Architecture principles for vision-based applications in agriculture

Initial step towards standardization

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WPR-OT-972

WAGENINGEN UNIVERSITY & RESEARCH

Architecture principles for vision-based applications in agriculture

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This study was carried out by the Wageningen Research Foundation (WR) as part of the **PPS PL4.0 workpackage 7 on architecture principles – use case robotics**. WR is part of Wageningen University & Research, the collaboration of Wageningen University and Wageningen Research Foundation.

Wageningen, November 2022

Report WPR-OT-972

Booij, J.A., Urdu, D., Boheemen, K., Graumans, C., 2022. *Architecture principles for vision-based applications in agriculture; Initial step towards standardization,* Wageningen Research, Report WPR-OT-972

This report can be downloaded for free at https://doi.org/10.18174/582851

Summary
In the last few years there is an increase in technology developments in agriculture using machine vision and deep learning to recognize specific plants or animals. A shared infrastructure to exchange image datasets and to support the workflow of image processing with neural networks could fasten up the developments of new vision-based applications in agriculture. This requires some form of standardization and architecture principles. The use case of plant specific weeding with robots is used to define an initial architecture for this infrastructure and to describe an initial set of preferred metadata for standardizing the exchange of image datasets and deep learning algorithms.

Keywords: standardization, Agro food robotics, weed control, machine vision

Chamber of Commerce no. 09098104 at Arnhem
VAT NL no. 8065.11.618.B01

Report WPR-OT-972

Photo cover: The autonomous 5G robot solution for weed control

Contents

List of definitions

- Dataset: this is a group of images acquired during one operation and supplemented with metadata to describe the context of the images.
- Data: all the individual images taken at the operations and its metadata.
- Data supplier: scanning machines or parties that collect data with scanning systems which is of interest in the ecosystem.
- Information producer: the service provider responsible processing data so that it becomes usable as information.
- Acting parties: Application or hardware supplier responsible for the actual execution of the spraying operation with the robot and spots prayer.
- FDE-PIAD: FAIR Data Ecosystem – Published Interoperable Algorithms and Data. The central ecosystem.

Summary

In the last few years there is an increase in technology developments in agriculture using machine vision and deep learning to recognize specific plants or animals. A shared infrastructure to exchange image datasets and to support the workflow of image processing with neural networks could fasten up the developments of new vision-based applications in agriculture. This requires some form of standardization and architecture principles. The use case of plant specific weeding with robots is used to define an initial architecture for this infrastructure and to describe an initial set of preferred metadata for standardizing the exchange of image datasets and deep learning algorithms.

Reading guide:
Chapter 1 introduces the use case and the challenges with vision-based applications.
Chapter 2 describes two business process models of the use case.
Chapter 3 describes in general the preferred metadata in messages from the business process model.
Chapter 4 proposes an architecture for a shared infrastructure
Chapter 5 discusses the outcomes and give recommendations for future work.

1 Introduction

1.1 Motivation:

In the last few years, we have seen an increase in startups and agricultural machine manufactures bringing robot technology to the agri-food sector. Robots which work with camera's, deep learning algorithms which detects weeds, crops, pests and diseases, and actuators to do an action place or plant specific. There are many parties working on the same use cases (e.g., weed control). Our experience teaches us those algorithms are quickly outdated as they cannot cope with new circumstances (climate region, varieties, species, etc.). Therefore, algorithms need to be continuously retrained with new data (images) in order to cope with those different (new) circumstances. This increases the development costs which causes suppliers of robots to focus on one use case (to guarantee the quality). However, we see that the farmer would like to use the same 'expensive' robot for multiple applications. So being able to make a robot work with different algorithms is a requirement. In short, two goals can be distinguished here:

1) To facilitate the application of algorithms on a wide range of robots while maintaining operational quality (this requires the exchange of real-time camera data with a cloud solution)
2) Propose a standard for harmonizing (camera) data captured in a field, with context required for efficient re-use of these data for development or training of algorithms

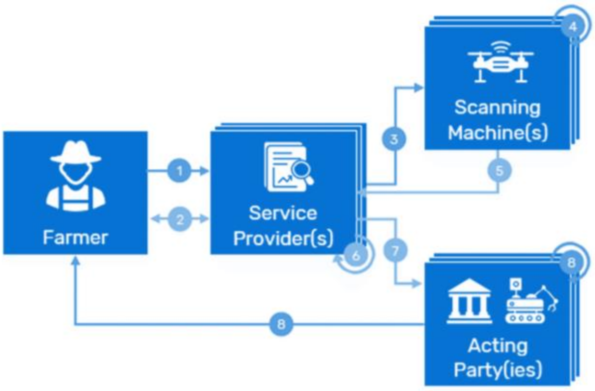
1.2 Current situation

From 2018 till 2021 experiments were done with a prototype spot sprayer developed by AgroIntelli. The system consists of an autonomous implement carrier, called the Robotti, which has an RTK-GNSS receiver on board. The GNSS messages of the receiver are made available on the robot's internal network so that they can be used by an implement besides being used in the robot's navigation algorithm. The implement is a spotsprayer which houses 4 RGB camera's assisted by LED lightning, a pc with a GPU, a PLC-board to control the spraying nozzles, and a spraying boom with nozzles. The basics of the sprayer work as follows:

- All 4 cameras acquire an image
- The robot's current position is obtained from the latest GNSS message
- The images are processed using an image analysis algorithm
- The location of each object of interest, detected in the images, is translated to the vehicle coordinate system using the camera-ID and the position of the camera inside the spot sprayer.
- The position, the vehicles velocity and current time (GNSS) and timestamp of image acquisition are then sent to the PLC, which responds by activating the correct spraying nozzle at the moment the spraying boom is (expected to be) over the object of interest. Most robotic platforms in the open fields have in common that there is a GNSS receiver, an image-acquisition system, an onboard pc with GPU to process the images and an actuator performing an action in the field.

Most suppliers have a separate operation to acquire images for training purposes. During an application in the field the image data is mostly deleted after the processing with the image analysis algorithm. This increases the time (and costs) to acquire data of fields where the performance of the system is low. Furthermore, in the current situation suppliers must count for sufficient data storage onboard of the robot, which has its disadvantages.

1.3 Desired situation:



In 2019 a 'Proof of concept' was demonstrated where the images were not processed on the onboard pc, but rather sent with a 5G connection and glass fiber infrastructure to a server 250km away. At the server the images were processed with a recognition algorithm and the location of detected objects were send back to the PC on the spotsprayer. The whole process of taken images and receiving GNSS position, sending the data to the server, processing the images, sending the location of objects back to the robot and actuation took about 250ms, which enabled in real time the application of weed control having the 'AI in the cloud'. This proof of concepts opens and calls for a digital ecosystem. At the current situation the manufacturer of the robot and implement provided the whole chain of scanning, an algorithm and implement/actuator. We see that robot manufacturers focus on one use case, where farmers desire a multi-operable robot. With a digital ecosystem the role of scanning, provide a service/algorithm, acting in the field (robot and implement) and the farmer can be split. Having such ecosystem can greatly enhance the development of algorithms and use cases. Therefore, the desired situation consists of a process as follows:

- All 4 cameras acquire an image
- The robot's current position is obtained from the latest GNSS message
- The image with metadata (location, description of used sensors, etc.) is sent to a server.
- On the server
    - The image is processed with a recognition algorithm by provider x.
    - Detected objects are converted to a command for action and send back to the robot. (So included are the real-world positions of objects of interest)
    - The data is stored in a structured and harmonized way (FAIR principles).

Advantages of such ecosystem are:

– the larger the pool (the volume) of accessible and usable high quality, well tagged images, the faster the learning of weed, pest and disease detection algorithms.
– The more sharing of properly annotated images the lower the cost, the quicker new technologies will be adopted by farmers on a large scale.
– The better the shared infrastructure to support the workflow of image processing, the lower the overall cost.

1.4 Problem description:

Image data and vision-based algorithms are not Findable, Accessible, Interoperable and Reusable to make it sharable between farmer, service providers, scanning machines and acting parties.

1.5 Goal:

The aim of the work package is to make data sharable in real time between data supplier (scanning machines), information producer (service provider) and application/hardware supplier (acting parties), across different agri-sectors and with standardized protocols. We focus on the use case to remove weeds with a robot equipped with a spot sprayer. The steps are to scan the crop with cameras, to do object recognition with an algorithm and then to spray the 'bad' plants, all in real time. The focus of the work package is on supporting farmers and research purposes.
At short notice, the goal is to describe and agree on an enriched standard metadata set (labels) for datasets of (annotated) images of weeds, diseases and pests.
In the long term, the aim is to improve the process of acquisition, collection, annotation and sharing of camera images in order to speed up the development and maintenance of algorithms for the recognition of weeds, diseases and pests under various field conditions.

This report describes

- The various data streams and desired metadata set for sharing images - between farmer - machine - service provider in the use case of weed recognition and control.
- Outline of basic infrastructure / architecture for data exchange with field robots.

1.6 Delimitation:

The greatest challenge lies in the standardized exchange of high volumes of camera data and datasets where value has been added in the form of annotations. The safe use and linking of algorithms by different service providers is also a challenge. The control of a tool on an autonomous platform is in our opinion already well documented. The exchange of machine data is also already well documented, such as rmCrop and ISOBUS protocols. Worldwide, various standards, exchange protocols and architecture principles are already available for the current agricultural mechanization (tractor & implement) and field data, see also '857125 ATLAS – D3.2 Service Architecture Specification'[1]. The focus of this document is therefore on the interoperability of camera images, annotated datasets and algorithms with a well-defined metadata in a FAIR data ecosystem.

