreover, the charging adapter consists of a Battery Management System (BMS) that ensures balanced charging of the battery's cells. Also, the charging station has an indicator screen that displays the battery's charging state. Finally, the charging station contains a pair of portable fire extinguishers that are triggered in case of fire.

Over the course of the project, three young researchers were recruited. During the project's demonstration events, the system was demonstrated to young farmers and basic training on the system's operation was provided. Finally, ten vine growers were supported to beta-test the solution and provide feedback during the development stage. In the market stage, a thorough market analysis was conducted, including the market landscape, the trends, and projections for the future. This



analysis helped define the business models appropriate for the Oenobotics solutions to penetrate the market. The prices for the system and for the service have been finalised and the financial projections for the first five years of the system's commercialization strategy are also specified, along with the strategy of expansion in European countries and markets with similar characteristics.

The main challenge encountered during the execution of this Innovation Experiment was related to the collection of the dataset, which included pictures of healthy and unhealthy conditions. This issue was mainly attributed to the fact that the experiment covered only one growing season and also due to the limited funding that curbed the amount of data that could be collected. Moreover, the target diseases (powdery mildew and downy mildew) are related to the environmental conditions. Only a limited number of vineyards were monitored during the execution of the experiment. As a result, data that included the target diseases were limited. Still, the Oenobotics algorithms were able to differentiate between healthy and unhealthy conditions. Another interesting finding was related to the data collection protocol that should be followed in order to collect UAV data that can identify powdery mildew and downy mildew. Because these diseases initiate from the bottom part of the vine, the UAV should not collect data directly above the target vine, but instead the camera should be tilted and collect data from a different angle. Water stress conditions, which start at the top of the vines, should however be reviewed from above, looking at the top of the vine.

The final product has been exposed to users' feedback, tested and demonstrated in real-life field trials. It is now ready for commercialisation.

4. Robotic solutions in harvesting and thinning

TOMMIE

Automating Crop Load Management for Apple Orchards

VIDEO

Country

Italy

Technology Fields

Robotic Manipulation & Handling

The TOMMIE Industrial Challenge experiment proposes a revolutionary robot for chemical blossom thinning which applies chemicals directly onto the flowers, in precisely targeted locations and in dosages customised for each tree. This approach will offer a new level of precision in flower thinning. Thanks to Artificial Intelligence, it will be possible to reach an optimum thinning rate even in highly variable environments, resulting in a significant reduction of the volume of chemicals sprayed.

The main goal of the experiment is the development of a demonstration system for a revolutionary technology that will increase crop load in apple orchards, while at the same time relieving workers from repetitive and exhausting activities and decreasing the use of chemicals. To accomplish this goal, this experiment combines state-of-the-art methods in AI to detect and monitor flowers in apple trees and cutting-edge robotics to perform localised thinning via chemical spraying at the level of each individual tree.

The TOMMIE experiment is led by Aigritec S.r.l. from Italy supported by the Rabbiosi farm, an end-user, the Laimburg Research Centre. CNR from Italy and CEA from France acted as DIHs.

In the development phase the consortium worked on the following four main activities: (i) developing and testing the spatial crop load mapping; (ii) developing the robot mobile platform; (iii) deploying, testing and refining the system at the end-user; (iv) developing the system prototype demonstration. The robot was tested at end-user Rabbiosi and feedback was incorporated through multiple revisions. As these updates were performed outside of the blooming season, for a realistic simulation of all relevant features of the monitoring pipeline a dataset of real images taken at Rabbiosi's farm in spring 2021 was used. Having access to the realistic image dataset allowed the partners to fully simulate the computer vision pipeline and directly connect it to the real robot-motion trials. Laimburg Research Centre made apple trees available which were cultivated in a greenhouse and were blooming. This enabled realistic indoor chemical spray testing.

The purpose of the system demonstration at Laimburg Research Centre was to showcase the capabilities of the robot for precision chemical spraying in orchards. The demonstration was conducted in a very systematic and scientific manner, in collaboration with the researchers at the centre, to ensure that the robot's performance was accurately evaluated. As part of the demonstration, a scientific experiment was carried out to further evaluate the robot's efficacy in precision chemical spraying. The results of this experiment will be used as the basis for a publication, which will be presented at the International Society for Horticultural Science conference. This conference is a prestigious event in the field of horticulture and attracts attendees from around the world. During the system demonstration, several stakeholders (including large and small local farmers, potential investors, and journalists) were invited to observe the robot's performance. This was an opportunity for the stakeholders to witness the robot's capabilities first-hand and to gain insight into how it could benefit their respective industries. In addition to the system demonstration for precision chemical spraying, a second demonstration of the system was conducted for the automated harvesting of apples. While automated harvesting was not the main focus of this Industrial Challenge, the consortium was able to showcase the capabilities of this technology, thanks to agROBOfood's grant and the fact that most of Aigritec's hardware is shared between spraying and harvesting.

