D12.1 First Annual Management Report
Public part

corosect.eu

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PP	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)	

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CoRoSect Consortium			
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17	FoodScale Hub https://foodscalehub.com/	FSH	RS
18	AgriFood Lithuania DIH https://www.agrifood.lt/	AFL	LT
19	CENTRO INTERNAZIONALE DI ALTISTUDI AGRONOMICI MEDITERRANEI http://www.iamb.it/	CIHEAM	IT

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AI	Artificial Intelligence
AGV	Autonomous Guided Vehicle
AR	Augmented Reality
CA	Consortium Agreement
DMP	Data Management Plan
EU	European Union
IPR	Intellectual Property Rights
ORDP	Open Research Data Pilot
PSC	Project Steering Committee
UC	Use Case
VR	Virtual Reality
WP	Work Package

Executive Summary

This deliverable contains a summary of the activities of the CoRoSect project partners during the first 12 months of the project. The summary has been written for a general audience. The deliverable highlights the CoRoSect progress of the project that aims at making crucial contributions in securing sustainable food production from insects and in building innovative artificial intelligence and cognitive robotic systems.

1. Summary of the context and overall objectives of the project

By 2030 over 9 billion people, along with animals raised for food or kept as companions, will need to be fed. This will generate inconsistencies between the demand and supply of food resources and promote food insecurity by rendering food as unavailable, unaffordable, unevenly distributed or unsafe to eat. Therefore, food security represents the big challenge of the 21st century and in that context, one promising potential sustainable solution is insect farming. Edible insects are set to be approved in the EU by late 2020 as novel food and insects also being a value food sources for farming animals; however research, innovation, farming protocols development and standardization, and a technology leap by robotizing and automatizing the mass rearing in insect farms are needed in order to concurrently scale the production and dramatically decrease the production costs. CoRoSect addresses the dramatic need of coupling research on bionomics and life cycle of insects intended to be used as food and feed, with new robotic tools and protocols for mechanization and automation of insect farming, which is a critical point stressed by the Technical Expert Consultation on Assessing the Potential of Insects as Food and Feed in Assuring Food Security. CoRoSect forms a novel integrated cognitive robotic ecosystem where the repetitive but also cognitively and physically demanding tasks requiring increased manual effort or continuous human supervision during the insects' lifecycle, are replaced by automatic robotic-based procedures which will also draw upon research performed on understanding biological, technical and economic requirements of insect rearing and optimizing all involved processes. Focusing on real insect rearing problems, CoRoSect technologies will be evaluated through large-scale pilots in 5 insect farms placed in 5 European countries rearing three of the most commonly occurring species, thereby contributing essentially to a secure and sustainable food supply in Europe.

2. Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

This section describes the objectives of the CoRoSect and summarises the progress of the work during the first project year.

2.1. Ethical, legal and social implications of human-robot collaboration in industrial automation

2.1.1. Objectives

WP1, led by KU Leuven, aims to address the most important legal and socio-ethical challenges raised by human-robot collaboration in industrial automation, in general, and the CoRoSect rearing platform, in specific. In this work package, KU Leuven supports the creation of a robust, safe and legal compliant environment for human-robot interactions. KU Leuven recommendations for a trustworthy AI must be followed from the development phase of AI technologies until their use (See Figure 1).

In summary, the objectives of WP1 can be summarized as:

1. Identifying the most pressing legal and socio-ethical challenges present in the CoRoSect platform;
2. Recommending measures or safeguards to mitigate the identified challenges in the development and testing of the CoRoSect platform;
3. Assessing whether CoRoSect's rearing platform complies with the ethical, safety and legal requirements;
4. Determining gaps in the current legal and ethical landscape and providing policy recommendations.

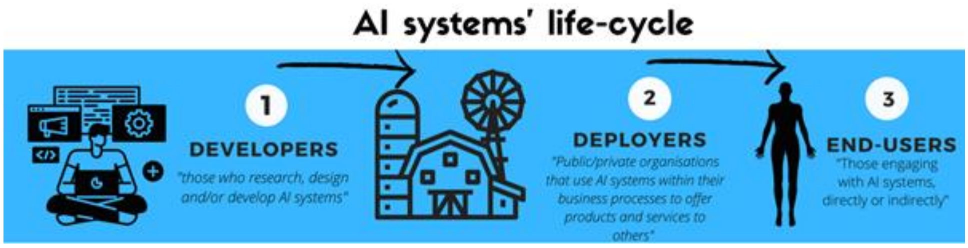


Figure 1. AI systems' life-cycle

2.1.2. Progress being made

In the first six months of the project, KU Leuven has accomplished its first achievement for WP1: it has released the **D1.1 Ethical and Legal Framework: Initial Assessment Report**. This report provides a high-level description of the legal and ethical framework that may be applicable to the development and use of CoRoSect's platform. It presents the relevant sources in a wide range of areas, including the developments regarding the governance of artificial intelligence in Europe, data protection and privacy, safety, liability, and ethics. D1.1 is publicly available. In the preparation of this report, KUL worked with CERTH to create a questionnaire that was answered by some partners. This questionnaire helped KU Leuven to have some perspective of the use of data by the consortium and served as a basis for the preparation of the D1.1.

Significant progress has been made to deliver the WP1's second report **D1.2. Ethical and Legal Requirements Specification Report** before the end of 2021. Based on the input received from the consortium during the project meetings and project documents including partner's deliverables and presentations, this second report specifies the ethical and legal challenges posed in the context of the CoRoSect's automated rearing platforms. The report recommends technical and organisational measures to mitigate these challenges. A brief overview of these measures can be seen in Figure 2. In this context, KU Leuven provided further guidance to the partners during the project meetings, one of which included a presentation dedicated to data protection issues.

In addition, KU Leuven contributed to the dissemination of the outcomes of the WP1 research by publishing a blog article on the website of the KU Leuven Centre for Information Technology and Intellectual Property Law (CiTiP)[1], and by providing input to the CoRoSect newsletter.

Table 1. An overview of the technical and non-technical measures

Technical Measures		Non-Technical Measures	

[1] Burcu Yaşar, Trustworthy AI for Insect Farming, KU Leuven Centre for Information Technology and Intellectual Property Law (CiTiP Blog), 21 September 2021, https://www.law.kuleuven.be/citip/blog/trustworthy-ai-for-insect-farming/ (accessed on 15 December 2021)

Architectures for Trustworthy AI	Limiting the AI actions with an ethically desirable behaviour and rules	**Codes of Conduct**	Internal practical guidelines in accessible language for developing trustworthy AI
Ethics and Rule of Law by Design	Implementing ethical, safety and legal rules (e.g data protection) in the design stage	**Standardisation and Certification**	Adherence to internationally recognized standards and certification relevant to trustworthy AI
Explanation Methods	Explaining the AI-based decisions and assessing that end-users are aware of decisions taken	**Governance Framework**	Implementing a governance framework for internal oversight, advice and documentation
Testing and validation methods	Monitored during training and deployment periods	**Diversity and Inclusive Design Teams**	Creating a diverse design team in terms of skills, profession, gender and cultural background.
Quality of Service indicators	Establishing reliable indicators to assess the performance	**Data protection measures**	Implementing organizational and technical measures (e.g encryption); carrying out a Data Protection Impact Assessment (DPIA)

2.2. Use-cases, user requirements and system architectures

2.2.1. Objectives

The overall aim of WP2 is to collect and to carefully analyse the user requirements of insect farms for the project, and based on them create the technical architecture, as well as the technical and functional specifications of the CoRoSect system. The following specific objectives are pursued: (i) Identify user-specific requirements from all contributing partners. (ii) Collect use-cases from all insect-rearing partners based on user requirements and use-cases create functional specifications for the CoRoSect system. (iii) Create the technical specifications for the system. (iv) Produce the technical architecture of the system.

2.2.2. Progress being made

2.2.2.1. Identification of use-cases and user requirements

The CoRoSect partners intensively worked together to identify the requirements for next generation insect farming. The CoRoSect partners identified use cases that best demonstrate the innovation driven by CoRoSect regarding the processes inside the next generation insect farm. These use cases in return will form the basis for the pilot studies planned in the second and third project year.

To identify use cases and user requirement in the complex scenario of insect farming, a myriad of formats were implemented to ensure that all stakeholders achieve proper grasp of the tasks and challenges.

