D5.2 – Design report on robotic module

Version 1.1

DLO, Fraunhofer, Lacquey, MAREL, Tecnalia

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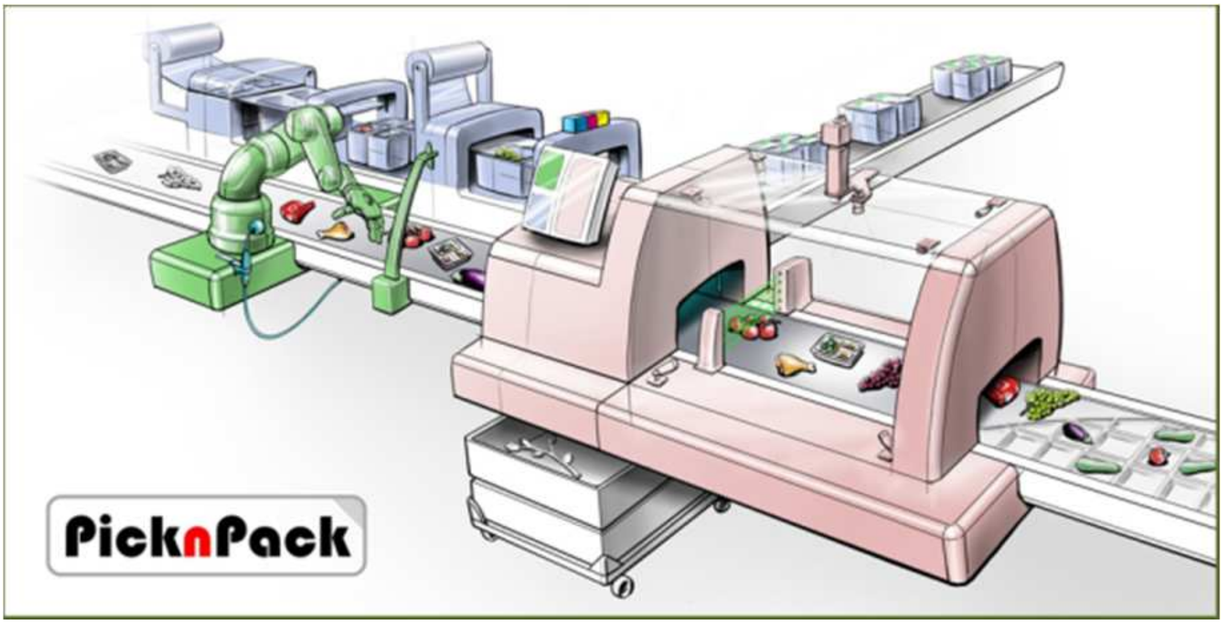

Flexible robotic systems for automated adaptive packaging of fresh and processed food products

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Dissemination level		
PU	Public	X
PR	Restricted to other programme participants (including the EC Services)	
RE	Restricted to a group specified by the consortium (including the EC Services)	
CO	Confidential, only for members of the consortium (including the EC Services)	

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1 Introduction

This document is a deliverable for the Pick and Pack project, in addition is the second one for the workpackage 5. As it includes design on novel developments, it is considered to be confidential and only members of the Pick and Pack consortium are allowed for its distribution.

The first chapter is an introduction for a better understanding of the rest of the document and second chapter present a general scenario considered on food industry applications.

Chapter number 3 is divided into the main submodules that integrate the robotic module. In section 3.1 the design of both robotic arms, Delta robot and cable robot, is described. For fresh foodstuff application, the former picks the samples from a bin to the conveyor, the latter put samples in the packaging point after the quality check. For ready to eat meals, both robots must do pick and place operations. The section 3.2 includes a selection of different gripper changes, for automatic and fast changes of the grippers in the application. In section 3.3 designs on Machine Vision are included. Two Machine vision systems will be implemented, one to pick products from a crate and other used in the quality assessment module whose information will be used for the guidance of the robot too. Moreover section 3.4 will show the definition of the typical conveyor systems used in food industry. In addition section 3.5 includes the design of the grippers. Four grippers are considered, one for each robot and for each kind of food (fresh and ready to eat). Section 3.6 covers hygienic requirements which must be taken into account for robotic module, for example in the development of the cleaning system, robotic covers or pneumatic supply. Furthermore, this section also includes design aspects for the internal communications of the robotic arm with all the components of the robotic system.

Chapter number 5 provides a list of directives and regulations that have been considered for the design of the submodules.

A summary of the achieved work and some conclusions area added in the last chapter of this document.

2 Scenario for robotic module

2.1.1 General scenario

The following general scenario should apply for a robot in the food industry:

- The food products will be fed into a conveyor belt.
- The operation to be carried out will target the placing of the food products in boxes, trays or aligning them in a given pattern.
- The food products might have different size and shapes so that the robotic cell will need to differentiate them and perform a different action for each one.
- The food product can be considered planar so that the gripper device can pick them without requiring a 5th degree of freedom.
- The robotic cell will thus require:
    - A vision system to detect the food products and determine their position and orientation (with respect to the normal of the conveyor belt)
    - A correct calibration of the vision system and the robot-conveyor calibration and synchronization.
    - A tracking-enabled path planning for the robot.
    - A specific gripper for each food product or group of products to be handled.
    - A 4 DOF robot.
    - The positioning accuracy required to pick and place the food element is considered to be low.
    - However food products are highly variable and not repeatable, so the capability of the vision system and gripper to adapt to such variability is key for the success of the application. This will also require a flexible concept of variable feeding of the line with food components.

2.1.2 PicknPack processing lines

Two different processing lines will be implemented in PicknPack project. Figure 1 and Figure 2 illustrate the probably layouts for the robotic modules.

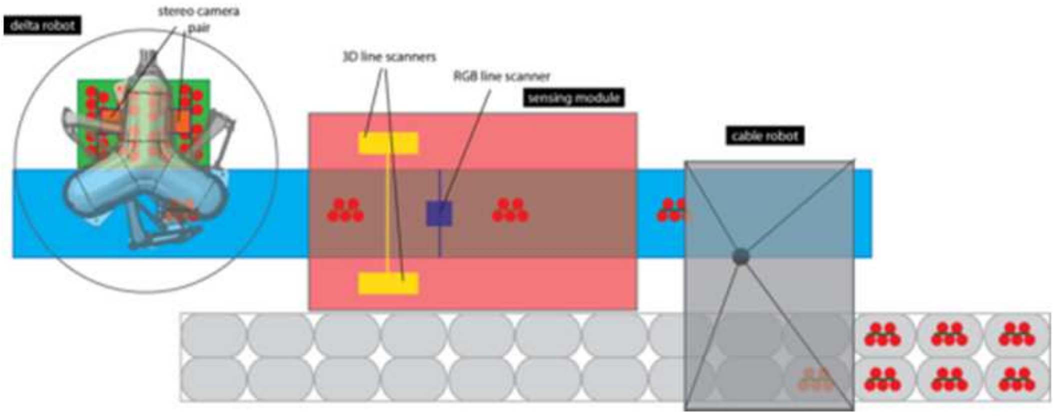


Figure 1: Layout of the vine-fruit line. A stereo-camera pair will be used to enable the delta robot to pick from the harvest crate. The cable robot will be controlled based on the 3D and colour information from the sensing module. Note that the details on the packaging line are not in this figure.

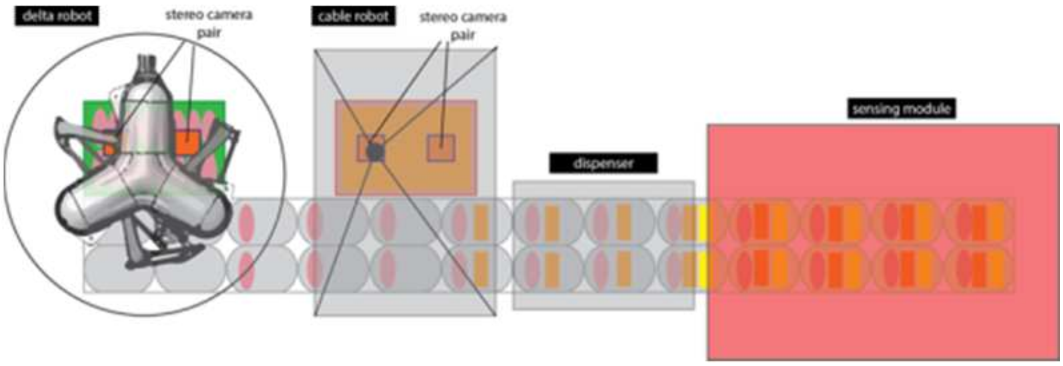


Figure 2: The layout of the ready-meal line. Both the delta robot and the cable robot will use stereo cameras to perceive the products. Note that the details on the packaging line are not in this figure.

In these layouts we can distinguish three different tasks:

1. Picking a product from a crate and placing it on the conveyor belt or in a package. Three versions of this task have been considered (and are already open): picking vine tomatoes from a harvest bin, picking chicken breast from a large container, and spooning carrots/pies from a large container.
2. Picking a product from the conveyor belt and placing it in a package or a bin depending on the quality of the product. This task will be demonstrated in the vine-fruit line on vine tomatoes and grapes.
3. Dispensing liquid product in the package. For this task, it is probably to use a commercial automatic dispenser. No visual control or robot is needed.

For more information, please read the deliverable 7.2"Report with required modules, integration functions, user interfaces and conceptual design".

3 Design of robotic module

3.1 Manipulators

3.1.1 Delta robot

Main advantages of Delta robot developed by Marel compared to commercial robots remarkable for PicknPack project are better performance for pay loads of around the 1 to 2Kg area, particularly in the rotary 4th axis capability, easier to service and support the Industry standard IEC 61131 control system, improved hygienic design without the use of Carbon fiber or exposed painted surfaces and lower production and market prices.

Below is the detailed technical Information of this robot:

- Speed: Product dependent. Picks and places up to 80 units/min./head
- Conveyor speed: 36m/min. maximum
- Product Programs: 400
- Electrical Supply: 380–460V ± 10% 3 phase + earth 12 kVA (single head)
- Air Supply: 20 l/min. Free Air/head
- Net Weight: 1300kg/head
- Hygienic design for washdown applications (IP69)
- Substantial reduction in manual handling gives longer shelf life
- Wide range of patented quick-change product grippers
- Reduced production costs
- Reliable, consistent production with high throughput

Dimensions

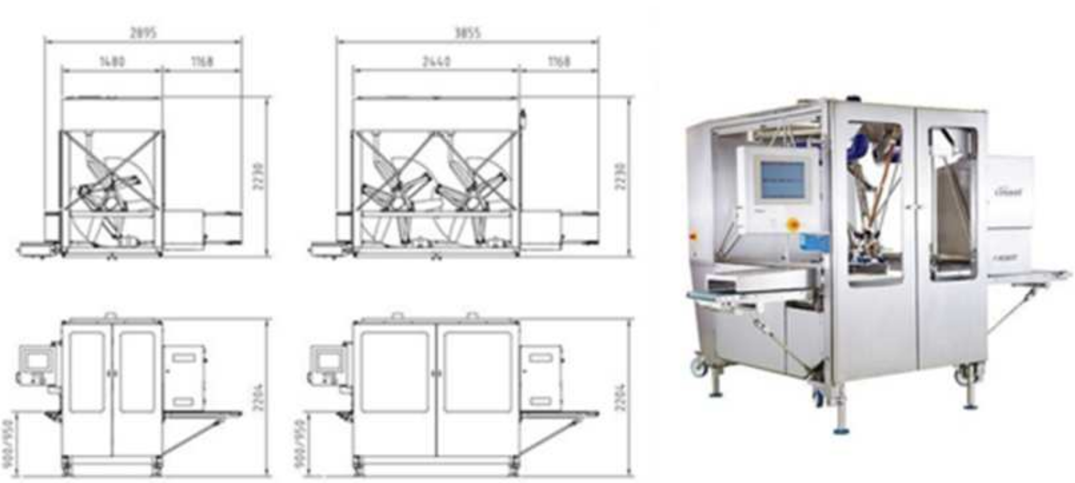


Figure 3: IPL robot plane

Vision

A vision system or photocell determines the size, position and orientation of the incoming product, then, at the appropriate point, the portion is transferred to the final pack to give the required pack style or presentation. Any out of specification portions pass to a makeweight operator or are diverted to a dedicated bulk or food service pack. The IPL Robot vision system is able to recognize a variety of product characteristics such as size or shape and can be programmed to place or divert products according to the requirements of the user. For high volume applications, IPL Robot's vision control system can operate up to 6 loading heads. In multiple head applications each head can be programmed to produce a different pack format.