Two different business models for the robot were studied. Selling the robot would give customers the freedom to operate the machine on their own and tailor it to their specific needs. Customers would also have full ownership of the robot, allowing them to make changes to it as needed. However, the high upfront cost of purchasing the robot can be a significant barrier for smaller farmers. Additionally, owning the robot also entails maintenance and operational costs, which can be an added expense for the farmer. On the other hand, selling the service of using the robot allows farmers to utilise the robot without the need for significant financial exposure. This service model is also more accessible to smaller farmers who may not have the capital to invest in purchasing a robot. The service provider would take care of maintenance and operational costs, making it easier for the farmer to focus on their core business. There may however be limitations to the customisation of the service to fit specific farm needs. After evaluating both models, it was decided to first provide the service of using the robot. This approach allows the consortium to gain valuable feedback from early adopters, which will be used to improve the product before finalising it for sale. It also allows us to reach a wider range of farmers who may not have the financial means to purchase the robot outright. By providing the service, the benefits of the robot can be demonstrated, such as its impact on crop quality and yield. This could potentially leading to increased demand for the product in the future.

During the implementation phase this experiment encountered a number of limitations to the integration of the motion software in ROS1. An upgrade of the software to ROS2 was decided upon. This unlocked a series of important features such as real time processing, better path planners and straightforward camera integrations. Spending time to move to ROS2 proved to be a good investment. The development of the vertical handling component was more difficult than expected, in particular due to the specific handling requirements because of the increase in the weight of the arm compared to the initial prototype. The lesson learned was: procure multiple path finder motors in advance, so you can immediately switch models in case one doesn't work. The approach to new end-users was initially easy, but we soon realised that we lacked an appropriate legal framework through which to decline a potential collaboration. Investing energy in advance to have standard models of collaboration drawn up by our lawyers, is advised.

Automato Harvest Robot

Country
Israel, Spain

Technology Fields
Robotic Manipulation & Handling

VIDEO

The Automato Harvest Robot, developed by the Israelian SME Automato Robotics LTD, is a game-changer robotic solution set to revolutionise tomato greenhouse farming by autonomously driving, navigating, detecting and harvesting tomatoes in harsh environments with consistent quality (level of ripeness), while providing up-to-date yield analysis and pest detection. Currently, tomato harvesting in greenhouses is based on handpicking. This method suffers from a number of limitations that can be overcome by robots, such as shortage of manual labour, daytime temperature, inconsistent quality and bringing diseases into the greenhouse. Currently, human labour costs, together with price pressure from the market, leave farmers with very small margins, making it difficult for them to make a living out of their farming business.

Automato Robotics offers a reliable 'mechanised workforce' at affordable prices, which fits our vision of helping every farmer to increase the profitability and efficiency of their businesses. Automato does this by combining advanced and well-trained detection algorithms together with functional arm manipulators and autonomous off-road platform. A software-oriented development process is used and the technology is based on of-the-shelf hardware products, which keeps BOM (bill of materials) low. Automato Robot will decrease the operational costs for farmers, prevent losses and improve product quality, offering an immediate tangible value.

The main objectives of the Automato Harvest Robot industrial challenge experiment are to adapt the robotic solution to the Spanish market conditions, maintaining its home-based market in Israel and to analyse and assess the benefits of the Automato Harvest Robot compared to human labour. To upgrade the existing Automato Harvest Robot to fit the Spanish market requirements, a commercial pilot in a Spanish greenhouse environment was conducted, followed by dissemination activities in the territory. The Automato Harvest Robot upgrade included navigation capabilities in Spanish territory and adapting the robot height in order to enable collecting benchmarks and statistics. Also, demonstrations at the commercial greenhouse level were carried out. Important metrics are quality of the harvested tomatoes with the right predefined colour and minimal or no damage, coverage of harvesting most of the ripe tomatoes, efficiency of harvesting a full row at the required speed, continuity of the net harvesting time per day, and cost-effectiveness of the robotic solution.

The Automato Harvest Robot is led by Automato Robotics LTD from Israel and they are supported by the DIH Centro Tecnológico TECNOVA from Spain. This way the consortium could connect and acquaint themselves with the Spanish market for tomato production. The main territories are Israel and Spain, but the same technology can be easily adapted to Italy, France or Greece. The main tests were performed at Polonky's farm in Hadar-Am in Israel and Perichan farms in Mazarron, Murcia, Spain.

In the development phase the system was upgraded in the following ways. The navigation was adapted to operate in southern Spain, a new harvest plain was built including a new lifting mechanism, vertical cameras and a plants protector were installed, the harvest platform was mounted on a new autonomous platform, and the appropriate software was developed to support the changes and enable harvesting within the selected greenhouses.