20 study sessions on the End Users perspectives were executed, during which the CoRoSect tech-providers learned about the insect rearing processes in the insect farms that support CoRoSect. Based on these sessions, insect farms and tech-providers defined innovative technologies and processes.

4 Reverse pitch sessions were organised to validate the constructed use cases and user requirements.

Over 3 months of guided multicriteria decision analysis was performed to assess with primary data and real-life checks the business value and technical feasibility of every task defined. The process included couple validation loops with the end users to improve the cases in th earliest design phase possible.

Another 3 months of narrowing down the tasks were spent to facilitate the Pilots definition process (Task 10.1). During this process fast paced interations between the partners were performed, including through one-on-one sessions between tech-providers and insect farmers, collective topical sessions, requesting trials, tests and small scale analysis form the end users, sample analysis and extensive task prioritisation.

Weekly working sessions were executed, following the overall agile phylosophy of CoRoSect.

The process of defining the use cases and user requirements went through four main stages to ultimately reach sets of analysed, prioritised and contextually connected set of tasks to represent the best value of CoRoSect technologies application.

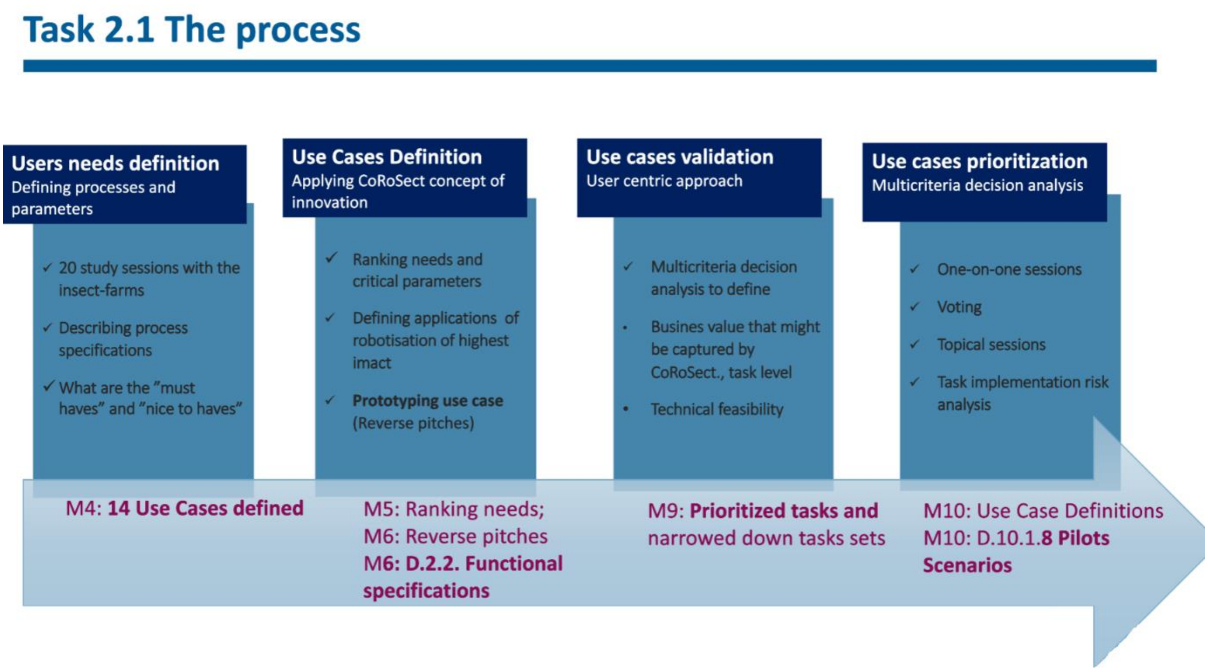


Figure 2. Process for defining CoRoSect use cases

Outcomes

Based on the concrete needs of the end users and the potential for innovation 14 Use Cases were developed that integrate multiple CoRoSect technologies. 8 Use cases were selected for piloting after thorough multi-instrumental analysis of all proposed use cases.

5 types of Use Cases were defined that represent the value which the CoRoSect concept delivers to the insect farms and meet the objectives of the project, these are as follows:

- Quality Management and Intervention
- Oviposition Management
- Larvae/Cricket Management
- Pupation Management

- Harvesting, Waste Management

2.2.2.2. Specifying the functionalities of the CoRoSect system

To support the precise definition of the functionalities of the CoRoSect system and technologies, information of insect rearing of the insects *Tenebrio molitor*, *Hermetia illucens* and *Acheta domesticus* was collected and reported in a separate deliverable D2.2.

The information generated in the task, complemented with specific information and requirements from final users in the project, set the starting point to define system arquitecture for CoRoSect system implementation in pilots definition in Task 2.3.

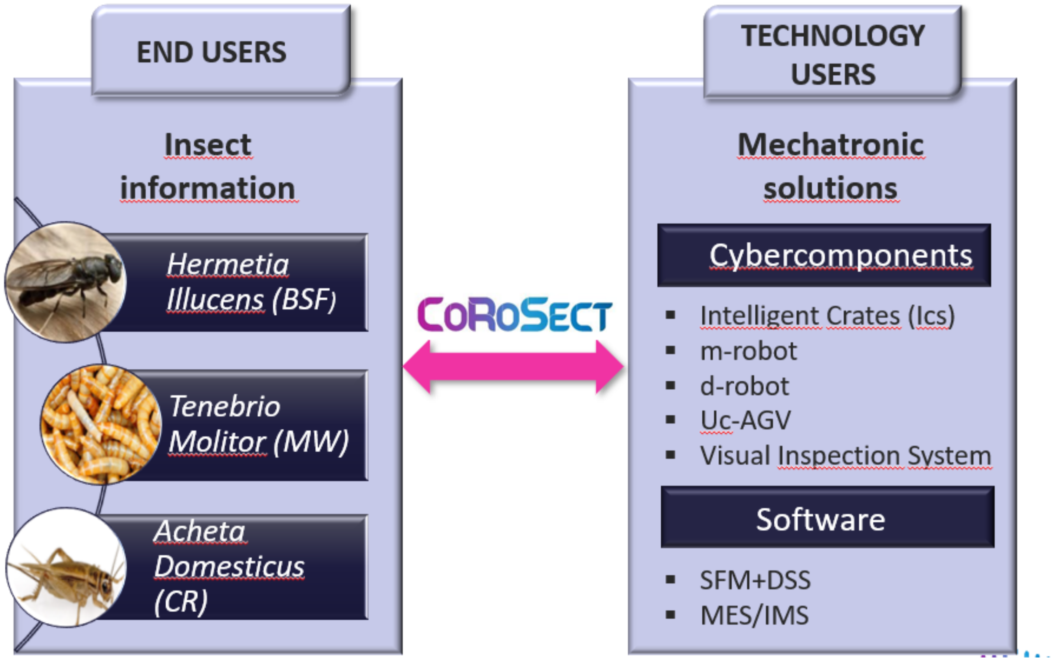


Figure 3. Insects and technologies in CoRoSect.

Deliverable 2.2 describes the technical characteristics and boundaries for mechatronic solutions in the CoRoSect project. Information is presented for each specie in the following structure:

- Life cycle and physiology
- Production requirements
- Farming operations, including Key Performance Indicators for the different production areas

Furthermore, information on technical requirements and technology implementation for the CoRosect Area including Software management and the different cybercomponents that will interact with human operators in the Corosect system has been described, considering the partners who are in charge of these technologies.