User frindlyness

IPL Robot has been ergonomically designed for efficiency and ease of operation. The system has straightforward, easy to use controls, thanks to a universal graphical user interface developed by Marel. This enables operators to switch between products with a minimum of disruption – so essential in today's 'fast response to order' environment. Remote access to customer's installations is possible, enabling rapid fault diagnosis and performance monitoring. Service intervals can be set at supervisor level, so that the machine always operates at its optimal.

Grippers

Effective grippers are vital to the efficient performance of a robot and Marel has made huge advances in vital gripper technology. Virtually any product – however delicate – can be lifted and placed, at speed into a tray or thermoformer in a wide variety of configurations. All Marel grippers are manufactured to the very highest standards and when serviced regularly deliver a long operating life.

Hygiene

IPL Robot, including the head and control panel, is 100% washdown to IP69, thanks to a stainless steel and titanium construction. The head pairs lightness with strength in a hygienic design for high product safety. All product contact parts are manufactured from stainless steel and food grade materials and can be quickly and easily removed for cleaning.

More information regarding Hygienic requirements on chapter "3.6.1. Cleaning Systems".

3.1.2 Cable robot

3.1.2.1 Motivation

After the requirements stage, and due to the conclusions of this task, Tecnalia tackles the design of the cable robot which was introduced in the deliverable 5.1. As this robot concept is a novel one, this motivation chapter is necessary to analyse the previous decisions which aim this development.

In the last years, a novel concept of robot has become a main actor for the food industry. These robots are called PKM (parallel kinematics manipulators), Spider robots, open chain kinematics manipulators or just parallel robots. The figure below shows some of these robots:

Figure 4: FANUC M3iA, ABB IRB 360 and ADEPT QUATTRO commercial robots

Although those are not the only robots for food industry, their growth in the last years has been very important. The success of this manipulator for the food industry is mainly due to:

- Very high speed robot (Food industry requires large volumes).
- Inverted mounting (Foodstuff are mainly transported on conveyor or belt systems).
- Low handling capacity (Individual foodstuffs are low weight parts).

In order to develop a real alternative to them, a novel cable robot is proposed to design, keeping the same dynamics, reducing costs, gaining flexibility, making work volume more efficient and improving required footprint. This is why Tecnalia considers this solution will answer the existing demand on market for many low accuracy applications, big volumes and low handling needs like food industry.

Previous experience

Tecnalia has already developed a prototype of cable robot which is patented. This has been used for handling heavy payloads in large workspaces and not for fast pick and place applications but the knowledge that Tecnalia´s team has achieved can be very useful for Pick and Pack.

Figure 5: Tecnalia's cable-robot existing prototype.

3.1.2.2 Design

Conceptual design

Cable robot is based in the same principles as parallel robots, but in order to increase the size of the workspace, the rigid bars are replaced by metallic cables. The cables are connected to a mobile platform at one end, and enrolled on winches that control the length and tension of the cables for the controlled movement of the platform.

The kinematic configuration for this robot is shown in the image below:

- Planar guidance on the top for X-Y axis and gravity support.
- 4 cables for planar control of X-Y movement.
- Z and θ embebbed in the platform.

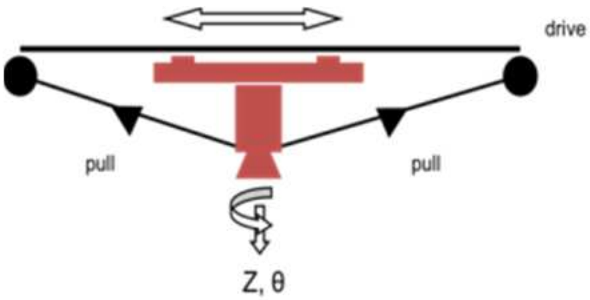


Figure 6: Basic concept for cable robot

Based in these concepts, a preliminary design for a fast 4 degrees of freedom cable robot has already been performed, as illustrated in image bellow. In this case, the cables driven mechanism is situated above the conveyor belt in order to avoid ventilation pointing to the food. It is probably to use an open frame guidance for the cables in the improved design of the robot (after the results of the feasibility trials) to fulfill hygienic requirements.

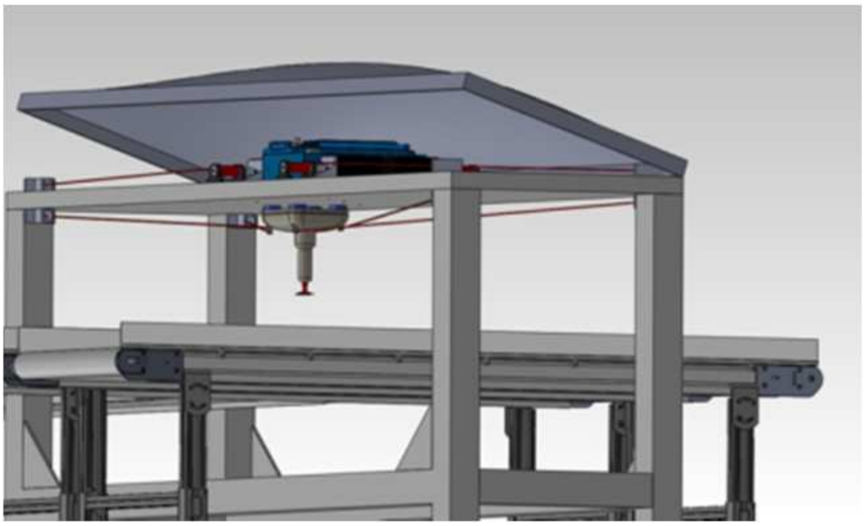


Figure 7: Preliminary design for cable robot

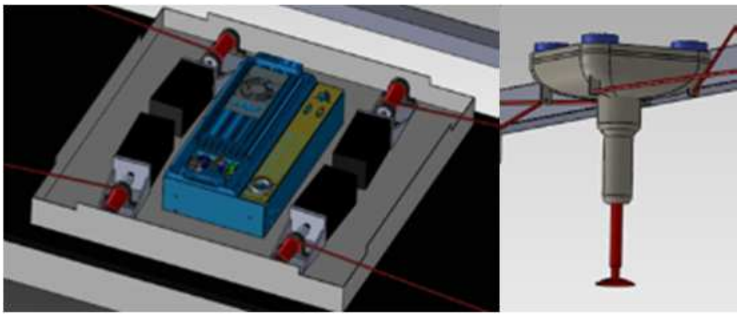


Figure 8: Detailed of preliminary design for cables driven and mobile platform

Dimensions

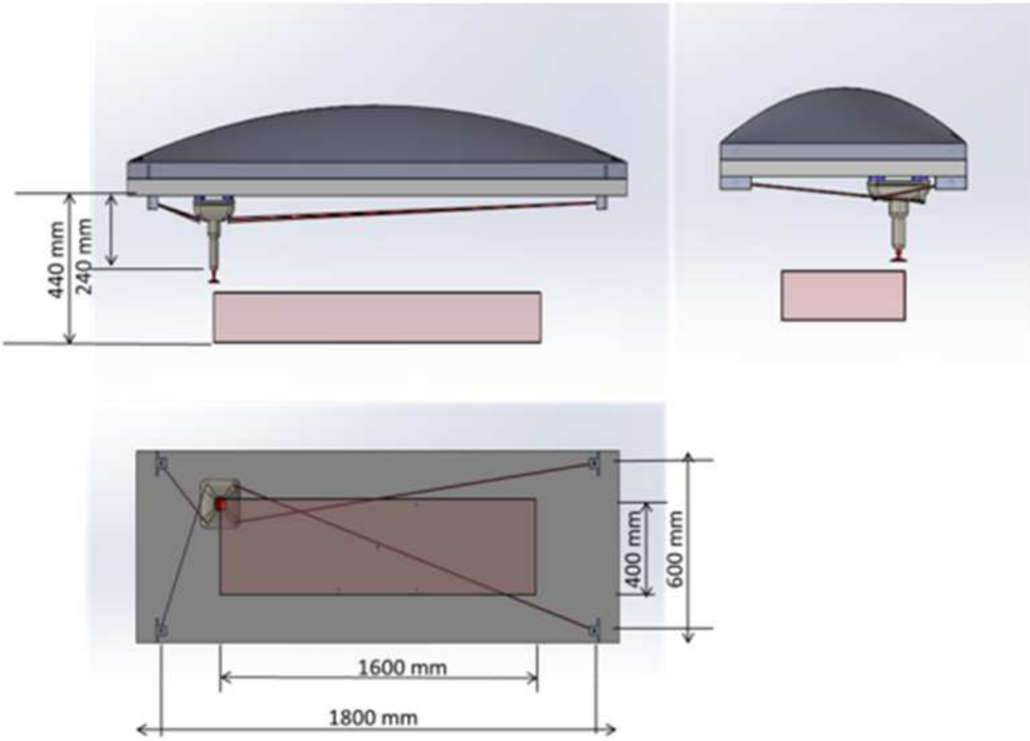


Figure 9: Dimensions of the cable robot

Detailed design

- **Mechatronics architecture study**

One the main technological issue of cable robot is how to generate planar constraints to keep the payload platform staying in a plane (X-Y) during the movement. Different alternatives have been deeply studied (for example the use of a passive articulated arm, the use of spherical joints, air bearings, electromagnetic elevation systems, etc) and their main advantages and drawbacks have been disaggregated.

The same procedure has been followed for the generation of z-axis rotation and z-axis translation (embedded in the platform, with cable rolling, with a directional handle plus an angle amplification mechanism, with a cable tension plus a spring, etc)

After the detailed study of the different alternatives set out above, it has been decided to develop a detailed design based on the ideas of a supporting plane plus an air bearing system to guarantee planar constraints, and the use of two additional motors embedded in the platform for Z and θ axis movement.

- **Motor and cable requirements estimation**

The starting point of the design is the load and movement requirements of the cables calculated form typical trajectory of the robot module and the basic drum design guidance. These include force, power, linear acceleration and linear velocity, cable diameter, drum diameter, etc.

The kinematic configuration, mechanical properties described below and some limitations in torque and tension have been introduced in a matlab program for the simulation and estimation of the motors and cables requirements:

- The mass of the travel plate is set as 6 kg (include load of 1 kg).
- Inertia of Motor Etel RTMB 0140-070: 3.13*10^-3 (kgm^2)
- Diameter of Drum: 0.08 (m)
- Inertia of Drum: 1.28*10^-2 (kgm^2)

Following figures show the results obtained along Y-axis and X-axis respectively:

In the next figure, blue curves represent the minimum solution of the cable force. The red curves represent the non-negative solution of the cable force. As the cables cannot push the payload platform, the red curves is more representative to the real situation.