During the period that was planned for testing at the multi-tunnel greenhouses of Perichan, there was a lack of appropriately mature tomatoes. This meant harvesting high-hanging tomato plants was not possible. It was therefore decided to perform the Spanish experiment in a traditional greenhouse, where the tomatoes are grown

using the folding-over-wire method. This method results in a complex environment with variable tomato density and obstructions caused by leaves and wires. This type of environment makes both detection and harvesting much more complicated. Both detection and harvesting algorithms were adapted to the new environment and good results were achieved. However, results couldn't fulfil all expectations that would have been demonstrated by testing multi-tunnel-high-hanging tomatoes.

Automato Robotics strives for continuous improvement. That is why a thorough learning process was conducted, in order to detect and improve the issues which came up during the experiments. The results of this experiment greatly encouraged us that a commercial harvesting robot is within reach. The project and the unexpected challenges taught us how to structure the solution in a more market-relevant way. For example, if we restrict the operating environments to multi-tunnel greenhouses with the Pera tomato variety, it is expected that a commercial solution should be feasible within six months of testing. To support harvesting in an 'over the wire' greenhouse, or in tomatoes with a different maturity colour gradient (e.g. Kumato variant), however, more time is needed to ensure safe and exact operations. Thanks to these lessons learned, the consortium intends to conduct a more in-depth market survey to see if the market is still big enough to justify the former solution, which we will be able to support promptly. If that's turns out to be true – we favour fast commercialisation over solution robustness. If the market is too small, we will start additional fund raising activities to create a robot that meets the challenges of these varying conditions.

FullPheno

Country

Finland, Germany, Italy

Technology Fields

Data Interpretation & Visualisation

VIDEO

To feed the planet in the changing climate, massive improvements in efficiency of agriculture are needed. These improvements can only be achieved with dramatic advancements in crop production R&D and optimisation. For this to be possible, we need next generation crop data with orders-of-magnitude higher accuracy and much more coverage in terms of phenotypic information. High resolution full canopy phenotyping is a technique based on spreading the canopy to obtain maximal visibility of all parts of the plant. It enables collecting the very same information by means of video intelligence and low-cost RGB sensors that a human expert can gather.

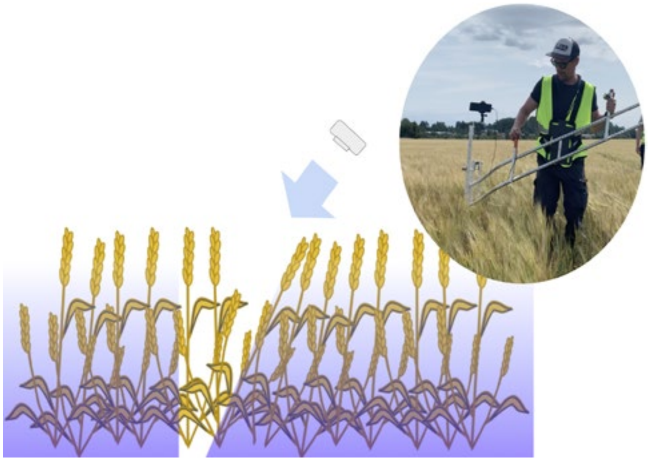
FullPheno enhances, robotises, demonstrates and disseminates machine intelligence for full canopy phenotyping and monitoring to provide robot and other machinery providers with access to cutting-edge full canopy phenotyping capabilities. These capabilities will speed up robotisation in agriculture, where an efficient machine vision component is a necessity and often becomes a delay for market entry. The availability of full canopy phenotyping can resolve the current lack of phenotypic data to create a significant impact in both sustainability and food security.

FullPheno stimulates the interoperable machine intelligence software component by providing access to full canopy phenotyping to third parties through an API. A Kubernetes-based video intelligence server was set up, via which collaborators and customers can get access to phenotypic estimates delivered as a response to input videos. FullPheno developed an end-user driven roadmap for technology development. It prioritises different phenotyping features, trait candidates and estimation methods with end-users to maximise industry value.

FullPheno developed an autonomous full canopy phenotyping robotic platform that contains a robotic module to perform the mechanical work of full canopy phenotyping which can be attached to various field machines / robots. FullPheno created a data pipeline and demonstrated the data set collection and the proof of the 'field-as-a-lab' concept. We created a publishable data set combining full canopy phenotyping, hyperspectral drone data and soil moisture measurements along with conventional agronomic data. A business plan was developed, based on the results of the Innovation Experiment. Faster and higher potential market fits were found from yield forecasting (origination, insurance as customer segments) and multi-purpose robotics. FullPheno provides an efficient solution for obtaining highly informative crop data with low-cost sensors by using video intelligence and canopy spreading. FullPheno robotises the necessary mechanical device manoeuvring and develops and tests a robot for efficient field phenotyping.