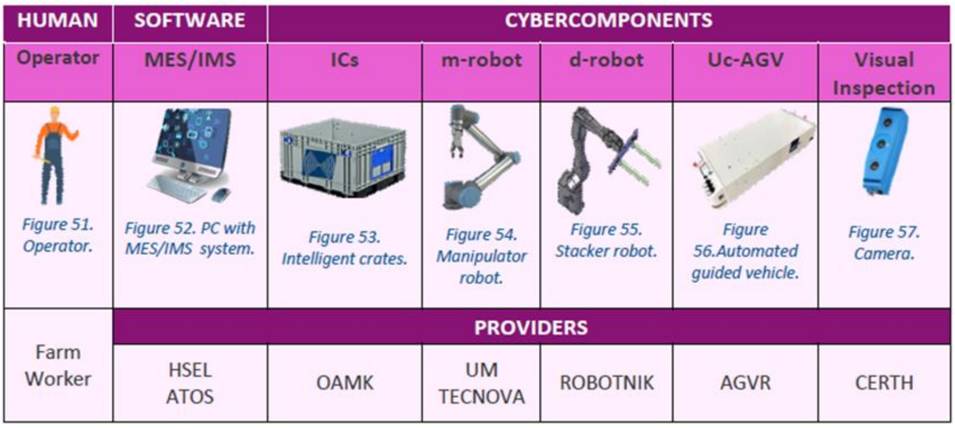


Figure 4. Components of the CoRoSect system

2.2.2.3. Definition of the CoRoSect system architecture

On this first stage, based on CoRoSect's initial objectives and functional requirements extracted from the use cases (specific insect rearing tasks) and scenarios (end-users' farms) a first CoRoSect Reference architecture (CoRoSect RA) has been described. This architecture identifies and interlinks the CoRoSect components and defines the tiers and functionalities that guide the integration of the final CoRoSect System. The following components have been defined:

- The logical implementation of the CoRoSect system (on its first version). This logical view depicts the communications and relationships between components inside a layer and between the OT/IT layers. These schemas will support the integration of the whole system to be carried out during.
- The CoRoSect process view, which provides the base schema to define the different orchestrations between components to perform all processes that compose the final use cases set.
- The CoRoSect development view, providing a first approach to implement the connections and dataflows between CoRoSect components.

These different views of the CoRoSect System Architecture have been done considering RAMI4.0 guidelines to define a novel architecture fully Industry 4.0 compliant. All these building blocks are detailed and referenced in deliverable D2.3.

2.3. Biological, technical and economic aspects and parameters to insect rearing

2.3.1. Objectives

The overall objective of work package 3 is to gain understanding on biological, technical and economic requirements of insect rearing processes and improve them through management, sensoring and automation: (i) To identify and describe factors which are critical for a successful and sustainable insect rearing process (ii) To identify, test and facilitate the use of printed sensors in monitoring insect rearing processes (iii) To develop sustainable insect diets for mealworm, crickets and black soldier fly (iv) To present a model-driven support system for optimizing insect rearing

2.3.2. Progress being made

During the first year of the project, work package 3 has synthesised scientific knowledge concerning the rearing of black soldier fly, mealworm and house cricket. The purpose of this work has been to characterise environmental constraints and biologically and economically optimal conditions for rearing these three insect species. This work has been complementary to the use case requirements specified in work package 2 and will provide input on necessary requirements for technology adoption in insect rearing processes, for application of sensors in the production process and robotization and automated control of the process. This has included identifying environmental constraints and biologically and economically optimal conditions for rearing the three insect species, indicator variables (such as temperature, ammonia) for monitoring the process and their typical variation and economic and technical challenges related to the rearing process.

The outcome is a set of parameters to be monitored and controlled when developing a decision support model that helps to control the rearing process, and digitising insect farming. For example, indicator variables that would need to be monitored by using sensors and their typical range of variation has been described. The importance of parameters varies from species to species. For example, the duration of mealworm's life cycle is heavily dependent on the rearing temperature. Small changes from the optimal conditions can slow down the larva development and moderate temperature stresses can cause uneven quality. Protein content and fat composition of mealworm by contrast are rather constant and not sensitive to diet.

During 2022, work package 3 will carry out experiments to collect data and to test different feed options for the above-mentioned insect species. Work package 3 has been designing the experiments. The aim is to develop standardized diets for insects by using side streams from agriculture and food industry, such as wheat bran, tomatoes or brewer's yeast or spent grain. Sensors will also be tested during the experiments. During 2021, the applicability of some of the sensor measurements have already been piloted at Luke's insect lab.

2.4. Farm-level modelling and orchestration

The overall aim of work package 4 is to define the system operational methodology, through advanced collaborative factory floor modelling and real-time orchestration, enabling human-robot collaboration through novel dynamic cells concept. Specific objectives of this work package are:

1. To define Farm-level process modelling: Definition of the dynamic cells to be set depending on the functionalities and resources (people, machines, sensors, materials) to perform tasks for the different stages of the biological cycle in the insect factory.
2. To integrate Shop floor management and decision support system for optimized resources management in cells operation
3. To implement a lightweight MES that integrates data from the sensors, the activity of the cells and DSS, as well as human workers' information to drive optimal decisions for farm layout configuration.

2.4.1. Progress being made

2.4.1.1. Adaptative farm process modelling

During this task, the work performed has been focused in defining a process model to foster adaptability through the farm´s floor with the definition of the concept of Dynamic-cell (d-cell). The concept of ***d-cells*** is presented as flexible modules comprising of various agents, such as robots, cameras, sensors, and humans to better manage the available farms' resources. The grouped resources, centrally or locally managed, can act as the building block of automation.

2.4.1.2. Shop floor management and decision support system

In this task, the project is developing the functional description and software for orchestrating and coordinating the robots, sensors, and material in the insect farm and for executing the tasks within the defined use cases of CoRoSect system. A decision support system software is being developed that contains the necessary information and logic for rearing insects. Such a system e.g. knows the optimal environmental conditions for insect rearing. A shop floor management software is being developed that communicates with all robots and sensors in the insect farm. The short floor management software distributes jobs to robots than then autonomously perform the assigned tasks and report back when they are done.

2.4.1.3. Service-Oriented Information Management System

In an insect farm, large amounts of data are being produced and have to be processed for high-quality insect rearing and for the safe operation and coordination of sophisticated robot and artificial intelligence systems. CoRoSect develops an Information Management System (IMS) that performs all CoRoSect data management functionalities. Such a system communicates with all robots, sensors, and other software. It receives and stores data in such a way that a human operator can get a full overview of all running and past processes in the insect farm.

2.5. AI-enabled perception methods

2.5.1. Objectives

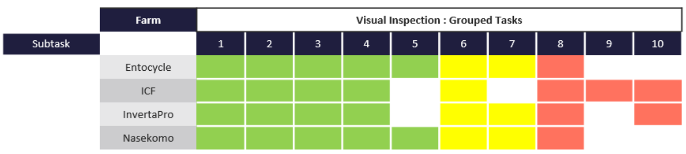
To train workers to use the advanced CoRoSect technologies we are preparing virtual environments that allow for efficient and safe training. To enable robots and insect farms operating autonomously they must be able to see and understand what is happening inside the insect farm. Thus, CoRoSect aims (i) To equip robots in the insect farms and the insect farms with advanced perception based on artificial intelligence that will boost the robots' and insect farms' level of autonomy and efficiency. (ii) To support robot vision tasks related to the perceiving of the surrounding environment. (iii) To investigate physics-based haptic simulation to enable a realistic and intuitive interaction in VR applications. (iv) To develop novel "sensorimotor" approaches for human-like object learning.

2.5.2. Progress being made

2.5.2.1. Environment analysis and registration

By identifying user requirements, we found a variety of tasks that require an automated analysis of insects and their environment during the rearing process. For quality management e.g. the count, the average size, the health, the fertility rate, the movement and the colour of insects are important. From a technical perspective, all these tasks are mostly related to the researching fields of automated object detection and object segmentation. CoRoSect aims at performing these tasks by training artificial intelligence.

	Priority	Subtask	Description	Research Addressing → Our initial perception
1	high	Count	Count/distribution of insects within crate	Detection/Localization
2		Size	Average size of the insects within crate	Detection/Semantic Segmentation + depth
3		Health	Detect non compliant batches	Anomaly detection
4		Monitor	Monitoring images of the surface of the crate	Detection of crate and substrate
5		Fertility	Hatched to non hatched eggs ratio	Multi-class detection
6	medium	Movement	Movement ratio	Multiple Object Tracking/ BG subtraction
7		Color	Color of the insects	Detection based
8	low	Growth	Estimation of growth rate	Detection/Semantic Segmentation*
9		Water	Level of water	Multi-class Detection**
10		Feed	Level of feed	Detection***



* same as growth
** depended on the camera movement flexibility
*** depth accuracy depended

Figure 5. Analysis of the end-users' requirements, grouping of tasks, and research addressing

For the training process data sets containing thousands of images of insects are being obtained. High-resolution videos were requested from our CoRoSect insect farm partners, illustrating insects in crates using various camera positions. Some of the most significant content-based properties observed rely on the fact that insects are extremely small, they may be found sparse or occluded, immobile or rapidly moving, changing colour and shape while growing. As for annotating the underdeveloped datasets, both automatic and manual methods are used. Premier annotations are extracted automatically using static colour filters for subtracting background. Then hand-crafted human-annotations are manually applied. However, since the insects are tiny, sometimes concealed or misleadingly confused with empty exoskeletons, human-annotating errors and time-consumption risks were also introduced. Therefore, optimization of annotating the large-scale dataset that will be used to utilise the final models, is currently under research, while adopting techniques for unsupervised, semi-supervised, and self-supervised learning is also considered.