[1] https://drive.google.com/file/d/1-o4-WHp8hW_CSCTbxOcWvo-ZBy601wRs/view

2 Business process model

In this chapter a description is provided of the desired workflow with two different views for a suggested FAIR Data Ecosystem – Published Interoperable Algorithms and Data (FDE-PIAD)
The figure in Annex 1 is a simplified entity diagram which shows a schematic overview of the desired data streams between the different actors such as the FMIS of the farmer, the service of a provider with the recognition algorithm, the machine portal, the machine itself (with the camera and actuator on board) and the proposed FAIR Governed ecosystem. For modeling the entity diagram Unified Modeling Language (UML) is used as a language and Enterprise Architect is used as a tool.
Annex 2 presents a detailed process model. In this model the same actors are involved as the entity diagram, however the different activities for each actor are elaborated. Each swimlane in the model represents an actor within the ecosystem. For modeling the process Business Process Management Notation (BPMN)is used as a language and Visio as a tool.

The process starts with the farmer, who would like to do an operation on the field. The main dashboard of the farmer is a Farm Management Information System (FMIS). In the Netherlands Cloudfarm from Dacom and Cropvision from Agrovision are well known FMIS's. They both have a website with a user interface, which connects to servers of the company. The farmer adds information to the FMIS (e.g., crop registrations, inventory listings, etc.) and uses precision farming services (e.g., visualizing soil- and biomass maps and making variable rate application maps). The FMIS can also be used to send task data to the machines in the field. The farmer owns a machine (or hires a contractor) and would like to use it for a certain operation, where also an algorithm is needed from provider X.
In the desired situation the farmer requests an order for an operation for his machine. Therefore, he needs to find and have access to several services who provides algorithms and choose a service. In this InitialOperationOrderRequest data about the field (boundaries, weather data, soil data, crop data as variety, growth stage, etc.) and data about the machine (type and model of machine, implement, GNSS receiver, camera's, etc.) should be available, so the service provider could check if the algorithm is usable or adapt the algorithm to the specific field circumstances and machine specifications. In the order request also information about the task limits should be included, like the minimum, average, maximum dose. Probably also a timeslot should be selected for when the farmer wants to perform the operation, in order to make GPU resources available.
An InitalOperationOrderResponse is send back whether the combination of algorithm and machine can work or not.
After the InitialOperationOrderRequest and InitialOperationOrderResponse the machine manufacturer can configure instructions to the server for the robot on how and when the algorithm and machine should be working. An algorithm itself detects objects on images, but the position of the objects on the images should be translated to real world positions, so the implement on the machine can take actions. This translation depends on the machine and camera specifications (e.g., position of cameras on the robot and height above the objects, position relative to the GNSS receiver, position relative to the implement, resolution of camera, etc.). So, machine parameters, inscriptions of the server use and the configuration file of the robot should be exchanged between the ecosystem, machine portal and robot. The FDE-PIAD can do the actual translation and send the real-world positions of objects and the action to be taken back to the weed robot, which is the ActivityFieldDataResponseMessage.
The weed robot has an edge device which takes care of internal communication between robot, implement and cameras/sensors. Robots are mostly developed with libraries and tools from Robot Operating System (ROS). There are libraries which allows for easy plug-in of cameras and sensors and which also subscribe not only the data from the cameras, but also the specifications of the camera to certain 'Topics'. The same accounts for e.g., GNSS receivers. So, images and metadata of the camera and positioning information and metadata of the GNSS receiver is going from the Data Acquisition swimlane to the Edge Device on the robot. The edge device takes also care of communication with the

implement. Most implements use ISOBUS or CANBUS protocols for the communication. ISOBUS is a well-defined protocol to exchange technical specifications of the implement, to send commandos to perform an actuation and receiving feedback on what the actuator did (e.g., the dose).
The information (specifications) of the implements and data-acquisition system are important to give datasets of images enough context and to check if the combination of data-acquisition system – algorithm – implement could work. Therefore, this information should be exchanged from the robot to the FDE-PIAD (Use of validate algorithms) or indirectly by the manufacturer (machine portal). The individual data/images could be sent directly to the FDE-PIAD, together with the position where the image is taken (Anonymized image and geodata). When an operation on the field is finished, the FDE-PIAD structures the images, geodata and metadata together as a dataset.
The FDE-PIAD is a sort of data-services-hub, which takes care of storing (annotated) datasets and algorithms in repositories and takes care of providing CPU and GPU processing capacity.
One essential key point in robotics with vision-based applications, is that the performance of the operation needs to be evaluated. If the performance is bad due to circumstances for which the algorithm wasn't trained for, new data must be annotated and labeled to retrain and update the algorithm on the robot. This means the farmer needs to have place where he can give feedback to the whole system. Furthermore, the farmer is an expert in recognizing weeds, pests and diseases, so a new business opportunity for him could be to enrich image datasets with his knowledge (annotations, metadata) and provide it to service providers. It also could be a business opportunity for service providers to enrich image datasets from the farmer with annotations and train and build algorithms based on it.
The images and detected objects on the images could provide essential (place specific) information to support the farmer in his decisions. A logical place would be to use the FMIS as central user interface. This would mean that the FMIS should include possibilities to exchange image data.

3 Description messages

This chapter describes the main contents of the data streams derived from figure 1. Within the project we will make a class model of these messages using the definitions from the reference model Agro as a next step in 2022. (AgroConnect).