The FullPheno Innovation Experiment was coordinated by Yield System Oy from Finland. They worked together with Probot Oy from Finland, Ackermann Saatzucht GmbH & Co. KG in Germany, and Apsovsementi S.P.A from Italy. Testing abilities from the north to the south of Europe were sought out, to benefit from seasonality. The experiment was supported by the DIHs LUKE DigiInno Services from Finland, CEA from France and the Danish Technological Institute.

In this Innovation Experiment an application-specific robot was developed to meet the requirements of full canopy phenotyping for breeding and seed production (off-type recognition). The robot is integrated by using modular UGV components created by the Probot Oy. The robot consists of three main parts: 2x UGVs / rovers for enabling the general movement on the field, an application specific linear unit for performing movements trough a test plot, and an application-specific tool for full canopy phenotyping device manoeuvring. Several



hardware developments were made to enable canopy resistance measurement, colour calibration and two person handling for very stiff canopies (in particular Central European winter crops).

Probot developed a Device Control Robot (linear actuator for performing the spreading of the crop, 30% down from the top of the crop top) to automate the manoeuvring of the current handheld device. The system is based on Lidar for estimating the canopy height. Based on the lidar measurement, the system adjusts the height of the tool by controlling the motor of the vertical linear. Local GPU computation is used for processing video data from a camera device. Special focus is paid for stabilizing the camera and the integration to the field-robot. Also the control of the cooperation between the two rovers with the in-between linear unit has been improved and tested extensively. The cooperation between rovers might stimulate also other applications where cooperativity between robots is needed.

The software infrastructure enhancements in the synthetic data generation pipeline (further degrees of procedurality) and video analytics core are implemented to achieve sufficient efficiency for delivering new traits. In the development phase the synthetic data pipeline was refactored and the degree of procedurality was extended to enable programmatically controlling DUS traits. Significant efficiency improvements were necessary given the increased computational load and they were achieved by changing the renderer. Extensive data collection at several sites and moments in Finland, Germany and Italy and 3D modelling took place on automatic classification of primary traits, such as spike glaucosity, spike pigmentation, and sterile spikelet presence in Barley, spike glaucosity, hairiness of the external surface of the glume, awn length, and plant counting in 2-leaf stage of wheat, and colour of the pubescence, plant count in 2-leaf stage, and pod count in soybean.

In the field tests we also worked on the ability to reduce plot size: can small plots be sufficient for estimating new traits? Major border effects were identified and as a result, it was established that plot size cannot be reduced. Instead, techniques to estimate the impact of border effects on different varieties should be developed. This is a powerful result and can bring something completely new to wheat breeding. Border effects are one of the long-standing and unsolved issues that may even affect genetic gain. Should Yield Systems be able to quantify it, a major impact can be achieved.

A big challenge for the Innovation Experiment was organising the people for the various tests and developments. Being active in several countries at the same time and being confronted in the (after) covid-19 period with serious health issues within the team, resulted in a very slow speed of development in 2022. Also, a delayed funding round by VC prevented the hiring of more personnel to compensate the reduced development capacity. As not all data could be collected as planned, also the modelling roadmap had to be revised several times during the experiment. As certain expertise profiles were unavailable, as a mitigation activity, alternative computational methodologies were explored (ones that the active team members had experience on). Due to the delays, almost all of the developed new traits still require further work. However, a hugely valuable outcome of the experiment was that it created much more understanding of the limitations of both imaging and computational techniques than expected.

During the project we found a new and even more lucrative and impactful market segment for this technology in post-registrational trials. After testing this concept with originators, breeders and satellite companies, there seems to be a large market for such an offering and competitive technologies are not efficient.

In summary, full canopy phenotyping enables recording pixel-specific yield (and other) phenotypic data from production conditions at a large scale. Based on empirical results and simulations on logistics, it is possible to create – for instance - variety-specific, AI-based management recommendation systems. Such systems could dramatically improve the agronomic performance.

5. Robotic solutions in livestock production

LitterBot

Country
Poland, United Kingdom

Technology Fields
Robotic Manipulation & Handling

VIDEO

FLOX – the Healthy Chicken Company, is a pan-European livestock welfare and performance SME. We use advanced robotics, machine vision (MV) and machine learning (ML) to help farmers automate and streamline previously manual processes, leverage rich data to systematically measure and improve livestock performance and welfare, minimise the environmental impact of poultry farming, take valuable cleaning action inside poultry sheds without any human interventions and promote transparency and informed decision-making along the entire agri-food chain. The initial focus is on high-value broiler chickens – an industry facing increased consumer demand and scrutiny, and an endemic labour shortage exacerbated by zoonotic disease pandemics such as Covid-19 and avian influenza. With notoriously tight profit margins, poultry farming is known as a '3D' job (Dirty, Demanding, and Dangerous), often subject to forced 'depopulations' which place further pressure on food supply.