Having created an adequate volume of annotated frames using the data received via the capturing framework, experiments on AI models were performed. Among them, the most promising systems for solving the detection task is Tinaface[2], a system that aims to predict detection of tiny faces in highly occluded and crowded scenes whereas for solving the distribution task, SDCNet[3] [2]. Current research on developing a novel approach involves the exploitation of spatial, colour, and movement visual properties to segment objects of interest, whereas finetuning and testing on the corresponding implementations is additionally performed so as to allow adaptation in case that the development of a novel system fail to reach the aims of achieving the optative accuracy.

2.5.2.2. Human motion analysis and prediction

For a safe collaboration of humans and robots it is important that the movement of humans can be detected and predicted. This e.g. allows predicting if a human will step in front of an autonomous vehicle or will place a hand in the path of a robot arm. In CoRoSect we are planning to implement for the detection of people a combination of:

- Fixed cameras: should be placed in high places in order to cover the entire room avoiding any blind areas.
- Software analyzing in near real time the footage of these cameras to detect people and their movement and will make the prediction of movement.

The software solutions we plan to use needs primarily to detect and follow people and to estimate their distance to the camera. With this relative distance, and knowing the movement, we can then predict the direction of the movement.

This can be further divided into:

Detection of people, tracking and the determination of their position relative to the camera: We will detect people in the camera, then, we will follow these people "keeping" their identities.

Detection of the position of people: We plan to use algorithms for the detection of the position of people in the space, that is, their distance relative to the camera.

Prediction of trajectory: Additionally, we will need to "project" (or predict) the movement of people detected in order to predict their trajectory. This is needed since we need to avoid potential collisions of people and robots avoiding people to get close to the robots (this could be dangerous for people and will force to stop the machines).

[2] TinaFace: Strong but Simple Baseline for Face Detection, https://arxiv.org/abs/2011.13183v3
[3] From Open Set to Closed Set: Counting Objects by Spatial Divide-and-Conquer, https://arxiv.org/pdf/1908.06473v1.pdf

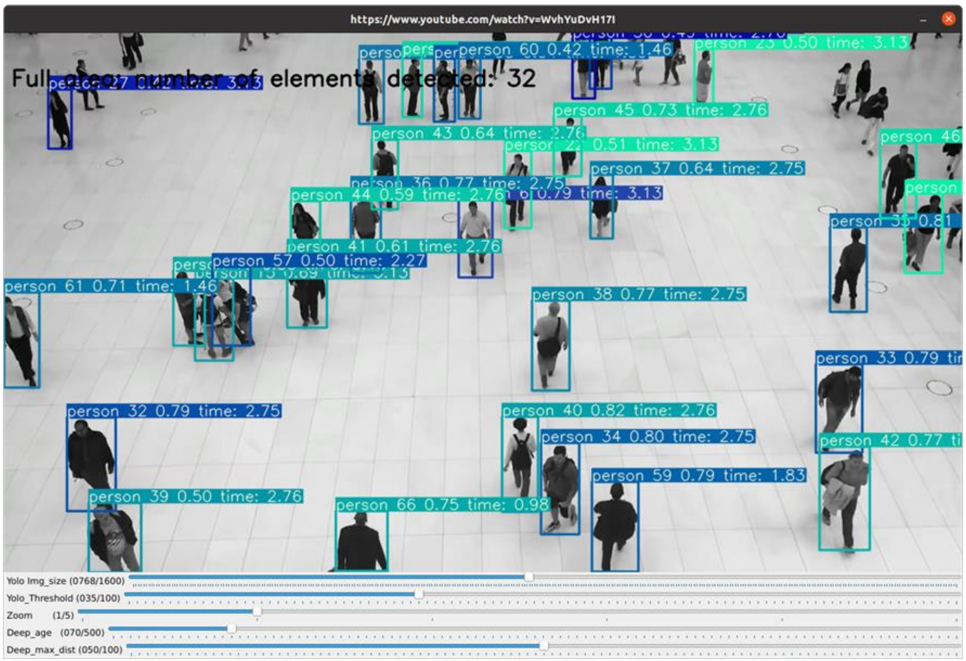


Figure 6. Detection and tracking of people

Figure 7. Distance of people to the camera

2.5.2.3. *Integrating physics-based force feedback interactions in VR applications*

With the advancement of technology in virtual reality, haptic feedback is an important method to be implemented. Within this task, the existing literature has been researched, and relevant techniques have been identified, along with technologies for force estimation, haptic feedback and grasping. To implement our techniques, we had to decide on the device we would use as a medium that satisfies the requirements. After extensive research, the device we chose is the SenseGloves, which is a wearable device that enables the aforementioned functions. The future step is to build a construction dataset that includes a multitude of data the SenseGlove can provide.

2.6. Robotic actions planning and control

2.6.1. Objectives

CoRoSect develops software to safely control robotic arms that autonomously handle insects and material required for insect rearing as well as autonomous guided vehicles capable of autonomously navigating and transporting stacks of crates filled with insects. For the robotic arm, the aim is to develop and provide safe handling of crates and insects. For the AGV, the objective is to provide a navigation control system for the operation in the farm. Finally, for the safety of people and moving robots, the objective is to detect potential obstacles in the path of people and robots, thus avoiding collisions.

2.6.2. Progress being made

In this period, the work has been centred around planning, experimentation and making first prototypes of the technologies and solutions that we need to develop/evolve.

2.6.2.1. Versatile force-adaptive control for handling crates and insects

Handling small moving insects and heavy loads in a dynamic insect farm requires excellent robotic manipulation skills. Especially for insects that move around and that have to be handled gently, robotic control software is required that used force feedback and information from automated image analysis. During the first year, the CoRoSect partners explored and developed multiple control approaches. Some are based on classical control frameworks. Others use machine learning and optimization so that robots can autonomously learn to move and to handle objects. Especially control techniques based on autonomous learning and optimization are interesting for insect farms as they allow robots to autonomously adapt to new situations.

2.6.2.2. Localization, environmental mapping and navigation of AGVs

CoRoSect develops an Autonomous Guided Vehicle (AGV) for transporting crates between factory locations. This AGV has a dedicated safety system that meets the highest level of person protection. The AGV can receive destination waypoints for executing movements and can receive actions to perform pick-up and drop-down operations. The CoRoSect partners AGVR develops software that allows the AGV to navigate autonomously inside the factory. For this the AGV must be able to determine its own location inside the factory, to build a map of its environment and to find optimal pathways to a destination.

The first 6 months of the project were used to carefully analyze and determine the requirements of the AGV when operating inside insect farms.

During the second 6 months, multiple research tracks were started.

- Simultaneous Localization and Mapping (SLAM)

Experiments are done with AGV and SLAM software in a simulated production environment. This resulted in a good overview how to integrate the SLAM software in the whole control concept.

- System integration and communication protocols

The communication protocols of desired system architecture are evaluated. The best suitable protocol is selected. This protocol matches a new standardized AGV interface description, which is used by multiple AGV suppliers. The standardized AGV interface description is evaluated for integration in AGV and higher-level systems. The result is positive, it matches current AGV standards, is very flexible, is future proof and accepted by in the AGV world.

- Overall AGV control concept in combination with higher-level system

The overall concept of mapping, localization, and navigation is a combination of AGV control system and higher-level control systems. In this phase, the functionalities of the higher-level system are not clear yet. Therefore, the AGV control system should be adjustable to multiple concepts of mapping, localization and navigation. The approach is written in deliverable D6.5: “Localization, mapping and navigation of AGVs (approach)”

2.6.2.3. Implementing safety control in robotic planning

We are addressing this task as part of the more general task of detection of moving and static “obstacles and people” in the factory space in order to avoid potential collisions.