3.1 OperationOrderInfo

This message is sent from the FMIS to the FDE-PIAD after the FMIS received a positive response on the operation request. It should contain some general info about the farmer, the field and the (predicted) weather conditions:

- FarmID
- FieldID
- Crop
- Variety
- Cultivation Purpose
- Soil type
- Weather conditions

Furthermore, it should also contain specific data about the operation like which machine and algorithm must be used, but also inscription data for the machine itself:

- Operation type
- MachineID
- Data-acquisitionsystemID
- ImplementID
- AlgorithmID
- Priority server processing (is an operation real-time and is processing done on a GPU server or does the edge device take care of processing and only sensor data is pushed to the FDE-PIAD?)
- Driver
- AB-guidance lines
- Date and timeslot
- Dosage (min, max, average)

Last it is preferred to also include information about possible taskmaps which are used for the operation and AS-applied maps after the operation is finished.

- Taskmap
- AS-applied map

3.2 Anonymized image and geo data

This data stream is a continuous stream of data send from the weed-robot to the FDE-PIAD containing the individual images taken during an operation and the location where each image is taken. The stream starts when the operation is started and stops when the operation is stopped. The individual images could then be packed in a dataset on the FDE-PIAD. The following data should be included in the stream:
From the camera:

- Imagefile (.tiff, .png, .jpg)
- Date and time of acquisition in GMT format (e.g., 2021-12-10T06:09:30+0000)
- CameraID/Serialnr camera (there could be more cameras on the robot)

- Exposure level (when auto exposure is on)

Messages from GNSS receiver[2]:
- GGA string[3] with
  - NMEA status
  - Latitude (degree, minutes, seconds)
  - Longitude (degree, minutes, seconds)
  - Height
- Heading (HDT format)[4]

From encoders (when used instead of GNSS receiver):
- Date and time of acquisition in GMT format (e.g., 2021-12-10T06:09:30+0000)
- Value

3.3 Machine parameters

As described at 'Anonymized image and geodata' the images gathered during an operation could be packed in a dataset. In order to interpret the dataset detailed information is needed about the used data-acquisition system. This information should be provided by the manufacturer of the acquisition system (scanning party) and/or manufacturer of the carrier system.
General info about the data-acquisition system:
- Artificial lightning (yes / no)
- Model and type of lightning
- Other specs on lightning?
- Amount of camera's
- Vehicle coordinate system (described in ISOXML)

Info about camera system (could be more than 1 camera)
- Model and serialnr
- Type of camera (RGB, Multispectral, Hyperspectral)
- Resolution (e.g., 1024X2400 pixels)
- Lens serial nr
- Focal length
- Position camera on vehicle (x, y, z, roll, pitch, jaw) compared to point 0,0,0 on vehicle coordinate system.
- Intrinsic and extrinsic parameters of camera (used for geometric camera calibration)
- Distance to object (Depth of Field)
- Settings of camera (gain factor, aperture, white balance/gray balance, ...)

Info about GNSS receiver
- Model and serialnr
- Coordinate system (e.g., WGS 84)
- Projection (e.g., empty, or WGS 84 UTM Zone 32N)
- Position GNSS receiver on vehicle (x,y,z, roll, pitch, jaw) compared to point 0,0,0 on vehicle coordinate system.

Info about encoders (if used)
- Model and serialnr
- Max value
- Tics per mm

[2] https://receiverhelp.trimble.com/alloy-gnss/en-us/NMEA-0183messages_MessageOverview.html
[3] https://receiverhelp.trimble.com/alloy-gnss/en-us/NMEA-0183messages_GGA.html
[4] https://receiverhelp.trimble.com/alloy-gnss/en-us/NMEA-0183messages_HDT.html

3.4 Annotate, train & deploy algorithms

Service providers will use image data and add annotations to it. Image data and annotations are used to train the weights of a neural network of an algorithm. The algorithm and its weights are then deployed and used for recognition. To exchange datasets with images and annotations there is a description of protocols found along the COCO dataset[5]. To exchange machine learning algorithms the ONNX format is usable[6],

In order to make algorithms FAIR (Findable, Accessible, Interoperable and Reusable) at least the following information should be provided:

- Title of algorithm: e.g., 'volunteer potato detection in sugar beet'
- ID of algorithm (thus there is a need for a global identifier for algorithms)
- Description of algorithm
  - DatasetID's used for training (can be multiple datasets)
  - Categories (example below)
    - 0 potato
    - 1 sugar beet
  - Region (e.g. North-East Netherlands, extent x1,y1, x2, y2)
  - Mean Average Precision (says something about accuracy of the algorithm)
- Ownership and licensing
- URL of weight file (contains weighting factors of a trained network)
- Name used algorithm: Yolov5 (or IDnr?)
- Buildnumber
- URL to GITHUB of algorithm

3.5 Use of validated algorithms

When performing the operation in the field, the FDE-PIAD and the robot must communicate with each other to make use of an algorithm. In this case it's assumed that the processing of images by the algorithm is done on a GPU-server of the FDE-PIAD. The following general information is needed:

- AlgorithmID
- URL of weight file (contains weighting factors of a trained network)
- Settings algorithm
  - Confidence threshold
  - Maximum number of objects per picture
  - Minimum object size
  - Maximum object size
- URL to GITHUB of algorithm

Furthermore, specific info is needed from the machine to the GPU-server in order to translate the objects on images to real world positions (and actions of the implement).