By combining this Industrial Challenge experiment's revolutionary LitterBot with the already proven NetFLOX product, FLOX is positioning itself as the go-to solution for measuring and improving key welfare and performance metrics for farmers in the broiler industry. In this experiment we built a commercial robotic system called Litterbot, to monitor and physically manage poultry litter through management actions like litter aeration. The key technical objectives of LitterBot are the remote observation of the broiler chicken shed environment, measuring the environmental conditions at 'bird-level' (allowing for intervention when necessary). LitterBot improves litter management and chicken welfare (reducing anti-social activity, reduces disease vectors), gives a better oversight and reduction of ammonia emissions and minimises the human-flock interaction and zoonotic transmission risk.

The LitterBot experiment is coordinated by FLOX, a SME from Poland, and supported by Kell ideas sp. z o.o. as part of the FictionLab Team from Poland and by the Menchine farms in the United Kingdom. The experiment was mentored by the DIH Fraunhofer.
LitterBot is made up of a combination of off-the-shelf components integrated in a custom (open source) rover platform – with the wider system integrated into FLOX's overhead camera based poultry monitoring platform (called NetFLOX). The onboard computer of the robot comprises an Intel i9 CPU and an Nvidia 3060 GPU, which together enable efficient data processing and real-time decision-making. The software stack of the robot includes ROS (Robot Operating System), FlexBE (Flexible Behaviour Engine), and Move Base Flex, which facilitate the integration of various functionalities, such as navigation, control, and sensor management.

The robot is equipped with an array of on-board sensors, including the Intel RealSense Depth Camera D455, which provides high-resolution depth data, and the T265 Visual-Inertial Tracking Camera, which enables accurate tracking of the robot's position and orientation and includes sensors for ammonia, relative humidity, and temperature. Additionally, the robot utilises wheel odometry and an Inertial Measurement Unit (IMU) for precise motion tracking and navigation.

The litter aeration tool was designed with ploughing blades that can be remotely extended and retracted, using a linear actuator. Strain gauges were also used for testing purposes to create heatmaps of litter quality. Two shed trials were carried out to test the tool and make design changes to improve its sturdiness and durability in the shed environment; a farm in Wypychow, Poland and a farm in Tiverton, UK. Both are commercial broiler farms, with some chickens in a higher welfare system and others in a conventional system. We were able to remotely observe the birds using cameras on the rover system, and enable manual control of the system if farmers wanted to check certain areas of a shed or a feeder or drinker line. This will be particularly relevant in the future when the NetFLOX functionality is added. At that point, when a drinker line is broken, machine vision can detect wet spots in the litter and farmers can ‘drive’ the rover to these locations, to see if the drinker lines are the problem. The impact of LitterBot on the birds was measured. The birds do move away and show increased activity when the system is used, but not in a way that shows stress. There was a normal level of ‘backfill’ after the rover moved, which can be used by NetFLOX to show ‘good welfare’.

There were a number of technical challenges. Enabling a robot to navigate in a poultry environment, even with the assistance of roof-mounted cameras, is particularly challenging during specific stages of bird growth due to a delay between the overhead system’s view and the robot’s perspective. Additionally, differences in litter quality and poultry house types between Poland and the UK, mean that some houses require more effort for the robot to navigate, while others pose physical obstacles. The robot’s navigation system encountered issues with precise mapping of the poultry house environment, especially where lighting conditions or house layout vary greatly. Standardisation is a huge problem in robotic commercialisation. Steps were taken to identify relevant standards, and make sure our robot fits them through using off-the-shelf components where possible and making limited changes. These include: IEC 61140:2016, Basic safety publication - ELV standards followed in the design and testing of the robot, ASTM F3244-17 - Standard Test Method for Navigation: Defined Area, ASTM F3327-18 - Standard Practice for Recording the A-UGV Test Configuration, ISO 13482:2014 - Robots and robotic devices - Safety requirements for personal care robots, ISO 18646-1:2016 - Robotics – Performance criteria and related test methods for service robots – Part 1: Locomotion for wheeled robots in indoor environments, ISO 22166-1:2021 - Robotics Modularity for service robots Part 1: General requirements, and IP66 Enclosure - IP rated as “dust tight” and protected against heavy seas or powerful jets of water. IP66 is particularly important due to the use of the robot in ammonia-rich environments which are wet and often subject to jets of water when they are being ‘cleaned out’, which also affects the robot.

While farmers express admiration for the robot, operational challenges include the need for more comprehensive training materials and user-friendly instructions for operating the system. It may be challenging to ensure that the robot operates consistently and effectively across a variety of management practices. Farmers who are contracted are usually ‘better’ managers and engaged with the experiment. The robot required more maintenance and upkeep than expected, which could pose a challenge for farmers who lack technical expertise or experience with robotics.