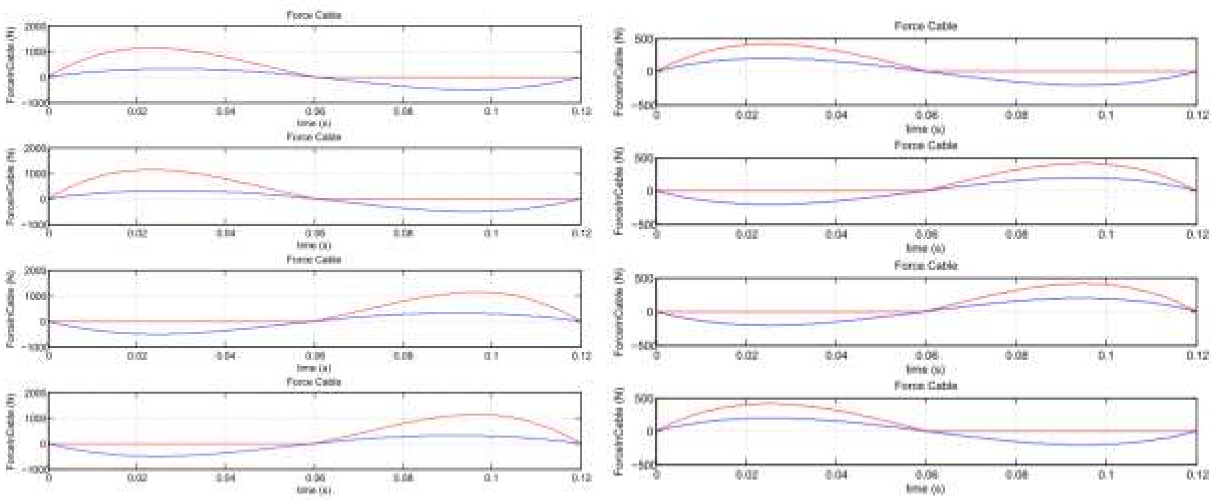


Figure 10*: Cables estimation (Force / time)*

The curves are only for first estimation of the forces that are needed in the cables, because in the real situation, it will need some minimum tension in the cables to avoid cable slacking and to ensure good winding of cables.

In the next figure, **PowerCableNeed** represents the power that the cables and the load needed for achieving required dynamics; **PowerMotorOutput** represents the PowerCableNeed plus the power that is needed to accelerating the drum; **PowerMotorTotol** represents the total mechanical power that is generated by motors (It includes the PowerMotorOutput and the power that is needed to accelerate the rotor of the motors).

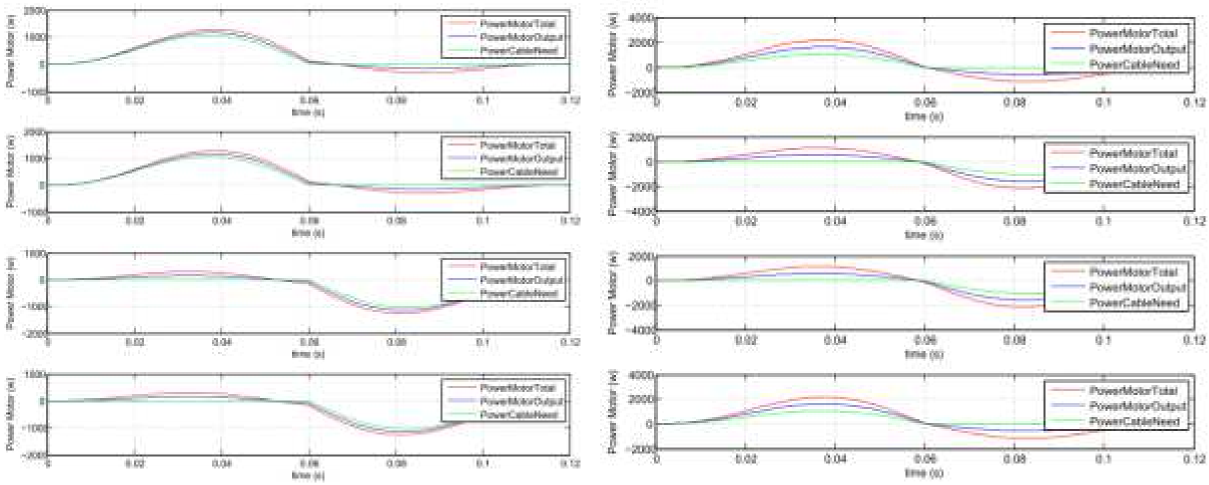


Figure 11*: Motor estimation (power/ time)*

The table below summarized the obtained results:

	Trajectory along y-axis	Trajectory along x-axis
Cable force max(N)	1137	411
Cable velocity max(m/s)	2.06	4.24
Cable acceleration max(m/s^2)	60	110
Cable power max(w)	1055	1055
Cable power average(w)	277	277

Table 1: Cable parameters estimation

	Trajectory along y-axis	Trajectory along x-axis
Motor power max (w)	1278	2159
Motor power average (w)	417	866
Motor torque max (N.m)	52	33
Motor torque average (N.m)	20	16
Motor velocity max (RPM)	493	1012
Motor acceleration max (rad/s^2)	1511	2762
Motor acceleration average (rad/s^2)	867	1758

Table 2: Motor parameters estimation

- **Parts design**

Based on the obtained results, most of the parts that compound the robot have been 3D modeled in detail. The robot design presented in this deliverable is a first design to validate mechanical operation of the robot. All hygienic requirements will be taken into account after the results of the feasibility trials and the required changes on the existing design will be done to fulfill the hygienic criteria.

In the figures below it is shown the entire assembly of the mobile platform as well as the cables driven mechanism.

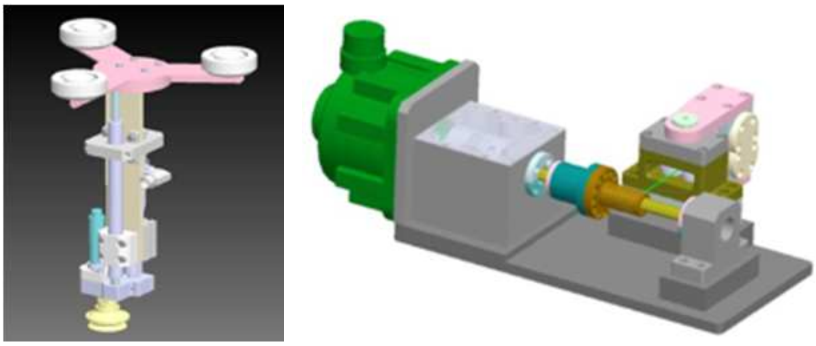


Figure 12*: Detailed design of the mobile platform and cables driven*

The next figures show different necessary components for the robot operation, for example the winch for the rolling of the cables and the caster pulley for the guiding of the cables.

Figure 13*: Winch and caster pulley*

Last figure shows the design of the test bench for the testing of air bearings behavior.

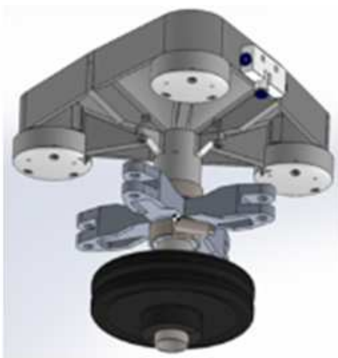


Figure 14*: Platform drum bench*

- **Air bearing selection**

The selected product to guarantee planar constraints of cable robot is the VPL Air Bearings from NewWay Air Bearings. These bearings are perfect for high-precision applications because of their adjustable fly heights, fast settling time and naturally stable design. NewWay has engineered a flexure mount to provide equal stiffness in both directions, while providing a low pivot point.

The main characteristics of these air bearings are shown in the image below:

SPECIFICATIONS: 90mm VPL Air Bearing #S209001	
Input Pressure MPa (psi)	0.41 (60)
Input Vacuum in Hg	15
Ideal Load N (lbs)	150 (34)
Stiffness N/micron (lbs/u in)	43 (0.25)
Maximum Hold-Down Force @ 68kPa N (lb)	260 (58.5)
Flow NLPM (SCFH)	1.48 (3.15)
Fly Height	5 microns
Bearing Size	90mm
Bearing Height mm (in)	22 (0.866)
Bearing Weight grams (oz.)	306 (0.69)
Housing Material/Finish	Aluminum/Anodized
Porous Media Material	Carbon
Bearing Face Surface Size - Carbon mm (in)	62.4mm ID x 88.2mm OD
Flatness mm (in)	0.001 (0.00004)
Mounting	Flexure
Pressure Port	M5
Vacuum Port	M5
Viable Pressure Range	0.414 - 0.552MPa (60 - 80psi)
Maximum Allowable Pressure Supply	.689 MPa (100psi)
Resolution	Infinite
Maximum Speed	50m/sec
Common Guide Surfaces	Granite, hard-coated aluminum, ceramics, glass, stainless steel, plated steel
Suggested Guide Surface Finish	16 RMS

Figure 15: Air bearing features

These bearings will be tested in next stage of the project to check detaching forces of them with different air-pressures and to prove the suitable dynamic operation of the entire robot.

There is a risk regarding hygienic issues because air bearings are made of a porous material which could provide both accumulation of microorganisms and their growth. These parts should pass a further proof of concept.

- **Plate selection**

The first option is to use a synthesis glass of polycristal or plexiglass for the top plate due to the good finishing of the surface for the glide of the air bearings and the stiffness of this material.

In the other hand, the air bearing system is often used for very high precision applications. In the case of PicknPack project, the required precision may considerably lower than the one of the standard setup so it is possible to use a more degraded supporting pane.

For this reason it is foresee to do feasibility trials also with Aluminium, Stainless Steel and Marble plates of different thickness and surface finishes (it is probable to include an additional rigid body in order to avoid plate deformation).

- **Cable selection**

The cables used in the robot must fulfill the following mechanical requirements:

- o The payload in the cable is 400N for a trajectory in the center of workspace, and 1500N for the trajectory in a very bad configuration in Workspace. All trajectories are tested within the required cycle time.
- o Diameter of cable can be between 2.5-4mm (without coating) 3.5-5mm (with coating). According to the payload in the cable, we will take the cable with 1/5 of the breaking force greater than the payload.
- o Diameter of the winches will be 55-80mm. In fact, it should be 16-20 times of the diameter of the cable.

Due to hygienic requirements, the entire cable should be cleanable, so it is nessecary to put the cables outside the frame. It is also not recommended to use braid cables because of the crevices on its surfaces. They also find very difficult to cover the cables because these covers could modify the rigidity of the cable. However, Tecni-Cable and CarlStahl commercializes stainless steel cables with different types of coats are probably suitable for food industry.

PVC-Coated 7x19 Galvanised Steel Cable is extra flexible cable with high breaking strength specially recommended for applications such as security cables and control cables. PVC is commonly used in food packaging; however, PVC coating is not suitable for prolonged operation over sheaves.

Clear Nylon Coated 7x19 Stainless Steel is an extra flexible cable specially recommended for the use around sheaves and pulleys, for example on drive cables or pull type control cables so it fulfill high mechanical requirements for cable robot. Nylon is approved for contact with food, it has a barrier effect to prevent degradation of the food and guarantees no migration of particles or additives of the polymer. Nylon has also a high wear and bending resistance; it protects the rope from dirt and keeps the manufacturing lubricant within the rope. The lubrication reduces the wear between the strands and wires and increases the working life by up to 50%. The coating life is very dependent upon the material, diameter & profile of the sheaves over which it runs.

Figure 16: Nylon coated Stainless steel cable

For the selection of the suitable cable, both types of cables will be tested under realistic conditions in the next stage of the project. The cables will be enrolled at different speeds and with different tensions on a drum, to check if wind up is always all right.

Regarding the design of the cable robot, probably there must be several cleaning positions for each cable, where every part of the cable can be cleaned and an open frame guidance because the guidance of the cables through a hollow structure interferes with basic hygienic requirements.

Control system

The model design of the cable robot requires a real time controller. In order to develop a system closer to the industrial final users in food industry, the PLC's seems to be the best option. The main advantages to utilize an industrial PLC are the robustness in the execution of the controller and the ensuring in the implementation of the industrial communication protocols like Modbus or Ethercat. Different control strategies will also be tested in order to fulfill the objectives of speed-acceleration while guarantying robustness of the controller.