- Open/close connection
- MachineID
- Data-acquisitionsystemID
- ImplementID
- ImageID (.tiff, .png, .jpg)

[5] https://www.immersivelimit.com/tutorials/create-coco-annotations-from-scratch
[6] https://onnx.ai/get-started.html

3.6 ActivityFieldDataResponseMessage

As a last step the FDE-PIAD translates the detected objects to real world positions and sends this data to the robot and instructions what to do with it:

- ImplementID
- Date and time of acquisition in GMT format (e.g., 2021-12-10T06:09:30+0000)
- Position of objects x1,y1, x2, y2 in WGS 84 in degree, minutes, seconds.
- Label of objects (according to categories e.g., 0, 1 ... n)
- Dose (e.g., 100 l/ha)

3.7 Annotated data with context

There are several parties who can enrich image datasets with annotations. This could be experts at the service provider, but also the farmer itself (business opportunity). Besides adding annotations to image datasets, information about the circumstances on the field which could influence the performance of a trained algorithm is needed (feedback and enrich data). To make algorithms more robust, they must be trained on a balanced dataset with a wide variety of circumstances for a specific use case. Service providers could preferably query the FDE-PIAD to select images from datasets best suitable for the operation of the farmer and its field (variety, region). Therefore, the following info should be provided:

- Information about the dataset with images and/or annotations:
  - Title of dataset
  - Abstract/description of dataset
  - URL
  - Version
  - Year
  - Contributors
  - Owner
  - Date created
  - Geometric Extent of dataset (x1,y1,x2,y2 in WGS 84)
- Licenses (see examples COCO annotations[7])
- Images (see COCO annotations)
- Categories (see COCO annotations) e.g.
  - 0 Potato
  - 1 Sugar beet
- Annotations (see COCO annotations)
- **Machine parameters** (See *Machine parameters,* used to translate objects on images to real world locations)
- Weather conditions (connection with weather service, download for extend and date of acquisition)
- From FMIS:
  - FieldID
  - Crop
  - Variety
  - Cultivation Purpose
  - Soil type
  - Growth stage

As the farmer (or contractor) has a role to check the quality of the operation in the field, probably he/she is also the person who can give feedback on the field performance of algorithms and enrich datasets with observations:

[7] https://www.immersivelimit.com/tutorials/create-coco-annotations-from-scratch

- Observations e.g., description of
  - Disease, pest or weather damage on crop
  - Tree leaves in the field
  - Grind stones
  - Drought / wind erosion
  - Etc.

3.8 Inscription server use

The manufacturer (scanning party, acting party) sends information to the FDE-PIAD on what to do with the data streamed from the robot and its data-acquisition system and which priority it has in processing it. During an operation the priority to use GPU-capacity for object recognition is high. But if the device is only scanning, only CPU-capacity and storage is needed. Furthermore data-streams from the data-acquisition system on the robot could be a continuous stream during an operation, but information about the machine, the camera's, etc. could be send once from the machine manufacturer. So, each data-stream in figure 1 has a different timing, frequency and priority of communication and processing.
In a next step of the project, this data-stream could be further detailed and be discussed with end-users (what does the end-user want to control and see?).

4 Basic architecture FDE-PIAD

In order to provide fundamental aspects for future activities and partners in the ecosystem, a proposed architecture is presented in this chapter. In Figure 3 an illustration of a possible reference architecture can be found. The architecture is divided in 3 columns, namely Data Breeding, Application Functionality and Data Harvesting. Each column consists of different relevant elements which is assumed to be required for the ecosystem. These elements could contain a different color representing a business process (dark green), application/data (light green) and technical infrastructure (yellow). Additionally, standards reference models are presented in the red square below called Common Ground.