In the period M1-M12 we have been planning and experimenting. We focus on the detection of “moving” or static obstacles present in the factory aisles. The moving obstacles can be other robots and the static obstacles can be any element blocking the pass (a crate or a fallen box for example).

The solution we are planning to implement for the detection of static or moving obstacles is to use a combination of:

- Fixed cameras: these cameras should be placed in high places in order to cover the entire room without any blind area.
- Software analyzing in near real time the footage of these cameras to detect objects in motion, the prediction of their movement and static obstacles.

The software solutions we plan to use needs i) to detect and track moving robots (AGVs) and to estimate the distance to the camera, with this distance, and knowing the movement, we can then predict the trajectory of the movement and determine the future position of these possible obstacles and ii) to detect static objects. In the case of static obstacles is a matter of determining the position relative to the camera. Additionally, in the case of moving objects, we will need to “project” (or predict) the movement of the objects detected in order to predict their trajectory. This is needed since we need to avoid potential collisions of people and robots avoiding people to get close to the robots (this could be dangerous for the people and will force to stop the machines).

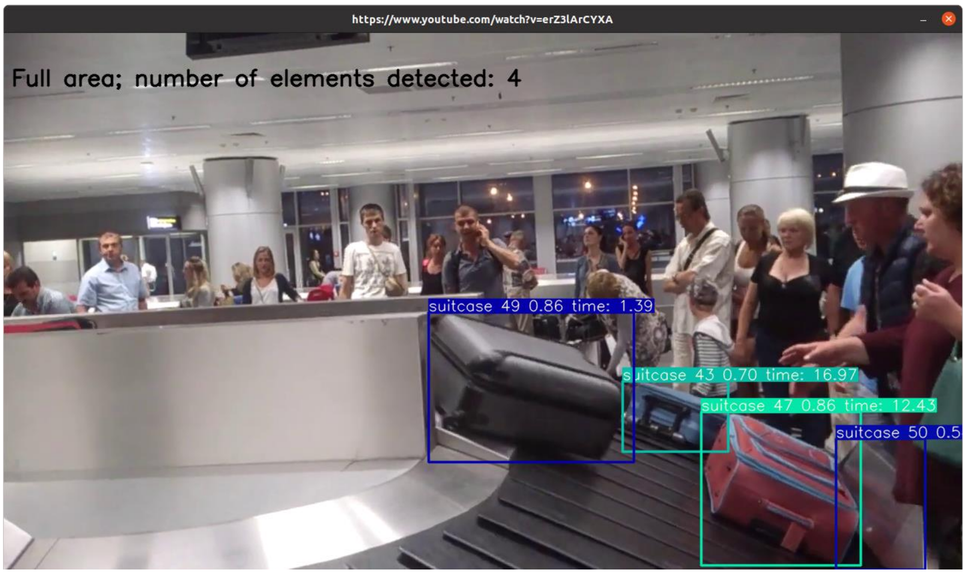


Figure 8. Detection and tracking of objects (in this example suitcases)

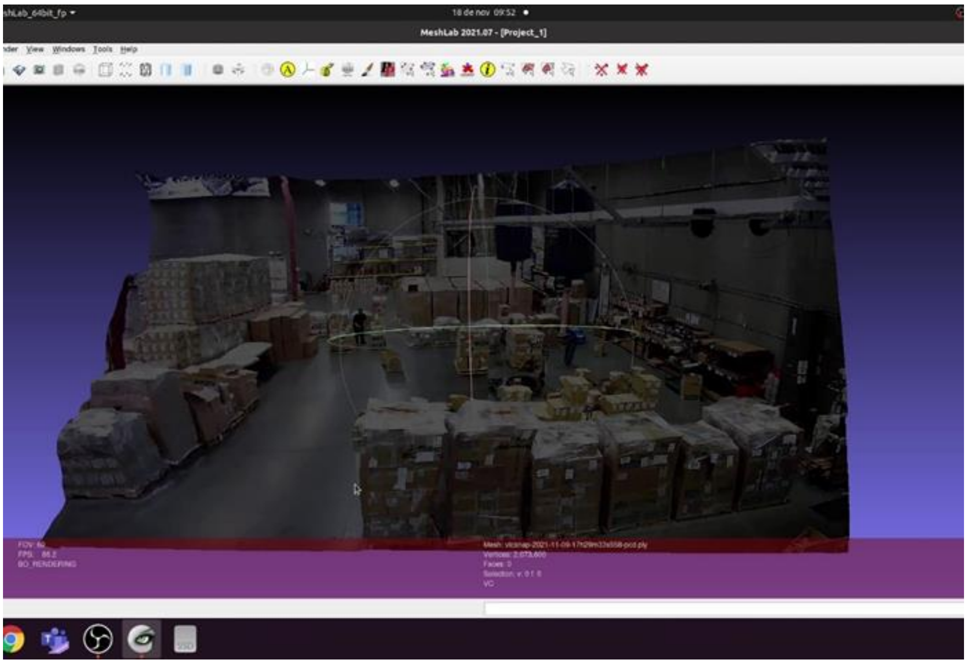


Figure 9 – Using AI and a camera to obtain a 3D map with objects in the factory

2.7. Cognitive robots and smart mechatronics

2.7.1. Objectives

The aim of CoRoSect is to design, manufacture, and test cognitive robotic systems and smart mechatronics for automated insect rearing. In detail in this work package, CoRoSect partners develop novel sensors and electronics to be integrated into the crates used for insect rearing. These sensors continuously monitor the insect rearing process and play a crucial role in quality management: If sensor measurements are out of the expected range, the CoRoSect system can intervene to ensure the well-being and proper growth of the insects. In addition to smart sensors, CoRoSect partners develop an autonomous guided vehicle (AGV) and two robot cells. These robotic systems cooperate closely. The AGV autonomously carries stacks of crates with insects within the insect farms. The AGV e.g. carries stacks of crates between storage locations where insects grow and CoRoSect robot cells that handle the crates. The robot cell for handling crates (D-Cell) stacks crates with insects for efficient transportation by the AGV and storage. The D-Cell also unstacks crates so that they can be handled by the M-Cell. The M-Cell fulfils the required tasks for supporting the well-being and growth of insects. Such tasks e.g. involve preparing crates (after they have been de-stacked) for insect rearing, providing feed for insects, moving insects between crates, and guiding a smart camera for quality inspections.

2.7.2. Progress being made

2.7.2.1. Printed sensors to monitor insect environment, intelligent crates

CoRoSect designs, manufactures and tests the sensors that can be integrated into insect growing crates to measure the critical variables which must be monitored to ensure a successful and efficient production process.

Based on the requirements the sensors are designed so that the performance, form factor, size, cost and environmental points of view and requirements are met. The result of this task will be sensor solutions (standalone and integrated to form so called “intelligent crates”) which support and improve the automated insect rearing process.

During the first project year, the work has been focusing on finding the available sensor solutions based on the use cases and user requirements collected. Based on the requirement specification, there were 6 critical variables that should be monitored. This means that overall 6 more or less different sensor types should be integrated into crates. In some cases there might not be need to integrate all 6 sensor types into the same crate and there might also be cost considerations that will guide the selection of sensors. Cost issues can also limit the number of intelligent crates, but in any case, the 100 % crate coverage might not be possible nor needed in large volume farming.

Work in this task started with the creation of the crate integrated intelligent sensors (IIS) implementation draft, which was then discussed and commented within consortium partners. Based on the discussion results, the decision of the IIS implementation method was done. Wireless communication methods were sourced and a comparison of methods was done to find the possible solutions to be used in this project. These methods were then discussed among the consortium partners. During the project, different options will be tested to find out the most suitable solution in this case. Wireless communication protocol to connect to MES system was agreed and protocol was tested using suitable gateway and server and was found functional and will be used in this project.

The first method for short range wireless communication – Bluetooth Low energy - for communication between integrated sensors and gateway has been tested and found functional. Test were conducted using Bluetooth development platforms and suitable gateway in laboratory as well as real insect growing environment.

At the end of this period, the first prototype of integrated intelligent sensor was created to test the functionality of the planned structure and way of implementing it. Temperature sensor with wireless connectivity structure was created. The same integrated platform can be used also with other sensor types.