In order to improve the precision is mandatory to develop a close loop control and measure the position of the platform, either directly or indirectly. For example it is possible to use Metris or LaserTracker. Some force feedback control will also be used to guarantee force balance.

The natural frequency of the platform will limit the maximum acceleration of the system in order to avoid excited vibrations

Preliminary cost analysis

In parallel robots all arms support platform movement in all direction, either PUSHING or PULLING, whereas, in cable robotics, platform is JUST PULLED by cables. This means that PULLING power required by each CABLE is GREATER that THE POWER required by each ARM for same trajectories. This is transformed in greater torque and power for the same performance.

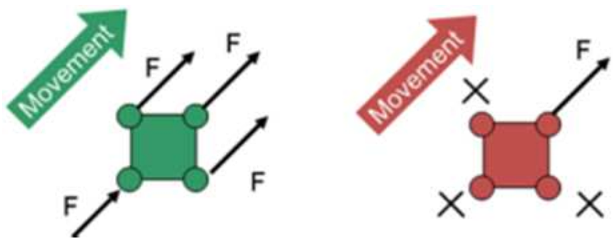


Figure 17: Parallel (green) and cable (red) technologies comparison

Due to this high power demanding, the cable robot increases the cost of its electrical motors. However, the required investment in linear guides, transmissions and frames are drastically reduced:

PRICE				
↓	• Reduced frame • Gearbox removed • Cables vs Fiber arms • Joints are avoided	↑	• 6 motors vs 4 motors • Drum and additional parts to guide cable are required • Air-Bearings and guiding platform	TOTAL ↓

Table 3: Positive/Negative aspects for cost estimation

At this level of development is not possible to make a reliable cost analysis, but taking into consideration positive and negatives parameters we should consider that the cable robot will have a lower price than parallel ones.

Main technical risks

The following technical risks have been identified. These risks will be checked in the next stage during the tests for the validation of the entire design of the robot. All necessary modifications will be made to avoid these risks and meet with the requirements of the application.

- Structural response (stiffness, nat. frequencies) → It is critically influenced by weight of the platform, cable positioning and motor selection. If necessary, the present design will be improved.
- Air-bearings response in high dynamics→ Use of mechanical bearings as alternative
- Z and Theta axis embodiment in platform→ Use of cables for Z-axis rotation and translation as alternative.
- Actuation (winch) design → Changes in the final design will directly impact in the total cost of cable robot.
- Calibration and influence of calibration errors→ It reduces the effective torque and generate vibrations.
- Hygienic requirements→ Additionally changes are required to fulfill hygienic criteria which may difficult to fulfill mechanical requirements.

Conclusions

List bellow summarizes some issues regarding the current state of Pick and Pack project:

- The requirements document has been accepted by the consortium
- European projects must go beyond the state of the art
- Four foodstuffs have been selected for the demonstrator: tomatoes, grapes, pizza and pie
- Foodstuffs are light (less than 1,5 kg.) and highly variable and not repeatable
- Grasping tomatoes and grapes is not considered a high accurate application
- Foodstuff sector requires fast enough robots due to its high production volume
- The process for pizza and pie is still undefined and the line layout is still undefined
- The products will be fed into a rectangular conveyor belt.
- Four degrees of freedom are required

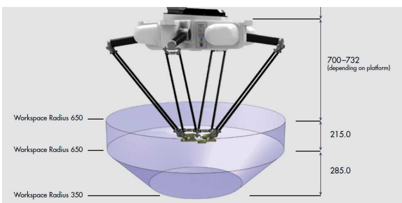
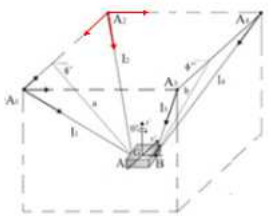
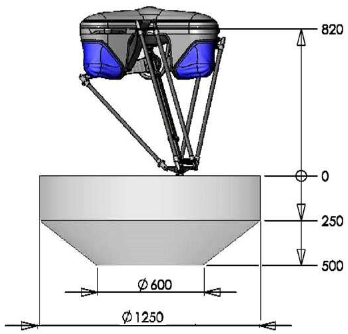
Cable robot would be an advantageous robot for this scenario, but its level of maturity is lower than commercial solutions, and would thus require a longer development and testing phase, associated with a higher technological risk. The foreseen performance would place cable robot solution as:

- A less repeatable robot (so only for food or not demanding applications)
- As fast as Parallel robots.
- Wider and rectangular workspace that can be easily customized
- Reduced frame and better integration on the production line.

- Better workspace-footprint ratio.
- Lower cost, mainly due to a much lighter infrastructure frame.

3.1.3 Comparison table

The following synthesis table aims at differentiating the specificities of three solutions (commercial pick and pack robot: Adept QUATTRO, Delta robot from Marel and Cable Robot from Tecnalia) and allows for easier decision making.

	Adept QUATTRO S650HS (parallel robot)	Cable Robot	Delta Robot	Comments
Repeatability	± 0.1 mm (Uni-directional)	It is expected +/-1mm over the full speed range	+/-1mm over the full speed range. Not still checked	High accuracy not required for food product handling
Accuracy (Absolute accuracy at picking and placing points)	< 0.5mm	It is expected +/-1mm over the full speed range	+/-1mm over the full speed range. Not still checked	High accuracy not required for food product handling
Cycle time	0.41seg (146 picks/min)	It is expected 0.4seg (150 picks/min)	0.75 seg (80 picks/min)	25/305/25mm, 90º rotation of total load 1 Kg
Payload	1 kg rated 3 Kg maximum	It is expected up to 3 Kg	Up to 3.5 Kg	
Work range shape	 Disk shape: 1300/700mm Z:285/500mm Rot Z:185º	 Rectangular shape: 1600x400mm* Z:150mm Rot Z:+/-180º	 Disk shape: 1250/500mm Z:250/500mm Rot Z:360º	*Easily configurable

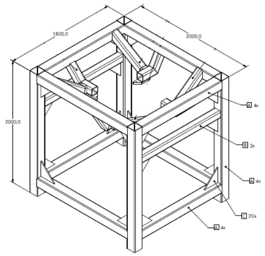
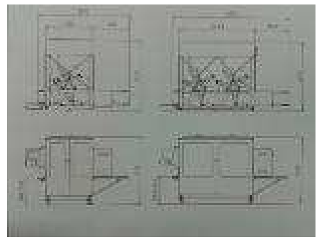
Flexible workspace/Re-configurability	No workspace adaptation. Only one commercial model (with different rotation Z)	Only modifying the cable length and the upper plate, the cable robot can adapt its shape (x-y). This can provide to robot manufacturers a wide range of robots regarding to standard dimensions of conveyors and so on.	No workspace adaptation. Only one commercial model	
Inverted mounting	☑	☑	☑	
Degrees of freedom	Four	Four	Four	
Flexibility (programming and communications)	☑	☑	☑	
workspace-footprint ratio	Workspace: 1300 mm Frame: 1800x2000mm 	Workspace: 1600x400mm Frame: 1800x600 mm* (200mm more than the workspace)	Workspace: 1250 mm Frame: 1480x2440 mm Total dimensions of the cabinet: 2895x3855mm 	*Less mechanical structure needed because linear guides, mechanical transmissions and rigid arms are not necessary.
Cost	31.000€(robot)+8.000€ (cabinet)=39.000€ aprox	Total price Is expected to be lower for the cable robot	24.000€ (robot) + 11.900€(cabinet) =35.900€	
Hygienic issues	☑ Manually Washable	Its detailed design (next stage) must fulfill hygienic requirements	☑ Manually Washable	*A huge analysis about hygienic requirements will be done after the feasibility trials and final design.
Applications - Food process production line	Well-suited	Further analysis after detailed design stage	Well-suited	

Table 4: Robots comparison table

3.2 Automatic gripper changer

One of the goals of PicknPack project is to develop a flexible robotic module with fast-changeover systems that complies with the regulations of the food sector regarding hygienic requirements. For this reason, some alternatives for gripper changers have been analysed.

Applied robotics

The model MXC5 is a light weight part and its payload is enough to fulfil the requirements. Following table shows some views of the product. Additional modules for electrical (see example at the table) or connections are also required.

Figure 18: Master-Tool adaptor and Electric module MXC5

Following table shows technical specifications for the main and electric connection modules:

Specifications	Master Adaptor	Tool Adaptor
Payload	5 kg	
Moment - Mx, My, Mz	17 N-m (Mx-My) , 20 N-m (Mz)	
Height x Width x Length	15mm x 35 mm x 35 mm	12mm x 35 mm x 35 mm
Weight	0.059 kg	0.032 kg
Repeatability - X,Y,Z	0.012 mm (X-Y), 0.005 mm (Z)	
Operating Temp.	5 - 60 Deg C	
Operating Pressure	6 bar ± 1 (87 ± 15 psi)	
Electrical module	**Master Adaptor**	**Tool Adaptor**
Weight	0.03 kg	0.03 kg
Size LxWxH	34.5 x 8 x 14.75mm	34.5 x 8 x 11.75mm
Pass-through Utilities	16 contacts @ 2 Amp, 0-24 VAC/DC	
Material	Delrin w/Silver plated contacts	

Table 5: Technical specifications MXC5

Sommer

The model WWR40 of automatic changer has been analysed, but the manufacturer considers that its products are not food grade, so detailed information is not included.

Figure 19: Master-Tool adaptor WWR40

IPR

The model TK40 has two material manufactured options depending of customer demands: Aluminium and Stainless Steel. Both options are also food grade if the cleaning detergent does not modify the coat of the aluminium changer (some applications with high hygienic requirements with the aluminium option are Wahrsteiner (Brewery), Chess packaging, and Harite Clinic (Berlin) Maxillofacial Surgery) and both fulfil IP 65 sealed electrical signal transmission.

The prize for Aluminium option is:

- Robot Side TK-40-R: 590,00€
- Tool Side TK-40-T: 185,00€

The prize for Stainless Steel option is:

- Robot Side TK-40-R-ST: 1.180,00€
- Tool Side TK-40-T-ST: 370,00€

Figure 20: Master-Tool adaptor TK40

Following table shows technical specifications for this product:

Technical data	
Recommended max. Payload	3 kg
Weight (without options)	0,17 kg + 0,1 kg
Air Consumption each cycle close/open	0.03l
Max. Tensile FZ (static load) at 6 bar	900N
Max. Compressive FD (static load)	2200 N
Max. Moment Mx-My, Mz (static load) at 6 bar	14 N , 29NM
Repeatability x, y, z-Axis	0.025 mm
Join Force (against spring loaded Ball Cover) in join direction	15 N
Max. permissible Axis Deviation x/y	+/- 1 mm
Max. distance between R and T side when locking	0,6 mm
Locking stroke	15,5 mm

Table 6: Technical specifications TK40

Staübli

The model MPS32 of automatic changer has been analysed.

Figure 21: Master-Tool adaptor MPS32

Following table shows technical specifications for this product:

Specifications	
Payload (kg)	32
Max. bending moment (Nm) / Torsion moment (Nm)	75/75
Max. tractive force (KN) /Compressive force (KN)	5/10
Max acceleration (m/s2)	50
Connection stroke (mm)	<0.5
Connection force (KN) at 6 bar	0.4
Weight robot side (Kg.)/ Weight tool side (Kg.)	0.4/0.3

Table 7: Technical specifications SWS

Schunk

The models SWS 005 and SWS 011 of automatic changer have been analysed. These models are made of stainless steel and use food grade grease. They fulfil IP64 and weight 0.68Kg. The prize is:

- Robot side: SWK-011-E10-000-VA= 3.993,70€
- Gripper side: SWA-011-E10-000-VA=1.421,79€

Figure 22: Master-Tool adaptor SWS

Following table shows technical specifications for this product:

Specifications	SWS – 005	SWS - 011
Handling weight [kg]	8	16
Locking force at 5.5 bar [N]	690	1068
Static moment Mx –My, Mz	12.5 (Mx-My), 17 (Mz)	25 (Mx-My), 34 (Mz)
Dynamic moment load Mxy, Mz [Nm]	37.5 (Mxy), 51 (Mz)	75 (Mxy), 102 (Mz)
Repeat accuracy [mm]	0.01	0.01
Weight [kg]	**0.37 -** 0.27 kg head; 0.1 kg adapter	0.21 - 0.13 kg head; 0.08kg adapter
Min./max. distance on locking [mm]	1.5 / 3.0	3.0

Table 8: Technical specifications SWS

Conclusion

There is a wide catalogue of automatic gripper changers capable for the food industry, for this reason it is not very useful to develop an own automatic gripper changer. The selected product to be used in the final application of PicknPack project probably will be IPR TK40 Aluminium model due to their balanced characteristics of weight, price and food grade material.