5 Discussion & Recommendations

5.1 Business processed

- This report describes the outline of a basic architecture for data exchange of image data and algorithms with field robots and the outline of various data-streams and desired metadata. Next steps in 2022 are to model the different data-streams in a class diagram using the definitions from the reference model Agro (from AgroConnect).
- One must keep in mind, that when sharing farmers data, legal regulations on data privacy (GDPR) need to be met; especially where data can be linked to an individual person. Take this into account when designing class models in future work.
- From the class model the different messages can be extracted. Suitable communication protocols for these messages must be further investigated, like ROSII (Robot Operating System) and ISOBUS. Our experience is that ISOBUS controlled implements cannot cope with the amount of commando's derived from object detection systems. However, for supporting the full process of data capturing and data processing probably different standard will be used.
- In future work make clear distinctions in images used for training of deep learning algorithms and the real time usage of images by an algorithm during the execution of weeding. The two different purposes might result in different requirements concerning the image capturing, tagging and the exchange and processing. Furthermore, images captured by the device during the execution of the job, could be used for other purposes, for instance in case the primary job is weed control the images could also be used for disease detection. After the operation the FDE-PIAD could send information about the disease to the farmer.
- The option of running algorithms in the cloud with livestream data exchange, and not on the device on the robot in the field (edge computing) depends strongly on the availability of 5G bandwidth in rural areas. In most rural areas 5G is not available. Therefore, on the short term it should be considered that real time detection is still done on the robot itself and algorithms are updated frequently (pushed from the FDE-PIAD). This also mean that there is probably not a continuous stream of images going to the FDE-PIAD like suggested in appendix 1, but that the edge device will send a dataset after the operation is finished.
- In future work it is advised to include an independent third-party service that validate the quality of the images taken by the devices and that validate the quality of the algorithms that are used. This is not included in the process diagram in appendix 1.
- Furthermore, it is important to be able to measure the quality of the executed jobs. For example, when spot praying, it is important to monitor if the spray was head-on or if the spray partly missed the weed. In the figure of appendix 1 the farmer has the role to check the quality of the system and give feedback in the form of describing his visual observations. However, it's a question if the farmer will pick up this role, so it is preferred to use a separate monitoring system (camera + algorithm). This monitoring system should send a warning to the farmer in case it detects that the quality of executed job is abnormal. The robot system itself should also send a warning about malfunctioning of the equipment.
- The day-to-day practice will be that each robot – device manufactured will provide its own proprietary app for monitoring the device. In 'the old situation' the operator of the tractor of machine did a lot of observations when working in the field (the performance of the machine, the condition of the crop, weather and soil condition, etc.). In the 'new situation' many of these observations need to be done by the robot – device. This also means that the manufacturer of the robots needs information about regulations, weather and soil conditions and take that into account in controlling the robot. For example, if it's raining, the robot should automatically stop its operation. Real time monitoring of weather conditions is important for caring out field operations by robots. For this, different weather condition data sources could be used: cloud weather forecast, in field weather stations, sensors on the robot itself. So, integrate this also when defining further class models.

- Project opendr.eu focuses on interoperability of algorithms. So, focus on future work of this project on the exchange of image datasets.

5.2 Annotated datasets

- Identify, review and make an overview of available resources and repositories (universities, private companies) that offer annotated images.
- Algorithm providers run into challenges to use datasets for training of algorithms acquired by different camera systems (not easy interoperable). This shows that it is important that metadata about the type of camera and data-acquisition and field- and light conditions is included in datasets, so developers can interpret if a dataset is useful or not to train their algorithm.