Regarding administrative challenges, grants were identified that could facilitate the deployment of this robot throughout Poland and the UK. However, farmers lack awareness of these resources, and the consortium must assist them in accessing and utilising these funds effectively. There will also be regulatory hurdles or bureaucratic barriers to deploying the robot in certain regions or countries –especially when you have bird flu lockdowns, which makes building/testing the robot difficult.

6. Lessons learned from the Innovation Experiments

In general, the twenty Innovation Experiments highly valued their cooperation with agROBOfood. The grants were used to develop, improve and test their robotic solutions. Some of the consortia are already selling their first robots or their first services. Others might need a bit more time and insight into their unique selling points and specific markets.

This fits the observation that agROBOfood only supports part of the development journeys. The open call funds indeed function as 'Public support/grants', and expectations should be accordingly. The Innovation Experiments generally reached TRL levels of TRL8, with some ending at a TRL9 or TRL7 level.

Most of the selected Innovation Experiments focus on robotic solutions for crop care management, followed by solutions for harvesting and logistics in post-harvest food processing. All are in the launching phase or the phase of early adoption. Many recognise the challenges they face for crossing the chasm between those two phases. We tried to prepare them for this challenge, by pushing them to start working on the market phase early.

When we compare our experiments to the mature robotic market for automatic milking, it is clear that some things are not yet fully developed. At the moment, there are no big partners with professional production and maintenance organisations. However, it is promising to see the further cooperation in the H3O-Spoton environment were connections are built with Kubota. Additional studies on the (re)design of the system in which the robot is expected to function might also be needed. Robotic milking really changed cow housing and management by dairy farmers. For the moment, we hardly see comparable studies and awareness as spin-off in the Innovation Experiments.

Another observation is that in plant production we are dealing with a mature tractor and implement industry. These are different types of companies and robots should bring these two worlds together. The struggle we see is that some robotic solutions still depend on tractor-mounted systems and have a robotised implement, while others try to also incorporate the AGV-platform. In automatic milking, the traditionally leading companies are still working on milking technology.

Part of a mature market is that end-users inspire each other, that there is healthy competition between producers, and that there is trust in the products. These factors are still lacking here, as we keep hearing in the discussions about these Innovation Experiments. Many partners are wondering how to gain trust and how to present a proper business model for their end-users and for themselves. It was disappointing that only one of the experiments was dedicated to the livestock sector.

As was intended the Innovation Experiments were performed by SMEs and start-ups. In general it is good to see that they are ambitious, eager to learn and are able to adopt quickly new technologies.

The biggest challenges for our SME's and start-ups were: Finding the right people and organising the work was very challenging. Covid19 really influenced this and companies had to find a way to deal with it. Experiments can benefit from extending test time, incorporating different production environments and getting contacts already in different markets. Awareness has grown that getting the expected data in practical situations is a tough job. A positive point was that the experiments put much more attention to remote support in applying their robots.

A second main challenge was the shortage of electronic components and materials for the production of the robots. Partners had to be creative in finding comparable components or develop other solutions.

- Finding their markets was challenging for many, and all experiments needed to find additional capital to finance further developments. Some of them have already been successful in attracting new capital. It was important for them to present/pitch their robotic solutions, show convincing test results and present a good team. Being selected as agROBOfood Innovation Experiment helped in finding additional capital. The international character of the agROBOfood network was also valued. It really broadened their international orientation.
- Of course, all experiments faced technical challenges when working on the AGV-platforms, the robot arms, the grippers, the AI-pipelines, the modelling, and the control. It was promising to see that some adopted the ROS2 environment and are now benefitting from it after a steep learning curve. Support from the agROBOfood specialist on this matter was appreciated. The same happened with the support in business modelling and market insights.
- AgROBOfood stimulated and provided opportunities for the experiments to present themselves at several events and on social media. This stimulated market awareness and helped partners to see where they could position themselves in the current robotic developments for the agri-food sector.

3 Main achievements of the agROBOfood project

The agROBOfood project (grant number 825395) developed a pan-European network of Digital Innovation Hubs (DIHs) and Competence Centers (CCs) to stimulate implementation of high tech robotic concepts for the agri-food sector. The project demonstrated the applicability of these robotic concepts under practical circumstances.

The current agROBOfood network consists of 105 DIH members and 79 business members. This network will be sustained after the agROBOfood project is completed. A prerequisite is that members of the network will be pro-active and are willing to learn from each other to professionalise the services for customers.