3.3 Machine vision submodule

3.3.1 Vision guidance for crate picking

Figure 1 and Figure 2 show three versions of the crate-picking task defined for PicknPack project. The task of the vision module is to find a suitable handling position and orientation (pose) for the robot to pick the product. Although the products are very different and therefore the visual processing will be different, there are some common constraints:

- The crate is stationary during the period that the products are picked
- Products can be positioned in the crate at various positions, heights and orientations.
- Products might move while another product is picked
- A minimum of 30 picks per minute needs to be realized

This results in the following requirements on the sensor:

- The sensor system needs to be able to scan the whole surface at once (line scanner requires that either the crate or the sensor is moved, which is not practical in this situation)
- The sensor system needs to be able to sense depth, that is, should be a 3D camera system.

We assessed a number of different 3D camera systems: the Kinect structured light sensor, time-of-flight sensors, stereo-vision, and stereo-vision with structured light. Our findings are as follows:

Kinect

The Kinect is an attractive sensor because of its low cost (± € 150,-), relatively high sensor resolution (800x600 pixels), depth resolution (± 1mm), and frame rate (± 15 fps). The fact that the sensor actively emits an infrared pattern makes it theoretically suitable to sense un-textured surfaces. Figure 23 shows that colour and 3D information from vine-tomato trusses acquired with the Kinect. However, the sensor has some serious drawbacks for this application: the infrared projection is often not properly reflected by the smooth and shinny surface of the tomato especially for parts that have a non-orthogonal viewing angle, causing lot of missing data, the quality of the colour images is poor, and no 3D data of the stalk is generated, which is a severe issue, since the gripper will be targeted at the stalk. The Kinect can furthermore not be triggered by an external source, making accurate synchronization impossible and the camera and projector lenses cannot be changed.

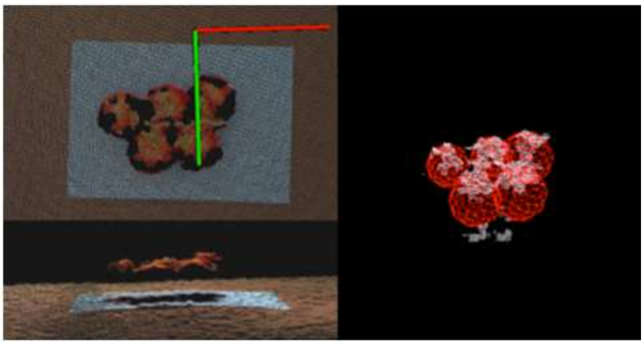


Figure 23: Kinect data. Left: two views on the 3D coloured point cloud of a tomato truss. Right: Spheres fitted to the 3D data of the tomatoes.

Time-of-flight sensor

The main disadvantage of time-of-flight cameras is the fact that they currently still have a low resolution. The tested SwissRanger sensor has a resolution of 176x144 pixels. Newer versions have slightly better resolution, but still rather low. This is problematic for crate picking, as we, on the one hand, need a large field-of-view to be able to observe the whole crate, but on the other hand need sufficient spatial and depth resolution to accurately sense the individual products to determine a handling pose.

Stereo cameras

The stereo-camera setup used by DLO consists of two Allied RGB cameras with a resolution of 1024 by 768 pixels. Both cameras have a firewire connection, but GigE cameras with standard Ethernet connections (1 Gbit/s) can be used instead. The sensors have a frame rate of 15 fps and can be triggered for accurate synchronization. At a viewing distance of 110 mm, a Euro Pool Middle harvest crate can be viewed using lenses with a focal length of 8.5 mm. For smaller objects, lenses with larger focal lengths can be used should high spatial resolution be required. For the tests, the cameras were placed with a 15 mm baseline. A large baseline will result in higher depth resolution, but comes with the cost of different perspectives on the scene in left and right camera, causing more missing data due to self-occlusions and less robust matching of corresponding points in left and right image.

DLO developed an easy-to-use method to calibrate the stereo setup. By placing a calibration plate in a number of different orientations and positions, the cameras can gather some calibration images (typically 15-20 stereo images). Using these images, the method estimates the intrinsic and extrinsic parameters of the stereo cameras, which are necessary to calculate the 3D information.

A huge advantage of this system over the Kinect and time-of-flight systems is the high quality and high resolution of the acquired images, which can be used for accurate detection and segmentation of the products (see Figure 24 for an example on fine tomatoes).

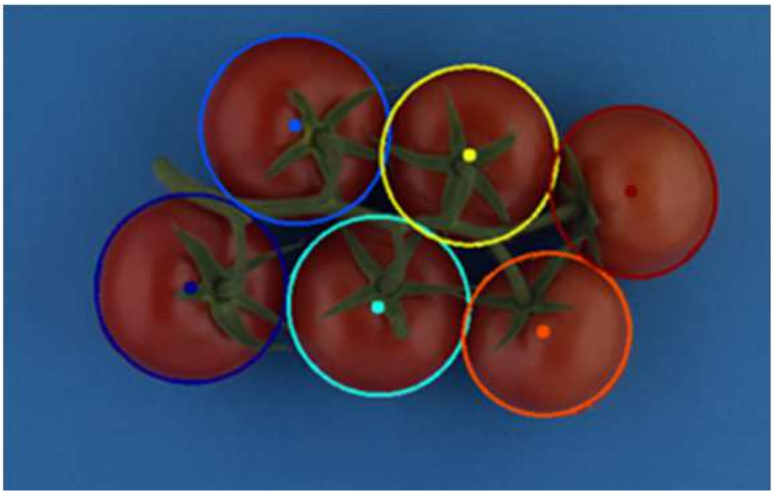


Figure 24: An example of how accurately the tomatoes on the vine can be segmented based on camera images from the stereo system.

A disadvantage of stereo-vision systems is that, using the standard techniques, depth information can only be calculated for surfaces that hold sufficient visual texture. This is, for instance, true for a container with pies or carrots, for which dense depth maps can be calculated. Tomatoes, on the other hand, have a smooth and uniformly coloured surface, resulting in sparse depth information. This is, however, not a problem for grasping, as depth information is only needed for specific points, such as, the grasping point on the stem or the centre of a tomato. DLO is currently developing a stereo-vision method that locally adapts the matching windows based on an analysis of the amount of texture in the image. Moreover, dedicated stereo-vision methods will be developed that use the segmentation of the product in left and right image to calculate the position of complete object parts, instead of on a per-pixel basis.

Stereo cameras plus structured light

In case the normal stereo-vision setup with the dedicated stereo-matching algorithms developed by DLO turn out not to be sufficient to grasp from the crates, we will make use of the additional projection of structured infrared light on the scene, to artificially add visual texture to the objects. Recently, such stereo-plus-projection sensors have come available, such as, the “Ensenso N10 3D camera” by iDS. Figure 25 shows an example of the 3D point clouds of a tomato vine and a grape bunch recorded with this sensor.

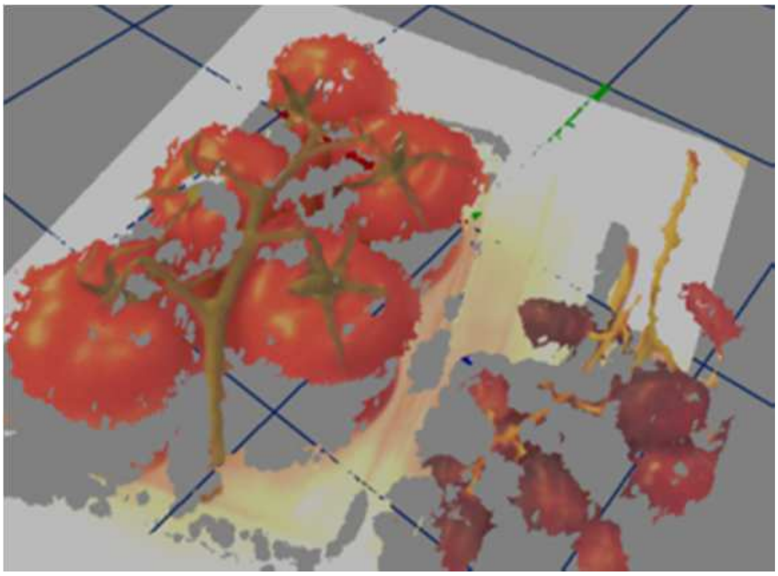


Figure 25: Example of the 3D point clouds of a tomato vine and a grape bunch using the Ensenso 3D camera.

Conclusion

Based on the above analysis, we deem the stereo-camera setup to be most suitable for crate picking in the PicknPack project. Moreover, DLO has extended research experience with the technique. Should it turn out to be necessary, structure-light projection can be added for improved surface visibility.

As is illustrated in Figure 1, the stereo system is preferably placed straight above the crate for an optimal view. However, the system can deal with a non-orthogonal view, as long as the products are still visible and not occluded by the sides of the crate. Tests need to be carried out how to optimally position the camera and the robot with respect to each other and with respect to the crate and conveyor belt. As the cameras will be above the workspace of the robot, care needs to be taken that the robot moves out of the way when a scan of the crate is made. As this will be the case when the robot places the product on the conveyor belt or in the package, this can be nicely synchronized with the motion of the robot. In case of the cable robot, it is probably that the cameras will need to look through the top plate of the robot. Tests need to be carried out how this influences the perception. Furthermore, the supporting rods that will support the top plate need to be placed in such a way that they do not obscure the field-of-view of the cameras.

Lighting

We will illuminate the products using diffuse lighting to reduce shadows and specular reflections. We selected high-frequency fluorescent lighting as it has a high efficacy (good lumen to power ratio) and a good lumen maintenance, which means a stable lighting condition with only little degradation over time. The Philips Master TL-D 90 Graphica has a specifically good colour rendering index (98 Ra), which allows an accurate reconstruction of the colours of the objects. Fluorescent tubes are by nature already a diffuse light source, but to further improve the diffuseness, we will place translucent matte material (diffusers) in front of the lamps to scatter the light rays.

As the robots have not been fully designed yet, the location of the light sources is still somewhat unclear. For the cable robot, we will install the lamps and the diffusers at the side panels. If the final design will use transparent synthesis glass of polycristal or plexiglass, then light source can also be installed above the glass to illuminate the products from above. For the Delta robot, several lamps and diffusers will be placed in a semi-sphere around the product location.

As the products need to be observed by the cameras inside the robotic workcell, it is important to coordinate the observations with the movement of the robot to ensure to not occlude the product or cast shadows on the product.

To control the lighting conditions in the robotic workcell as much as possible, the cell will be covered to prevent external light from entering.

3.3.2 Vision guidance from conveyor to package

As the products on the conveyor belt are singulated and they will stay stable while transported by the conveyor belt, it is possible to scan the products using line-scan sensors. A line-scan RGB camera has the advantage of higher possible resolution and lower shutter time, causing less motion blur and reducing needs for illumination. A laser-triangulation line scanner has the advantage of being highly accurate and robust, and gathering high resolution data. As these sensors are already in the sensing module developed in WP4, we will use the information from the sensors in the sensing module for picking the products from the conveyor belt (see Figure 2).