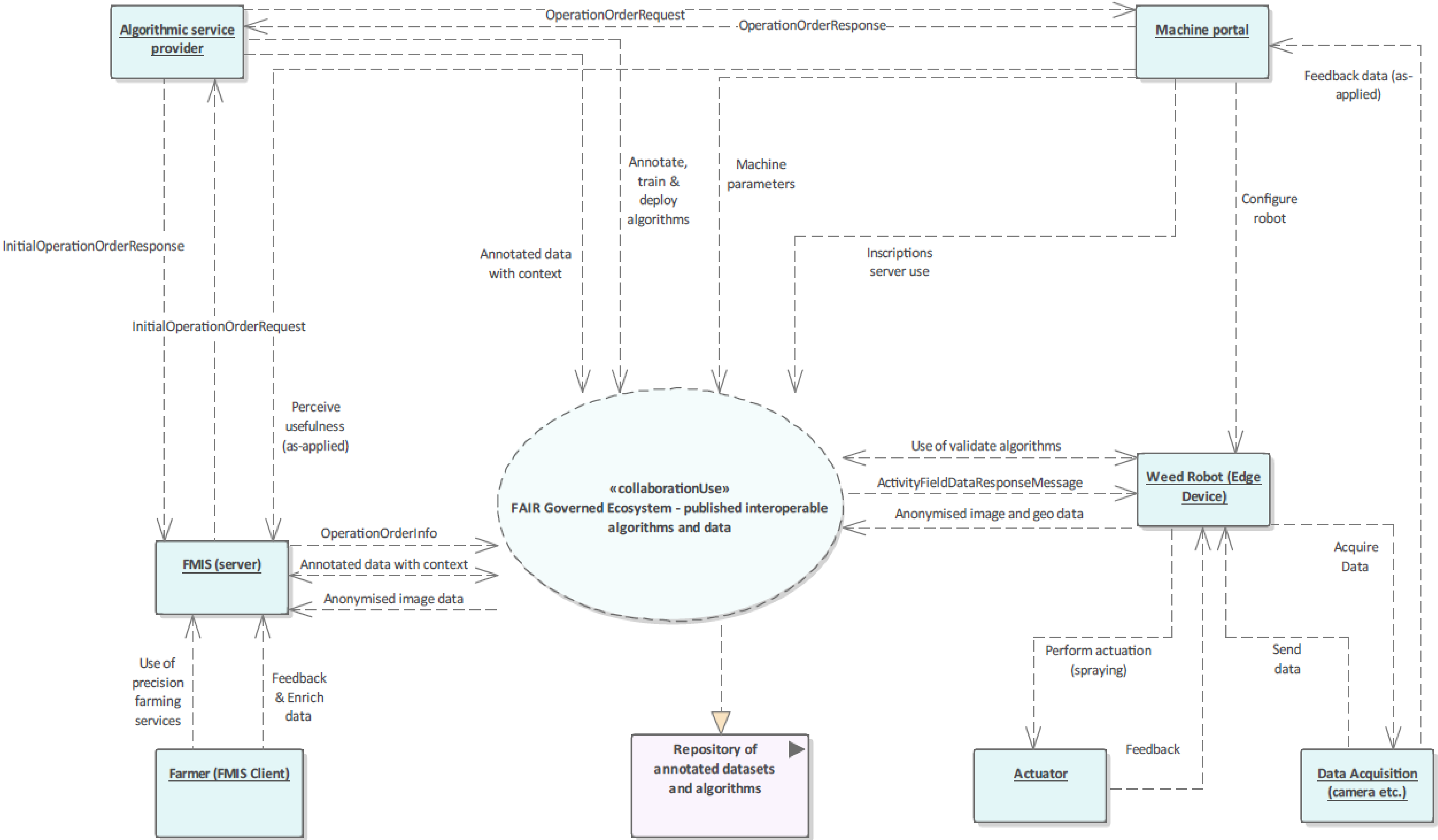
5.3 FDE-PIAD

Future steps for the architecture of FDE-PIAD are considered as following:

- When looking into the information infrastructure, also take existing platforms like DKE-Agrirouter into consideration.
- Link data flows as described earlier in the entity diagram and process model as input and output arrows.
- Gather requirements and wishes from algorithmic developers. A representative community of modelers are potentially available at Wageningen University & Research. Based on the architecture start the dialogue to design a roadmap for the coming years together with interested stakeholders.
- Match and map this architecture with existing and developing architectures, such as the Atlas Service Architecture and FIware enablers.
- Its needs to be investigated in further detail if there should be a difference in image processing between images taken by field robots and images taken by drones (difference in handling static images versus video images.