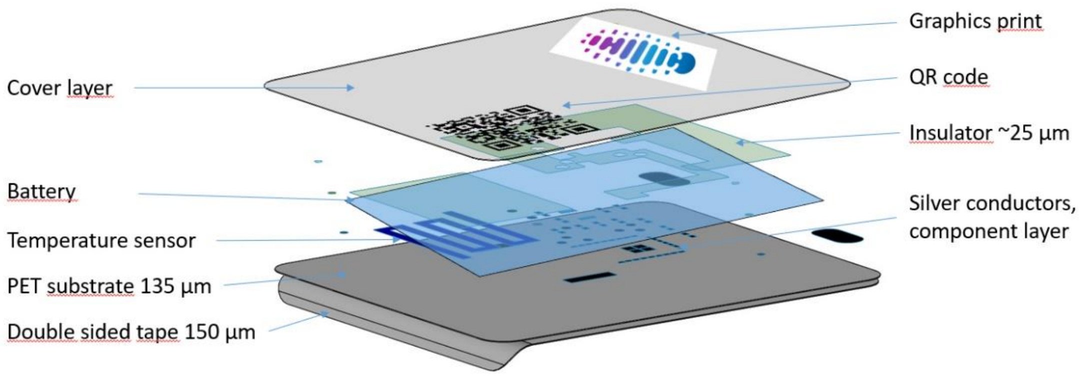


Figure 10. Stackup of the sensor prototype

2.7.2.2. Task 7.2 Robot cell for handling crates

Robotnik designs, engineers and builds a robot cell for handling crates; with integrated robot arm (6-axis industrial design), high-resolution vision scanner (to identify location and orientation of crates) and a tool for picking crates.

The robot cell is equipped with a dedicated control system (PLC) and user-friendly HMI. Communication with other equipment in adjacent work packages can be achieved through e.g. Profinet or Ethernet modules. The main task of this robot cell will be to separate stacks of crates by picking them individually from the AGV and placing them on a conveyor system, in that way handing them over for manipulating the content of the crates to the robot cell for handling insects. After insect handling, the crates are received again by the robot cell - on the same conveyor system - and stacked on an AGV for transportation out of the cell e.g. to storage locations.

Work during the first project year has focussed on transforming the use cases and requirements collected in work package 2 into a specification for the robotic cell for handling crates.

The robotic cell must handle four different types of crates, grouped in two categories. First, three small types of crates with a size of 60x40 cm and weight up to 15Kg. The small crates may be handled in pairs to speed up the cycle time of picking and placing, with the possibility of flipping them to empty the inner part. Small crates will be placed in euro-pallets transported by the AGV, and will be arranged in several rows, each one containing four crates. Second, a big single type of crate with a size of 120x80 cm and weight up to 50Kg. Big crates will be handled individually and will not be flipped, and will be transported in sets of two, one per row.

Two options for the robotic arm were initially considered. First was to use a collaborative robotic arm from UR, which benefits from reduced weight and installation costs and it can operate close to humans without requiring safety fences. However, the payload this type of robotic arms is reduced (up to 15Kg, including gripper and tools) so this option was discarded since not all types of crates could be handled. The second option, and the chosen one, is to use an industrial robotic arm, which can handle the required payload, at the expense of bigger installation costs and the requirement to operate separated from humans to comply with the latest safety regulations, which are defined in the standard ISO 10218/1:2012 and ISO 10218/2:2012. Also, a solution to coordinate the D-Robot, the M-Robot and the AGV has been envisaged, as they will operate in a shared workspace.

After selecting the robotic arm, work has continued with the design of the end effector to handle the crates. For small crates two gripper designs have been considered, one that grabs the crates from above and one that grabs them from the side. A device has been designed and manufactured to measure the required force and torque to effectively handle in both positions, although experiments must yet be done. For big crates, a fork-shaped end effector will be used.

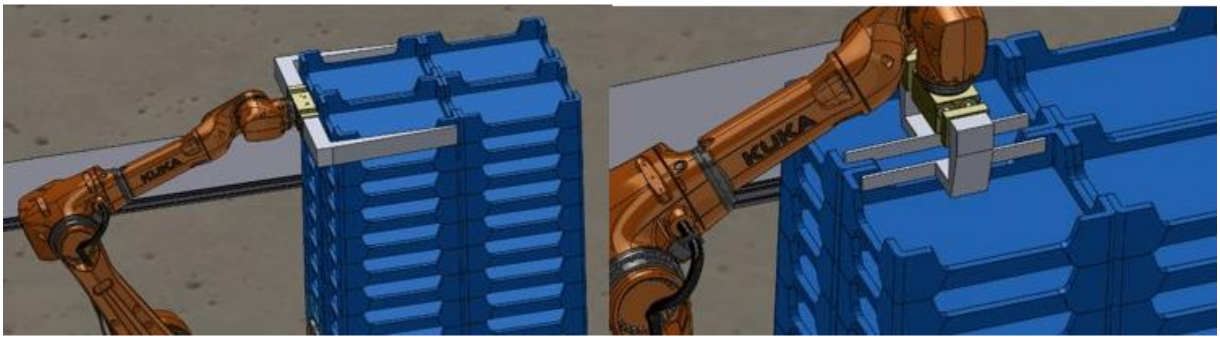


Figure 11. Approaches to handle small crates.

Figure 12. Force/torque measuring device.

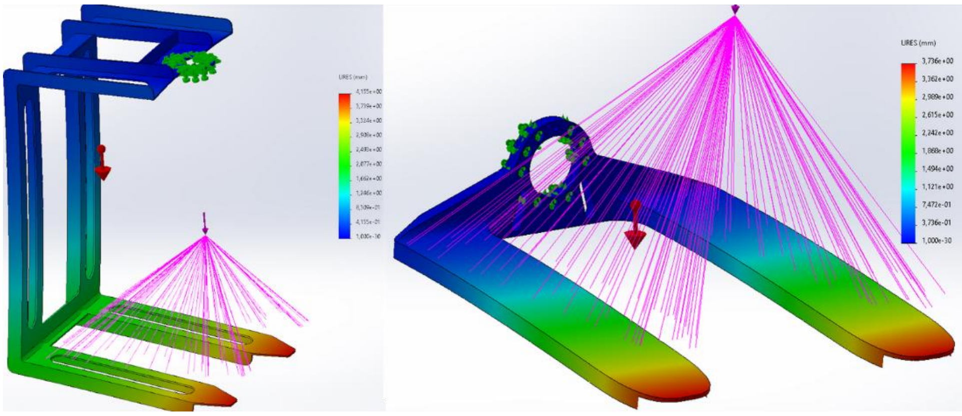


Figure 13. Analysis of force/torque exerted in end effector for big crates.

2.7.2.3. Robot cell for handling insects

During month 1 to month 12, we carefully studied existing robotic solutions and compared them to the requirements of our insect farm partners. Based on a careful requirement analysis (work package 2), the KUKA iiwa LBR robot has been chosen and purchased to act as the robot arm for handling insects and material required for insect rearing. The robot has been setup in a lab environment. Software for safe robot control has been adapted and first material handling tasks have been explored. Cameras have been integrated into the robot cell and tested with the robot so that in the coming months the robotic system can autonomously identify insects and objects to be handled. In addition to the robot, end-effectors for insect and material handling have been studied. CoRoSect partners are now developing custom-made robotic grippers and end-effectors for feeding that will be mounted on the robot arm. TECNOVA has performed pilot-test for end-effectors operating with OnRobot Gripper G2V2 to evaluate the adaptability, precision and force performing task of feeding (positioning, picking elements and insects, filling). This initial pilot has been tested in UR5 model.

Figure 14. Initial gripping tests

2.7.2.4. Autonomous Guided Vehicle (AGV) for transporting crates

The provided AGV is a based on a standard product (hardware and software), the crawl under CU600. The hardware will be modified for usage in the insect farms. The software will be modified in Task 6.2 SLAM/Navigation of AGVs.

In general approach is as follow:

- Setting up the requirements to the load to transport
- Setting up the requirements for the AGV
- Modifying the standard design (mechanical and electrical)
- Building the AGV
- Factory acceptance test of AGV in-house
- Integration test with other system components
- Commissioning

The first project year was used for getting the requirement clear and to start the design of the AGV. The analysis of the user requirements and use cases resulted in the requirement to the loads and the AGV. These are captured in the requirement documentation. The first mechanical design drawings for the AGV are 90% finished.