We use a 3-CCD RGB line-scan camera wich gives very accurate colour measurements and, compared to normal RGB cameras, gives good information around the contours in the image. We will use a NED 3-CCD line scan camera with 2048 pixel resolution. The maximum scanning rate is several kilo Herz. The sensor uses a Camera Link connection for data transfer and triggering. The camera is straight above the belt, having an orthogonal view on the products on the belt.

The sensing module has two Gocator 2370 laser-triangulation sensors from LMI technologies. The sensor provides 1280 data points per scan line. Depending on the scanning area, the frame rate can be between 170-5000Hz. Resolution in the x-direction is 0.3-0.6 mm. Depth resolution (z-direction) is 0.1-0.5mm. Field-of-view is 308-687 mm, and the measurement range (max height of product) is 500mm. The clearing distance (distance from the belt) is between 400-900mm. The sensors are connected through gigabit Ethernet connections. The two scanners are collinearly placed, one with a -30° and the other with a -30° orientation towards the center of the belt, in order to get more information about the 3D profile of the products. Figure 26 shows a points cloud gathered by the 2 Gocator sensors. The data is very accurate and contains very little noise. DLO is currently in the process of registering the colour information and the 3D information, so that the correspondences between both sets of data are known.

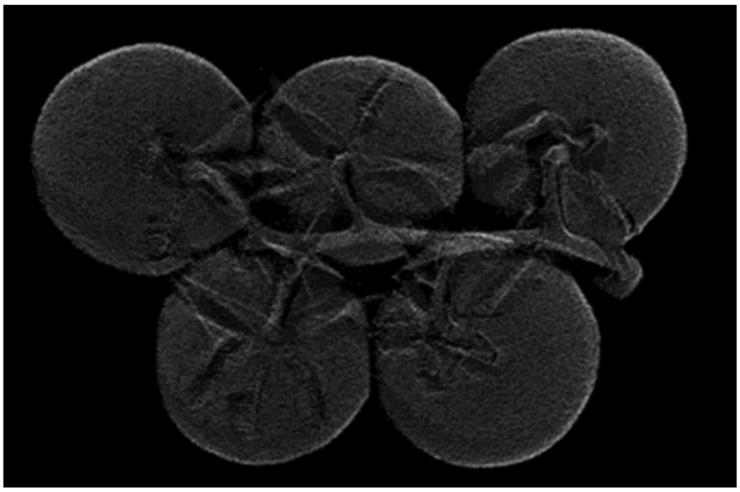


Figure 26: 3D data from the Gocator laser-triangulation sensor. The data is of high resolution and very accurate.

When the products are on the belt, the height (z-coordinate) of the optimal handling point is fairly constant. We have shown in preliminary tests to be able to successfully grasp vine tomatoes from the belt based on only the 2D RGB images, where the xy-coordinates were determined based on the images, and the z-coordinate was set as a constant. To be able to handle vine tomatoes of different size, the height information of the handling point (i.e., a point close to the stem where the gripper's 'thumb' will hook onto) can vary. In that case the 3D information is necessary to provide height information. In case the vine tomatoes and grapes are gripped with a multi-finger gripper without the thumb, the grasp will always be executed at a fixed distance from the conveyor belt, as this serves optimal grasp stability. In that case 3D information is not necessary to control the robot.

3.3.3 Colour calibration

The perceived colour of objects is influenced not only by the properties of the object's surface, but also by the lighting properties and the camera's colour sensitivity. The latter two depend on manufacturer and type, but might even vary from instance to instance. Moreover, lighting properties and the camera's colour sensitivity change over time due to, for instance, aging and temperature. To compensate for the influence of the lights and the cameras on the perceived colour so that solely the colour properties of the object can be measured, we will use a colour calibration procedure.

To accurately calibrate colour, we will make use of the GretagMacbeth ColorChecker (see Figure 27). The checker contains 24 different colour references, of which the true colour values are known. By placing the checker in the camera's field of view, the colours perceived by the camera can be compared to the reference colours in order to calculate a correction profile. Based on that profile, the colours in the camera images can be mapped to the correct values.

By performing the colour-calibration procedure on a regular basis, the system is ensured to measure the correct colour properties of the food products.

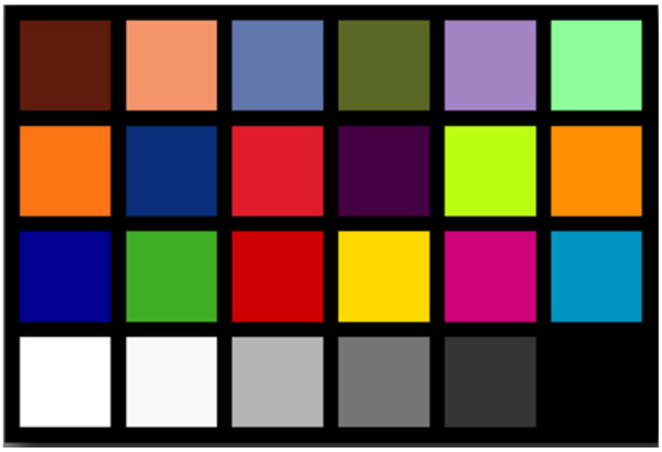


Figure 27: The GretagMacbeth ColorChecker.

3.4 Conveyor systems

In PicknPack project, it is possible to use only one large conveyor for the complete line, or different short conveyor belts for each module.

It is expected that the layout of the line will be modular, so it is probably to use many short conveyor belts. The dimension of the conveyor is still not defined, but the typical conveyors used in food industry have the following features:

- Stainless steel ladder construction.
- Removable stainless steel deck plates for cleaning.
- Food approved PU conveyor belt with central tracking strip for positive belt tracking.
- Automatic belt tensioning to ensure correct belt tension and enables fast removal of the belt for cleaning.
- Central under mounted drum drive roller. This has integrated AC motor Drive and an external encoder to enable belt position tracking.
- All in feed and out feed belt transfer rollers are removable for cleaning without the use of tools.
- Variable speed inverter drive system as standard.


Figure 28: Example of conveyor belt

3.5 Grippers

3.5.1 Gripper design for ready to eat meals

For the ready to eat meals, the robot must scoop small foodstuff parts like onions, carrots and beans. For this kind of task the gripper must be as simple as possible because this is not a high accuracy task and a simple and cheap solution must be implemented.

The current idea consists on a four finger gripper. When these fingers are closed, the gripper works as a scoop and always assures that a minimum volume is grasped. It is considered that this design is good enough for a robotic scooping task. The box where the robot picks the foodstuff must assure that there is always volume enough in the picking area. It can be considered that this system is similar to a dredger used to excavate and remove material from the bottom of a body of water.

Figure 29: Conceptual idea for the scooping device

3.5.2 Gripper design for fresh foodstuff

Lacquey has finished development of a gripper for grasping vine tomatoes and grapes.

The grasping strategy is that vine tomatoes are grasped by using a 'thumb' attached to the stem and extra fingers from the outer sides. Grapes are grasped only using the fingers, so without the thumb.

There are four fingers from each side of the product, which are all actuated with a single motor. On one of the two sides the fingers are completely flipped upwards during gripping opening, above the bin edge level. This will enable picking vine tomatoes from bins where space around the tomatoes is limited.

Both products can be grasped using the same gripper; the only required modification is an adaptation of the thumb. Using a lever the thumb can be extended or hidden.

The gripper is suited for bin picking, this will only apply to crate picking of vine tomatoes.

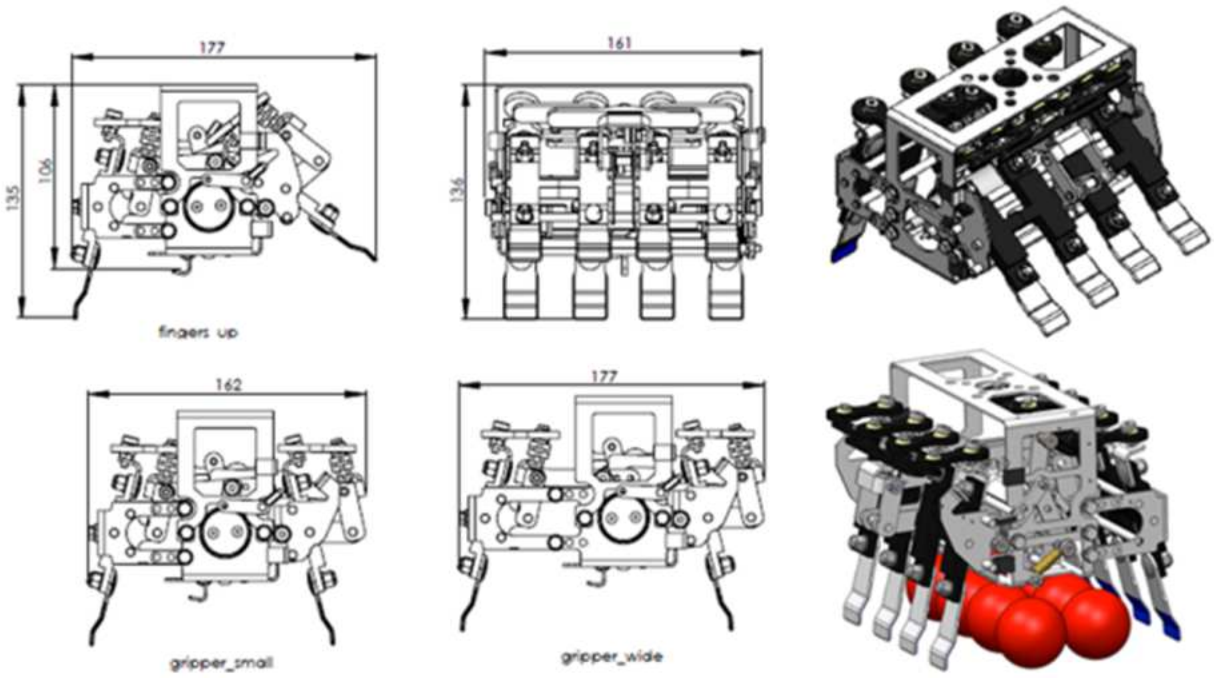
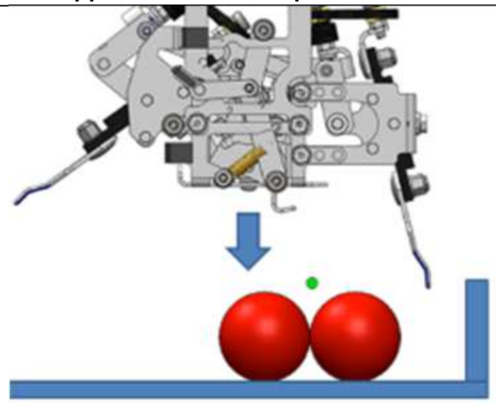


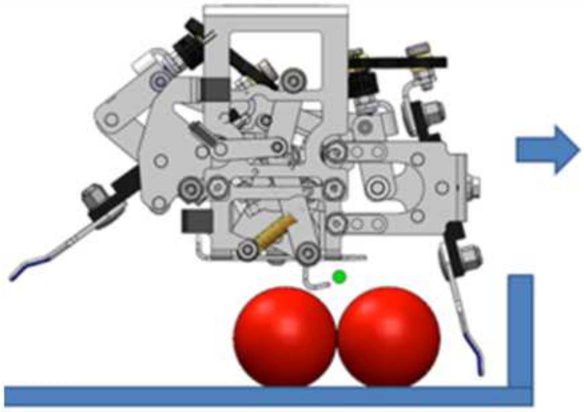
Figure 30: Dimensions and detailed design of a gripper for fresh foodstuff