To demonstrate the value of the agROBOfood network and robotics in agri-food, the project worked with eleven Innovation Experiments (IE) and nine Industrial Challenges (IC). In an IE, a small group of SME's, start-ups and industrial partners work together cross-border. Based on relative mature technology these partners work on and demonstrate robotic solutions. They also experiment with agROBOfood services and end-users. Each experiment went through the stages of design, development and market orientation, and was supported by a mentor from an agROBOfood DIH. The experiments were selected in open calls, which attracted a lot of interest. This shows that there are a lot of companies working on the development of robotic solutions. Availability of funding for the selected experiments was a real driver. To stimulate connections between companies and funders we started the yearly Pitch your Robot events where companies can pitch their robotic solution for funders.

agROBOfood is a dedicated network where people interested in robotics in agri-food can find each other. The network also provides information. Visibility of the network is actively supported by a website and portal environment, an active presence on social media, a monthly newsletter and by organising different events. We organise these on a European level, but also promote visibility on a regional level. This 'local' approach is key for a successful uptake of robotics in agri-food. To provide information of the robotic market, a dedicated market research was performed in 2022. This study shows the complexity, diversity and professionality in the market and also takes stock of current developments.

The agROBOfood project worked with the following five major objectives

ONE-STOP SHOPS: *a network of DIHs which offers a complete service portfolio to companies at close geographical distance. A web portal is used as a location-independent doorway and gives each DIH access to both the local facility and the entire network of robotics agri-food hubs, covering all key European regions. The one-stop shop provides access to technological, business and brokerage (ecosystem) services.*
The network of DIHs has been build and is still growing.

The local presence of DIHs is a success. Although all key elements are in use, effectivity still depends on a limited number of active partners. We expect that the update of the website portal will enhance practical use in such a way that the members in the network become more active themselves. Of course not all contacts and results will be visible, but the network facilitates networking.

GROWTH of the ECOSYSTEM: *stimulate growth of the eco-system by attracting and fostering new DIHs/CCs in the network, collaborating within the broader ecosystem, engaging end-users across the value chain, and by stimulating business growth.*

Building and growth of the network is already reflected in the goal of the one-stop shops approach. agROBOfood is a network of experts working on robotics in agri-food. We experienced that agriculture and the food market need different approaches. Our current network in agriculture is much stronger than it is in the food market. It is still a good idea to address them both and be aware of both. agROBOfood has become visible to a variety of stakeholders and as a project it has been successful for instance in working together with EU-Robotics, CEMA, AEF, GOFAR and robotic innovation actions in other domains. To support the transition from the agROBOfood project to the agROBOfood network, a dedicated communication strategy based on customer journeys, and a list of organisations to be connected with have been developed. It will be exciting to see how this network will be sustained in the coming years.

SERVICES: *support industry's digitisation and robotisation through: 1. showing end-users how robots can help them and promoting their deployment and use, 2. supporting smaller organisations developing new robot products through technical, business and educational support and 3. contributing to common system platforms and industry-led standards.*

The agROBOfood project has been able to increase the transparency of the network of DIHs with their business, ecosystem and technical services. For this, the service catalogue and the role of service coordinators are key. The mentoring and supporting of companies who are designing and developing robotic solutions showed the capacity and the added value of the DIHs. The main focus was on companies who will sell or service robotic solutions to end-users. So, impact to end-users was indirect, but of value. End-users were involved in the innovation experiments. In the network there are dedicated DIHs who are engaged in standardisation and platform activities.

VALUE DEMONSTRATION: *demonstrate the value of agri-food robotics applications by 1. advertising how a system can be tailored to unique agri-food business needs, 2. letting end-users build hands-on experience by participating in highly-innovative cross-border experiments, 3. showing the added value of DIH services.*

We supported and worked on 27 different experiments to create robotic solutions for the agri-food sector. These experiments were working through the phases of design, development and market orientation. All experiments have been finalised. The added value of agROBOfood was really appreciated. Of course the funding was appreciated, but also the mentoring and the perspectives of international cooperation and market insight were valuable. It is encouraging to see that supporting their experiments supported the companies in a part of their journey. Their full trajectories will take much more time and involve many more aspects then could be addressed during the experiments. It is good to see how active and successful companies are in attracting additional funds for further development of the product and the company. The Pitch your Robot events also addressed this need for finding additional funding. It should be emphasized that, although the companies involved in the experiments are very active and eager, more attention might be needed to demonstrate and showcase the added value of the agROBOfood support. It is clear that there is a need for robotics and there are a lot of companies working on robotic solutions. The large interest for the open calls was an example of this.

SUSTAINABILITY of the NETWORK: *ensure the long-term sustainability of the agROBOfood network, through developing business models that generate sufficient income to safeguard the network's viability after project completion.*

Although we see a changing environment in the Digital Europe strategy with EDIHs, DTA and TEF and a further alignment between AI, Robotics and Data, we also aknowledge the need for a dedicated and specialised network of experts and expertise in robotics for the agri-food domain. We have analysed the context and the expectations and based on different scenarios we designed a proposal for the agROBOfood network. In this proposal we will work with DIH and Business members, will support the network with a website-portal-news environment, will organise events and will strengthen and expand connections with a variety of stakeholders and projects. In short the discussion on sustainability of the agROBOfood network has led to the creation of a partnership between founding partners. The partnership is not a new legal entity, but it is based on the D2.10 advice to create a small, centralised governance body with strong regional coordinators and connections in almost all EU-countries. The explicit wish is that the agROBOfood network will integrate or be closely connected to the existing euRobotics network that is already a legal entity. This integration needs time and proper discussion. A Memorandum of Understanding has been signed between agROBOfood and euRobotics.