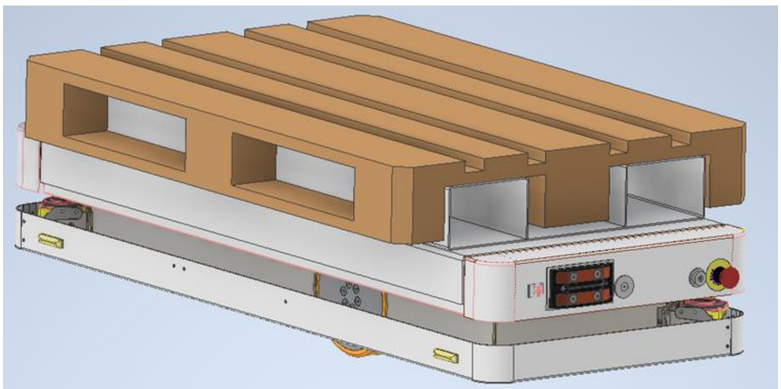


Figure 15. AGV design: undercrawler AGV carrying an empty pallet

2.8. Human-robot collaboration schemes

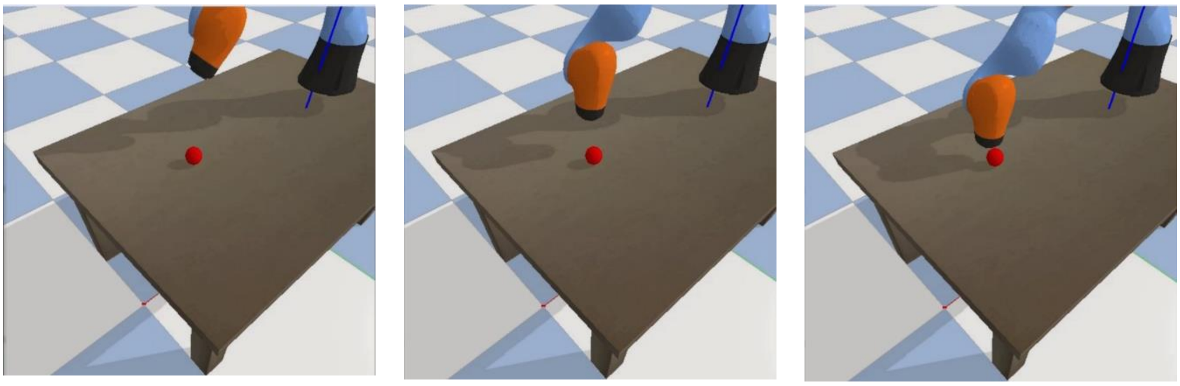
2.8.1. Objectives

For a successful operation of robots inside insect farms an effective human-robot collaboration is important. CoRoSect aims: (i) To develop machine-learning techniques that learn from human input using communication methods that are responsive to individual needs. (ii) To implement autonomous systems that allow the robotic components to work without endangering the human workers. (iii) To allow the workers in the farm, both human and robotic, to work together in an optimal way.

2.8.2. Progress being made

2.8.2.1. Learning from human input

Within this task, the existing literature has been researched, and relevant techniques have been identified. Techniques using reinforcement learning with image-based information were tested in basic tasks producing meaningful results. Next steps will include the design of specific scenarios, and the acquisition of real-world data. The final step will be the translation of the algorithms in the real world to tackle manually performed tasks. The figure below shows an example of solving the reach problem of a randomly placed object using imitation from observation.



(a) (b) (c)

Figure 16. Trained policy for reaching a randomly placed object. Each subfigure (a-c) shows the movement of the robot across time

2.8.2.2. Autonomous and human-aware robot trajectory planning for safe and efficient HRC

This task has not started yet. From month 16 onwards, CoRoSect partners will work on trajectory planning for autonomous guided vehicles that takes the movements of human co-workers into account.

2.8.2.3. Human-machine interactions with AR for situation awareness and training

CoRoSect aims to implement mechanisms that are necessary to facilitate human-machine interactions for situation awareness as well as human worker training for human-robot collaboration-based insect care activities. A multi-level augmented reality-based worker-robot communication system is being developed that uses optical see-through augmented reality techniques to interact with the worker. The worker will be provided information about the robot's next steps, notifications and advice provision, farm floor assignments and issues such as robot failure that necessitate human intervention. For the aforementioned, communication between ROS and Microsoft's Hololens 2 needed to be achieved. Microsoft's Hololens 2 is used to visualize simulated trajectories and an augmented-based safety net around the KUKA. Warning messages are also provided to the worker in an augmented manner, regarding the safety distance to the robot so that collisions with the robot can be avoided.

Figure 17. The robotic arm follows the predefined trajectory (left to right). Through augmented reality a human co-worker can be made aware of the robot trajectory before the movement is starting.

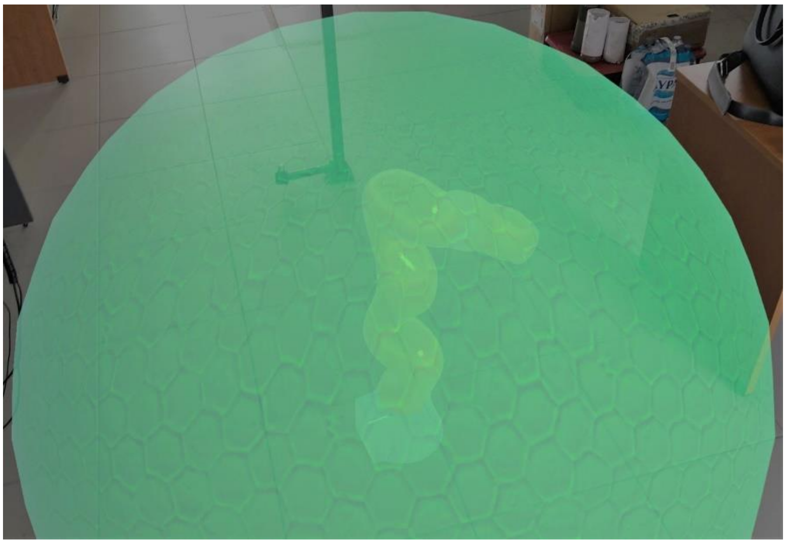


Figure 18. Green 3D Safety-Sphere around the KUKA displayed in augmented reality makes a human co-worker aware of the area in which the robot might be moving.

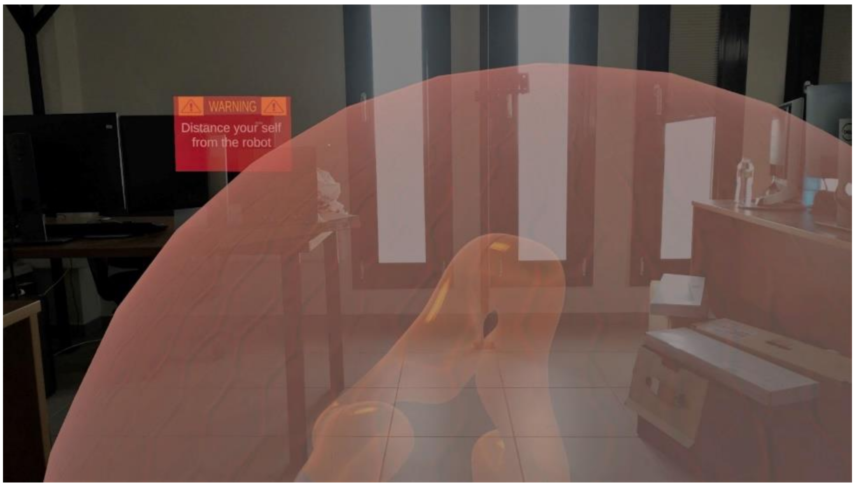


Figure 19. Red 3D Safety-Sphere and warning message is provided when the human co-worker is getting too close to the movement range of the robot

2.9. Secure platform integration

2.9.1. Objectives

CoRoSect aims to provide a fully integrated system. For this an integration plan is developed and the necessary interfaces are being developed to integrate all robotic and software components developed in CoRoSect. Test cases are being defined to verify all the integration points which will cover the validation of the CoRoSect system and components.