Grasping principle

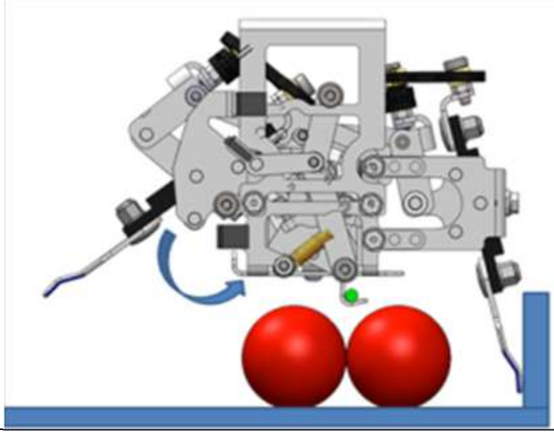
1. **Gripper located above product**



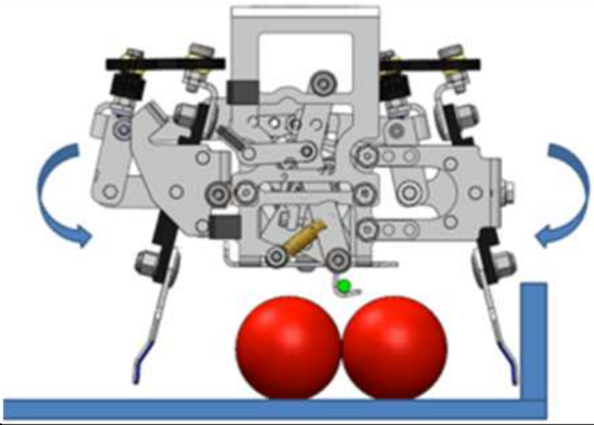
2. **Gripper moved downwards**



3. **Gripper is moved sideways. In case the gripper colides with the bin edge the low force actuated fingers will bend. The thumb is fixed to the product stem. If required, the tomatoes can be repositioned by slightly lifting and moving the truss by its stem.**



4. **The row of fingers that is flipped upwards is now rotated downwards.**



5. **All fingers are rotated inwards and the product is grasped and can be lifted.**

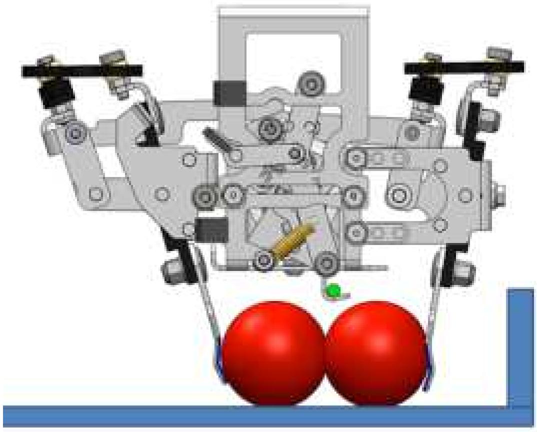


Figure 31: Grasping principle of the gripper for fresh foodstuff

Thumb change system

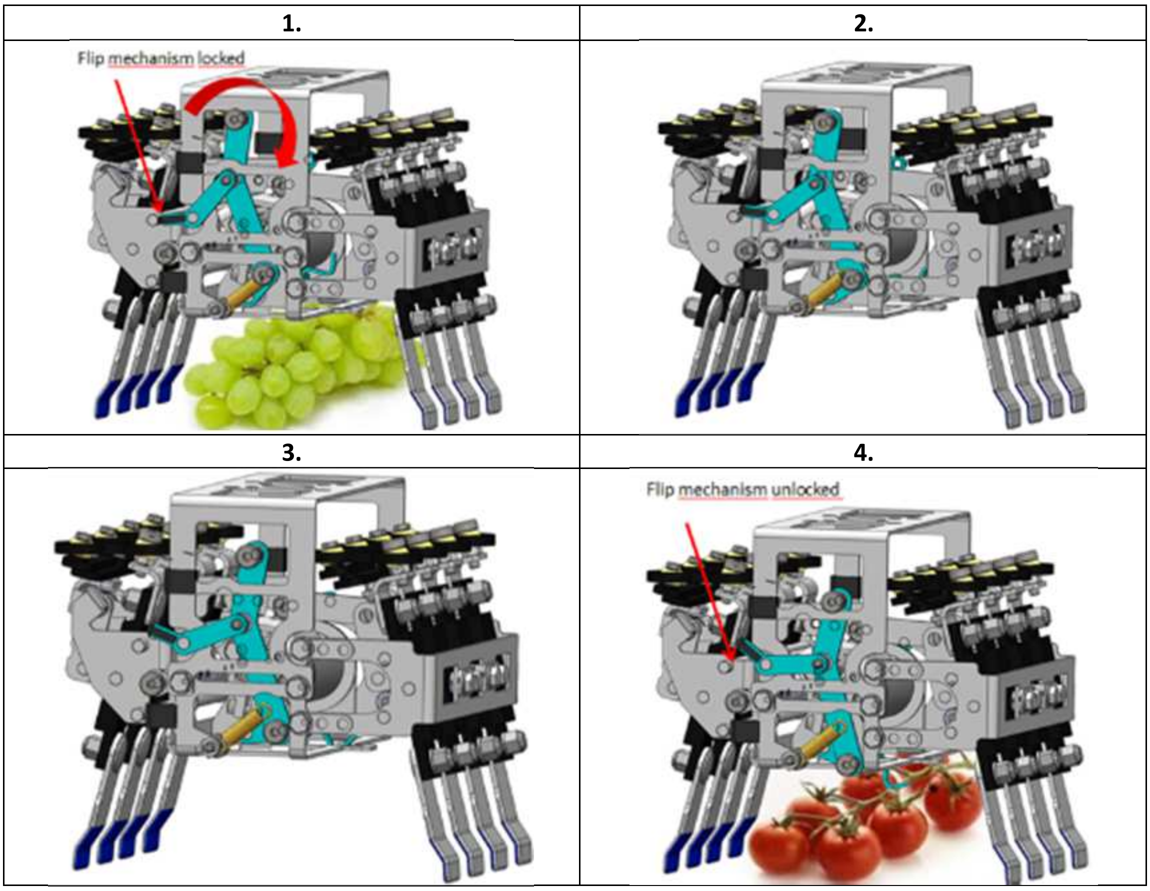


Figure 32: Thumb change system of the gripper for fresh foodstuff

Hygienic design

Extra effort has been put into hygienic design of the gripper. The number of edges and crevices has been drastically reduced compared to the previous prototype. Furthermore, almost all plastic bearings have been removed by using parts of the finger also as bearing material.

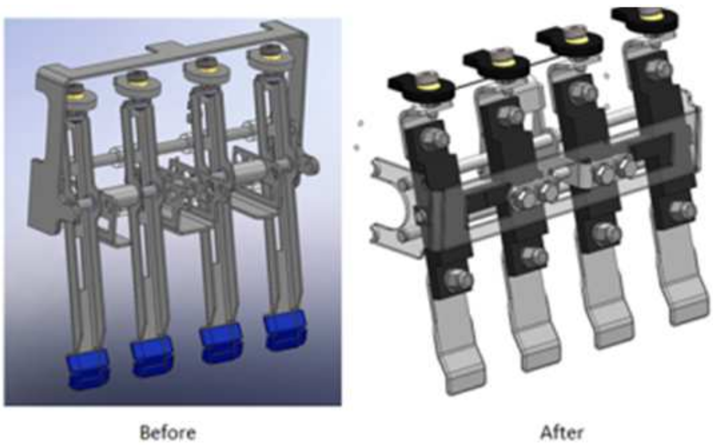


Figure 33: Hygienic design of the gripper for fresh foodstuff

3.6 Hygienic issues

3.6.1 Cleaning systems

A research by the University of Lincoln shows that the use of robots reduces the rate of bacterial growth, when compared to manual loading operations. As a result the shelf life of the product can be extended.

The cleaning system for the robotic module (including robot, grippers and conveyor) in PicknPack project is not still defined. The development of a self-cleaning system for the robot will be studied. It requires the definition of a cleaning protocol with different cleaning positions to ensure the complete cleaning of the entire cables and the use of a nozzle as a robot gripper with an alkaline cleaning media. Product contact surfaces like the gripper have to be cleaned before each use, so it would make sense to apply a cleaning station where such parts can be cleaned without being removed.

The most suitable cleaning media should be spray cleaning at low pressure but also foam or gel could be an option. Some Spanish provider recommends the use of "DEOBAT", a fungicidal disinfectant cleaner, diluted at 5% to clean the robot and the gripper once a week (or in each change of product). For a more complete cleaning, it is also possible to use "ASEPCOL", an alcoholic disinfectant indicated for maintenance disinfection during the production process, especially designed to be applied by spraying. More information about cleaning systems on deliverable 8.2.- System requirements".

Regarding Marel experience, it is very difficult to ensure a complete cleaning in self- cleaning systems, because it is practically impossible to reach all the edges and holes, dripping is usually a problem, and lot of detergent is wasted. It is preferable to use a trolley for out-of-place cleaning and submerge al the removable parts for cleaning.

Figure 34: Example of cleaning trolley

These trolleys conforms to the most stringent AMI and European standards and they open fully to reveal all working parts for quick inspection, easy maintenance and fast, thorough cleaning. Shear edges, blades and other key components are quickly and easily removed then placed on purpose built hygiene trolleys for cleaning. Downtime is yet further reduced with a purpose made sharpener that ensures fast and accurate blade sharpening.

3.6.2 Robotic covers

There are some robotic applications for the food sector which include covers for the robotic arms in order to improve hygienic issues. In Pick and Pack project this kind of covers have been analysed as a solution to improve hygienic behaviour for the cable robot.

Figure 35: Cover for a non-anthropomorphic robot, for a prismatic axis and for the food industry

These covers have two main functions. The former is to avoid projections from the robot to the manipulated food. The latter is to allow the wash down function when cleaning the robot. The materials of these covers could be PVC or other kind of material suitable for the food industry and could be manufactured as an only part or as a set with two parts. A movable metallic ring can be assembled inside the cover to improve its behavior for complex robot movements.

Additionally it is possible to apply overpressure at the inside of the robotic cover. This would have the advantage that wrinkles could be smoothed easier and in addition no dirt from outside the cover could reach the inside. But it also means that the inside of the cover has also to be cleaned.

Another approach for the problem with the wrinkles is to apply several cleaning positions to reach all areas of the cover surface while it is in motion. It is also necessary to be able to reach the inside of the cover for reasons of inspection. A 100% safety in density can never be reached so therefore it cannot be excluded that dirt or detergents can reach the inside. Due to the higher humidity while cleaning there is also a high risk of condensation inside the cover what could cause corrosion. Therefor a periodic inspection is essential.

A supplier for this product in Spain considers that a cover could be a suitable option for the cable robot and he has done a schema to preview the use of the cover with it.

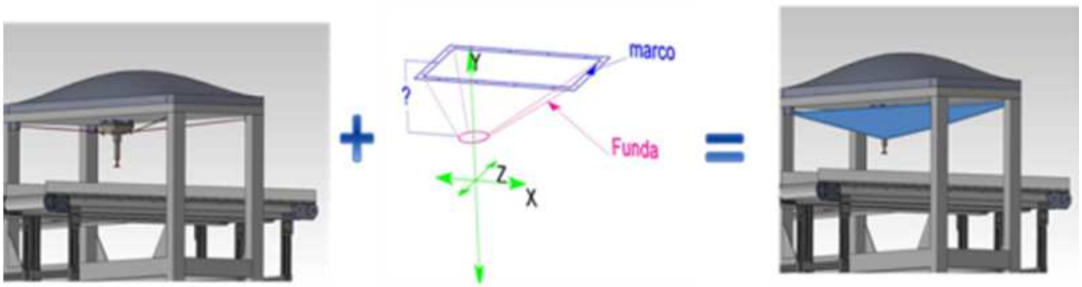


Figure 36: Possible cover for cable robot

Conclusion

Although this cover is not the best solution regarding hygienic issues due to the possible wrinkles that difficult a correct cleaning of the complete robot, it could be considered as an option if it is not possible to develop a robot with food grade materials or it does not pass hygienic tests.