Best practices:

Based on our work during the project we identified the following five main best practices.

1. The agROBOfood network

- regional approach with local DIH acting as one-stop shops provides a unique network for robotic experts in agri-food with a European coverage.
- Willingness to continue the network after the end of the project
- Capable of covering diversity in agri-food in Europe
- Capable of building bridges between small and large companies
- Created - together with EU-Robotics - a long term vision on robotics for agri-food production networks
- With good connections to (EU) policy makers.

2. Pitch your Robot event – find your investor

- New yearly event that brings together developers of robotic solutions and investors.

3. Visibility:

- Monthly newsletter with a variety of categories of information
- Social media (Twitter, LinkedIn) shows much information traffic
- In COVID situation we were able to organise a variety of online events
- Variety of events organised, both for whole community and also dedicated regional and national events
- Strength of video is coming back in products of experiments and communication through agROBOfood YouTube channel.
- Developed brand of agROBOfood as a part of the Robotic Initiatives in the EU and based on customer journeys

4. Wide range of services and robot technologies (in the catalogue)

- Catalogue with 113 DIHs with their services (technical, ecosystem, business)
- Working with service coordinators and mentors for experiments
- Insight in market developments
- Broad scope of technical services and good examples in experiments

5. Impact on the sector through open call project outcomes

- Huge interest in open calls
- Grant (access to funding) and guidance trough design, development and market phase was of real added value
- Cross-border cooperation and insight in bigger EU market
- Experiments organised and partnering in demonstration activities

Working in a project environment with a variety of partners, involvement of a lot of new members and a rapidly changing environment caused by COVID and migration challenged the network and the consortium. There were consequences in terms of the availability of labour and components. Inevitably, introducing the concept of DIHs and building this network also resulted in some disappointments.

1. Network learning from experiments

- half of the budget available was for the network and half for the experiments, but what we can put forward and showcase is much less about the experiments than about the network
- there should be active showcasing of agricultural robotics by network members (so far, this has been limited to the open call experiments, and the robotics catalogue that was made in the project, but individual DIHs did not showcased their activities in the agROBOfood network)
- experiments are part of a long term development of companies and this is not the same time line that the agROBOfood network has, so they are aligned for a while after which eachs follows its own path.

2. Process of service delivery

- The service catalogue is large, but it has proven difficult for a lot of stakeholders to find specific services
- Service providers have been idle or unresponsive during the course of the project, making the service

provision efforts quite difficult. It might have been a mistake to allocate budget to DIH partners in advance, without knowing which experiments and service needs would pop up during the execution of the experiments.
- DIH-DIH services developed quite late in the project, whereas the primary customers of the network are the DIHs

3. Commitment
- Network engagement after the final open call has dropped
- Motivation for external parties is becoming more and more challenging without financial promises
- Partnership for the agROBOfood network is based on the organisations who are regional cluster coordinators and INESC Tec. Other agROBOfood partners will join as members.
- Some lack of communication between members and partners
- Disparity between the commitment and engagement of various DIHs and organisations in the network resulted in a great variety in the quality of mentoring and service provision to the experiments.

Obviously, learning from these disappointments is also important. These lessons will be taken up by the sustained agROBOfood network over the coming years.

To conclude:

agROBOfood is aimed at stimulating the **development** and uptake of robotic applications, visibility of robotics and **investment in robotics agri-food technologies** to advance Europe to be the vanguard in providing safe and adequate food for the generations to come, in a sustainable manner. To do so, agROBOfood created a pan-European network of DIHs in **the world of Robotics and Agriculture, involving the multiple dimensions** (technical, human, financial) **actors and stakeholders** (DIHs and CCs, SMEs, farmers and agribusiness suppliers, traders and technology providers, research, government, investors, the public).

The **agROBOfood network** plays the role of catalyst and binding actor in this ecosystem (both with public and private actors), spurs the launch of different initiatives in European regions, while at the same **time allowing smaller and newer players to also capture value.** By **being inclusive to all** network members **agROBOfood** brings forth **a shift towards diversified and decentralised innovation,** locally-applicable knowledge and **open-access robotics technologies, evoking a new 'wide tech paradigm'**, addressing the root causes of consolidation. With this in mind, we aim **at turning the diversity of the agri-food sector and robotic technologies into a strength** through collaboration and cooperation, and drive transformation by focusing on stimulating knowledge, data and innovation sharing in the domain of robotics in the agrifood sector. The experiments in the agROBOfood projects demonstrated the benefits of cooperation and support and showed the variety of robotic applications, which was really stimulating.

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