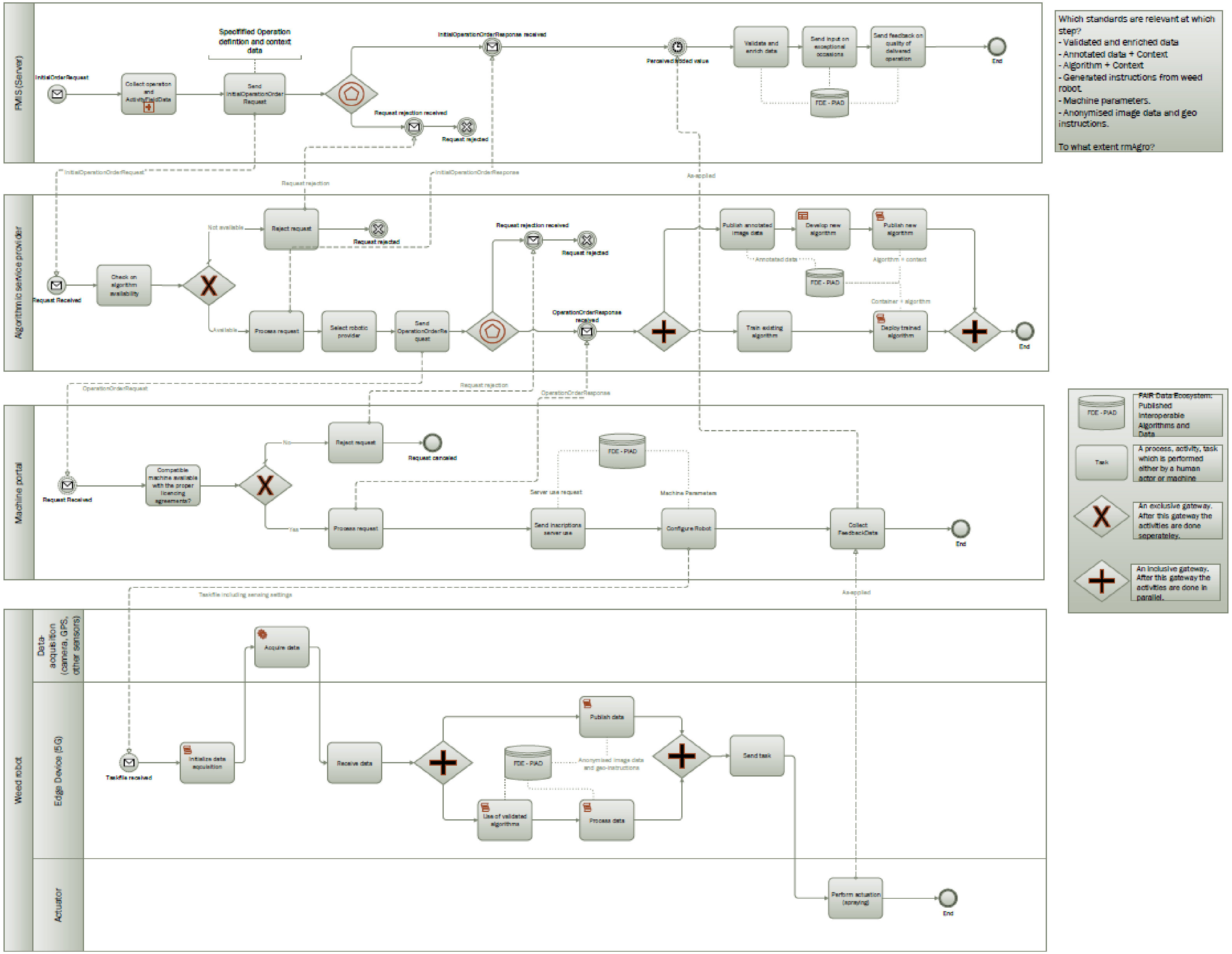
Annex 1 Overview datastreams

A schematic overview of the desired data streams between the FMIS of the farmer, the service of a provider with the recognition algorithm, the machine portal , the machine itself (with the camera and actuator on board) and a FAIR Governed ecosystem.

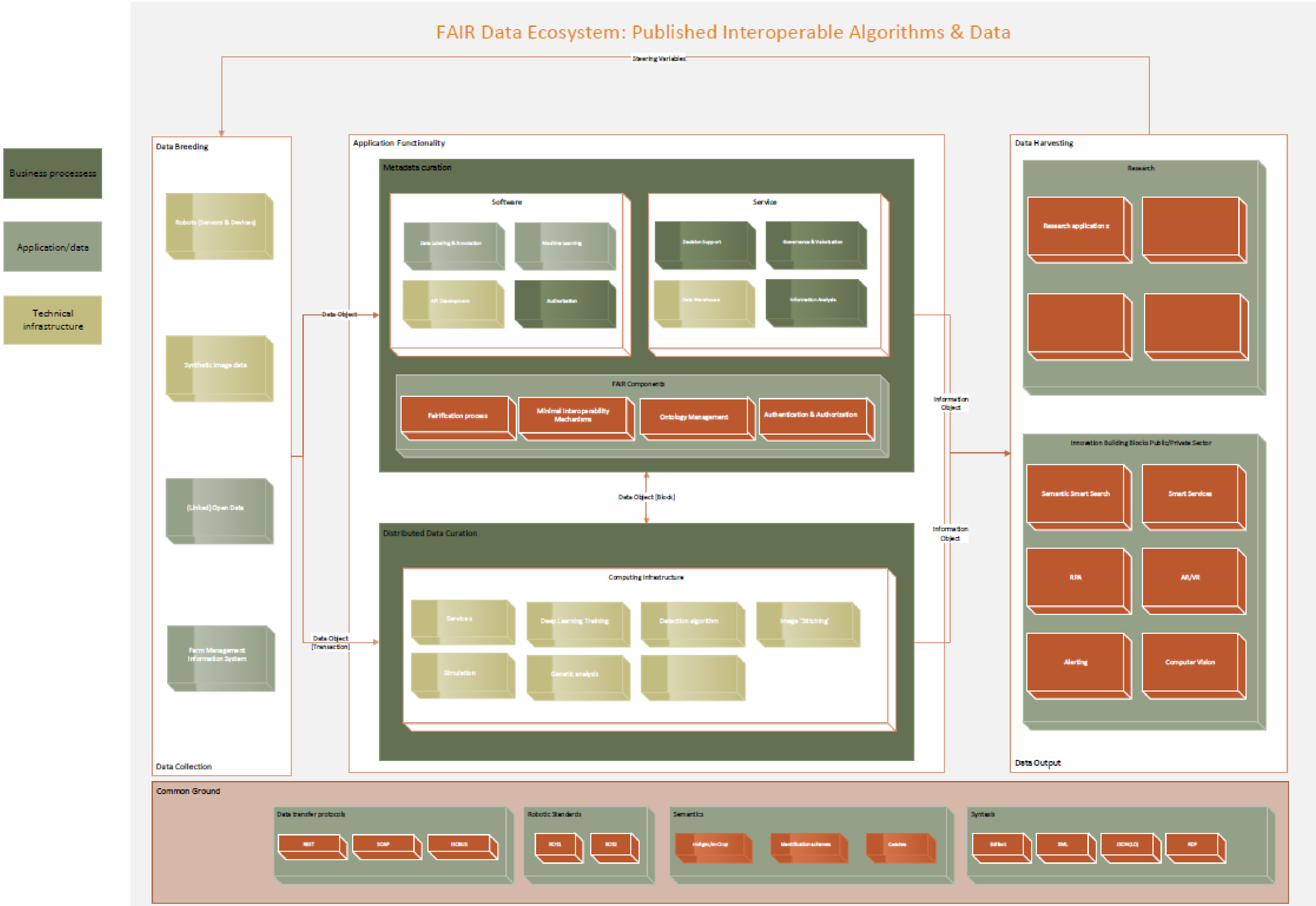


Annex 2 Business Process Model

Process model of the desired situation with activities of the relevant actors concerning the data-exchange of the robots weeding case within a FAIR governed ecosystem.



Annex 3 Reference Architecture FDE-PIAD



To explore the potential of nature to improve the quality of life

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Report WPR-972

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