3.6.3 Pneumatic supply

ISO 8573-1:2010 specifies quality requirements for compressed air and stipulates maximum permissible levels of contamination regarding solid particles, water content and total oil content.

ISO 8573-1 Class	Dust		Water		Oil Concentration
	Dimension	Concentration	Dew point	Water content	
1	0,1 µm	0,1 mg/m³	-70°C	0,003 g/m³	0,01 mg/m³
2	1 µm	1 mg/m³	-40°C	0,11 g/m³	0,1 mg/m³
3	5 µm	5 mg/m³	-20°C	0,88 g/m³	1,0 mg/m³
4	15 µm	8 mg/m³	+3°C	6,0 g/m³	5 mg/m³
5	40 µm	10 mg/m³	+7°C	7,8 g/m³	25 mg/m³
6	n.a.	n.a.	+10°C	9,4 g/m³	n.a.

Table 9: ISO 8573-1:2010

In PicknPack project, we will probably use air bearings that are above the food, so we should assume that compressed air comes into direct contact with food. The following classification in accordance with ISO 8573-1:2010 recommended in this case is: Solid particles: class 1 Water: class 2 Oil: class 1.

Atlas-copco

Atlas-copco has in their product catalogue different types of oil-free air compressors that guarantee 100% oil-free and clean air of class 0. Additionally, some versions include the integration of drying technologies and filters that ensure compliance with our air requirements and allow reaching the class 1:0:1.

The price for an oil free compressor LFX 0.7 10 220 V-50 Hz with included filters and absorption air dryer is 2.825 €

Figure 37: Atlas copco oil-free air compressor

Bambi

Bambi commercializes oil-free air compressors with stainless steel air dryers (VT-D model). It has an integral downstream HE dust filter that removes any residual dust and a fan assisted after-cooler that reduces the air temperature prior to entering the dryer that enables the integral coalescing filter to collect and remove water droplets as small as 0.01 microns.

The price for an oil-free air compressor with air dryer VT75D model is 1922€.

Figure 38: Bambi oil-free air compressor

Worthington Creyssensac

Worthington Creyssensac commercializes small pistons air compressors with galvanized tank and oil-free lubrication. Additionally he recommends the use of an active carbon filter and an absorption dryer (that includes input coalescing filter and output dust filter) that eliminates the risk of contamination by residual water vapour.

Figure 39: Worthington Creussensac oil-free air compressor

The price is:

- Oil free compressor BK 1A: 1600€
- Absorption air dryer with included two filters: 1095 €
- Active carbon filter: 130€

Festo

Festo recommends the use of the following filters and dryer in cascade (in this order) to reach the required [1:2:1] case.

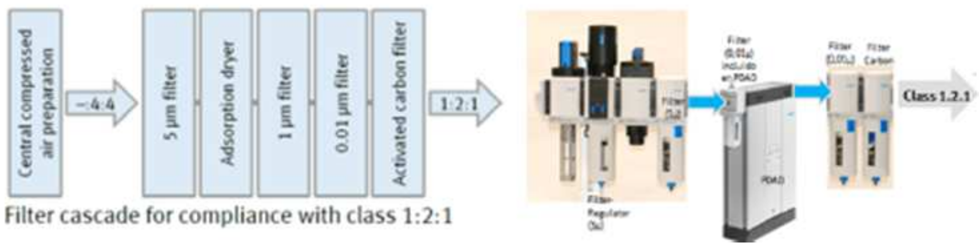


Figure 40: Festo recommendation

In special cases it's advisable to use a sterile filter, if possible in direct proximity to the consuming device. The price is:

- Filters phase 1: 237€
- Absorption dryer: 3.241€
- Filters phase 2: 200€

Conclusion

There are many options to fulfil hygienic requirements regarding pneumatic supply. The selection of the most suitable oil-free compressors, dryers or filters will be made in function of the situation of the final application (depending for example, on the existence of a pneumatic ring in the workshop).

3.7 Internal communications

The communication between different modules that share information has been studied in the PicknPack context. Regarding the main signals through the robot, it has been identified the information from the vision system and the commands for the gripper actions. With this information a preliminary scheme of the data flow through the robot is under development. It has been established that the pick and place of fresh products could have several configurations that should be modeled inside a semantic model, where, the main states, functions and operations in the pick and place processes could be directly implemented maintaining the flexibility.

In order to clarify the communication flow and the different modules that interact with the robotic module, an user case is going to be developed. In this case, a vine-tomato is grasped by the robot from the line and placed into a package. Many factors should influence this pick and place operation, but maintaining the user case simple, the most important is the quality of the tomatoes, because it defines the kind of package that the robot must use.

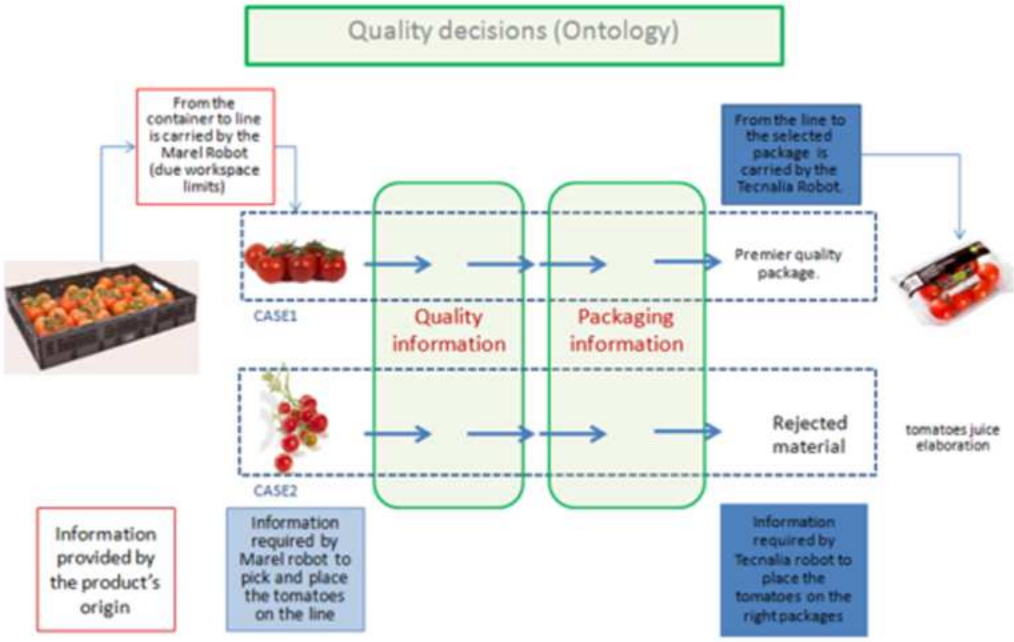


Figure 41: User case for vine-tomatoes

The purpose of define the operations is identify the basic blocks or components that are required to perform a pick and place operation. Once defined it should be easy progress with the correct standardization of the inner components.

The main components identified in the pick and place operations are:

- Visual information (Localization).
- Trajectory planning.
- Pick planner.

Each component is executed several times inside the same operation. The visual information is provided by the vision system module, the trajectory planning is performed by the cable robot controller and the pick planner has been defined by the gripper designer but should be executed by the robot controller.

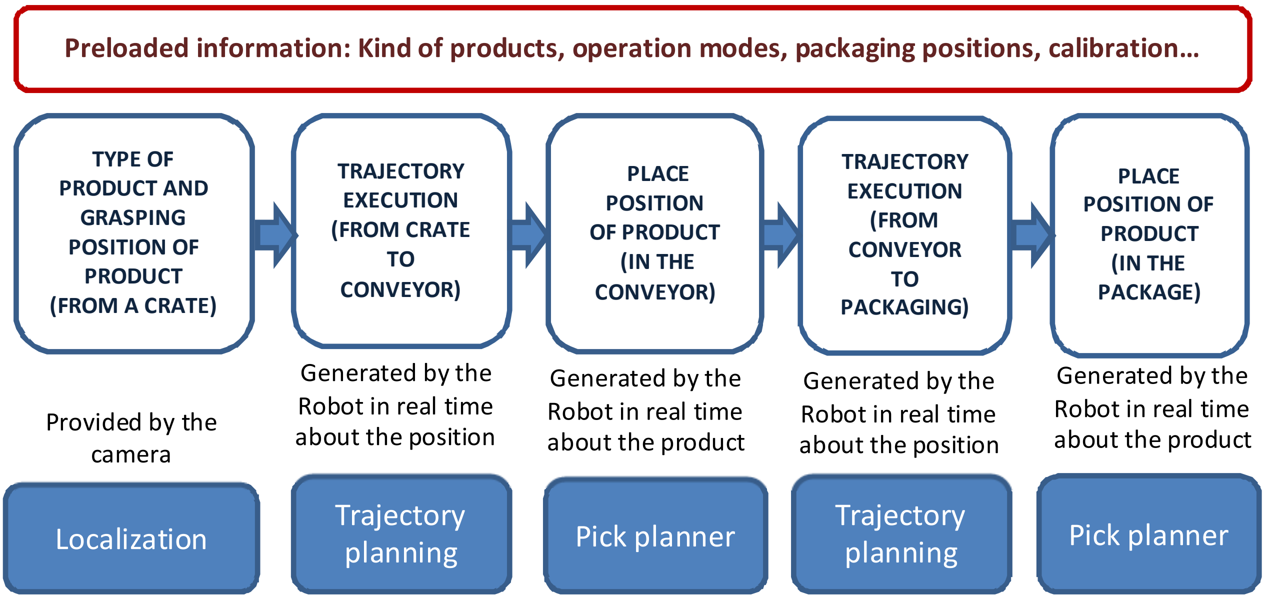


Figure 42: Internal information flow on the robotic module

If the component model is already a novel manner to describe software/hardware implementations, PicknPack wants to go a step further, defining a component based in a ublx, inside the ublock the functions can change following the orders of a coordinator and a scheduler, allowing the system to being configured with a large range of different working conditions (kind of product, quality levels, status of the robotic module, status of other modules, etc).

The key in this design is the correct identification of the functions inside the component and how use this information in the task definition. The first results of this modeling are expected in the next month.

4 Standards

Alimentary Codex- Food hygiene

- Machinery directive 2006/42/EC →Hygienic design criteria.
- RE (EC) 178/2002→ General principles and requirements of food law.
- RE (EC) 852/2004 → Hygiene Foodstuffs.
- RE(ED) 2073/2005 →Microbiological criteria for Foodstuffs.
- RE (EC) 1935/2004→ On materials and articles intended to come into contact with food.
- RE(EU) 10/2011 → On plastic materials in food contact.
- RE (EC) 2023/2006 → On food manufacturing practice for materials and articles intended to come in contact with food.
- Guidelines from EHEDG (European Hygienic engineering&design group) → Guideline 8: "Hygienic equipment design criteria".
- EHEDG Yearbook 2013/2014 (ISBN 978-3-8163-0640-5).

Legal text

- Food and drug administration (FDA) → Food code
- United States Department of Agriculture (USDA) → Legislation on machines processing agricultural products.

5 Conclusions

This document shows the work that has been achieved for the design of all the modules which are included in Workpackage five. Those main modules are the manipulators for pick and place operations, the automatic gripper changers for fast change overs, the machine vision systems for robot guidance and the grippers for foodstuff grasping. In addition there are some equipment and peripherals which are necessary and have been also taken into account.

We can find both novel and commercials components in this design report. The new elements are the delta and cable manipulators and the grippers. A huge design work has been done to develop these new parts taking into account both the requirements of the Pick and Pack project and the food industry. To complete the demonstrator and the Pick and Pack concept other food grade components like gripper changers, conveyors and so on must be selected.

Last March, the team of this workpackage ended the deliverable 5.1 which registers the requirements for the robotic module. Within this new deliverable, 5.2, design aspects have been added. Summing up, consistent steps have been tackled to accomplish the goals of the PicknPack project.

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