2.9.2. Progress being made

To achieve the goals, HSEL has conducted two consortium wide workshops explaining the major requirements and strategies for the digitalisation approach in CoRoSect. HSEL has also conducted various specialized workshops with smaller groups and individual partners that explained the benefits and methodology of performing digitalization and networking of their respective assets. Until now various data has been collected with regards to various functionalities that each of the CoRoSect assets would be providing. For digitalization the corresponding business cases have been identified.

2.10. Pilot studies demonstration and evaluation

2.10.1. Objectives

CoRoSect aims at providing software and hardware that works under real-world conditions and truly supports insect farms during their work. Thus, CoRoSect plans for pilot studies where the CoRoSect system and its components are carefully tested within the facilities of the CoRoSect insect farm partners.

2.10.2. Progress being made

2.10.2.1. Pilot scenario definition

Following the definition of use cases, user requirements and technical specifications, the CoRoSect partners defined applications of the CoRoSect innovation for the use-cases through the perspective of technical feasibility (exploring benefits from deployment, but also technical limitations and specifics of integrations) and from business value delivery perspective. These defined applications resulted in the definition of pilot scenarios that describe under which conditions and how CoRoSect technologies will be tested and demonstrated. The pilot scenarios are described through 4 different layers, starting from the most general information to the most detailed:

- Functional areas: All end-users have defined the minimum infrastructure parameters which will be ensured on site for the pilots. They have also specified particular parameters (if any) for designated functional areas. Every insect farm has provided a blueprint of the floorplan with key dimensions of the space, construction elements and objects to inform the Pilot planning process.
- Hardware elements: The hardware mapping was developed for every use case, for every task, following a unified matrix aiming to clarify the availability of movable, moving and statistic elements, but also prerequisites for data communication. This information gathered is of importance for further development of the CoRoSect System architecture and integration
- Software elements: The software mapping also was performed for every use case, for every task. The methodology applied distribution of the tasks towards every tech-partner and required breaking down the tasks into subtasks with input and output at every subtask level defined. Next, partners had to define requirements for mutual understanding with the other devices and systems, level of prioritising within the system, as well as constrains an delimitations for every task.
- Data layering (as simultaneous mapping process in the hardware and software layers development)

A final step in the construction of the scenarios was the **Task risk assessment** performed by the partners which resulted in selection of tasks that are challenging for implementation. Mitigation plans were developed by the tech-partners as strategy for minimization of the identified risk

The final selection of pilot scenarios comprises 14 integrated use cases that target the specific requirements of the CoRoSect insect farm partners.

2.10.2.2. Pilot preparation and planning

All CoRoSect partners are working now on the organizational and technical preparations for the proper pilot implementation in the different locations.

The pilots will be performed at the following locations:

- Entocycle – 4 uses cases – located in UK
- Italian Cricket Farm – 3 uses cases – located in Italy
- InvertaPro – 3 uses cases – located in Norway
- Nasekomo – 4 uses cases – located in Bulgaria

2.11. Dissemination, communication and exploitation

2.11.1. Objectives

CoRoSect aims to maximize the impact of the project and to ensure proper communication and dissemination of the project results and subsequently to raise awareness of general and scientific public, helping CoRoSect solutions to find their way to the market and relevant industrial stakeholders. CoRoSect also aims to ensure the sustainability of the project results once the project is over in correlation with the individual exploitation intentions of the partners.

2.11.2. Progress being made

2.11.2.1. Communication, Dissemination and Ecosystem building

In the first year of the project a comprehensive set of communication and dissemination activities has been implemented. During the first year of the project, we focused on awareness raising on two fronts: on the benefits of insect farming as well as on the role of AI and Robotics in insect farming.

Social Media and the CoRoSect project website also played a significant role in this awareness raising phase of the project. Several Social Media campaigns were launched.

During the first project year, CoRoSect attended two major online events and co-hosted a panel discussion alongside one of the largest agrifood events in Europe. Participating in such events and promoting the project is vital since it brings the project closer to its target audiences. The events where CoRoSect was presented played an important role for the exploitation activities. During these events, we had a chance to discuss with potential future adopters and end users of the CoRoSect Solution. Events included the European Robotics Forum 2021 (ERF2021), the INBOTS Conference 2021. Furthermore, CoRoSect also co-organised an event alongside Robs4Crops, FlexiGroBots, and Robotics4EU, all funded under ICT-46-2020 and in the frame with the AgriFood Forum 2021.

2.11.2.2. Exploitation

Through our communication and outreach activities we are preparing the market and the ecosystem for CoRoSect Solution to go commercial after the project end. We are communicating with our target audience, getting valuable insights from key stakeholders and evaluating various business models suitable for CoRoSect.

While preparing the market we are also preparing Consortium partners for a smooth transition to post project exploitation. This process involves mapping partners' expectations and ambitions when it comes to future exploitation activities. We are also collecting information on IP rights and finding pathways towards successful integration of all partners' interests.

During this process, we closely collaborated with end users and conducted several activities such as Problem and Solution Interviews as well as compiling CoRoSect Exploitation and IP Catalogue. The Problem and Solution interviews were held in March and April of 2021. and targeted internal stakeholders to understand operational issues, end users' needs and requirements as well as the technological ambitions of the researchers and tech providers.

CoRoSect Exploitation & IP Catalogue represents a database of all key project results that have a potential to be exploited once the project finishes. The Catalogue includes all types of results such as the tangible and intangible (knowledge or information; commercial and non-commercial), it also covers all potential uses (scientific, societal, and economic) and briefly highlights partners' strategy and intentions for the future. The Catalogue will also be the basis on which the Exploitation Strategy and the IP strategy will be built.

3. Progress beyond the state of the art, expected results until the end of the project and potential impacts

CoRoSect drives innovation in a variety of domains. In this section we describe which results are expected until the end of the project and where CoRoSect aims as advancing the state-of-the-art.

3.1. Legal and ethical aspects of artificial intelligence and the digitalization of insect-farms

Building upon the existing literature, policy and guidelines in the EU on the ethical and legal aspects of AI, the research carried out within the scope of WP1 identified the specific challenges developers and insect farms may face in the development and use of the artificial intelligence and robotics technologies. Ethical guidelines for trustworthy AI, data protection legislation, food and safety legislation and insect-farming industry's animal welfare standards have been considered to be potentially relevant sources to regulate the development and use of the CoRoSect solutions in insect-farms. In the view of the dynamic regulatory landscape concerning artificial intelligence in Europe, ethical guidelines for trustworthy AI have been identified as an important regulatory tool. Further research will be carried out to analyze whether, and to what extent, the ethical guidelines for trustworthy AI and any other relevant tool can address and mitigate the legal and ethical challenges that AI poses to the individuals, insect-farms and society. Future research will assess whether there are any gaps in the regulatory and policy framework that may specifically affect the implementation of the emerging technologies in insect-farms. The developments in law and policy in the area of artificial intelligence will be taken into account.

The research will contribute to the academic discussions on the legal and ethical aspects of the digitalization of insect-farms, teaching activities carried out by the academic staff in KU Leuven and public debate in this area. It will further ensure that the consortium develops and uses their innovative solutions in a legally and ethically compliant manner. This will, in turn, ensure that any potential risks and challenges to the individuals and society will be prevented or mitigated.

3.2. Environment analysis and registration for cognitive systems

CoRoSect develops an AI-enabled cognitive system that autonomously detects and analyses all visible insects lying on the surface/substrate with an efficient accuracy. Such a skill is crucial for automated quality management where e.g. the number of insects have to be found and where one has to automatically register if insects are growing as expected. A deep learning-based analysis system is currently designed by CoRoSect partners that takes images of insects and analyses these autonomously. All in all, defining an architecture that can adaptively model insects utilizing spatial, colour, and movement visual properties for segmentation, is under research, while unsupervised, semi-supervised, and self-supervised learning techniques are also investigated.

3.3. Integrating physics-based force feedback interactions in VR applications

Training factory workers in a virtual reality (VR) is useful e.g. when workers should be trained safely on expensive and potentially dangerous machines. However, VR training becomes challenging when the training requires the worker to feel the objects and machines the worker is trained on. The CoRoSect partners develop a system that will allow users to pick up, drop and use held objects in a way that naturally replicates real-life mass-driven interaction with other rigid and non-rigid bodies, as well as artificially simulating weight when interacting with these objects in VR. Initially, we will conduct research to create a machine learning dataset in which we will input data from various subjects in order to capture hand movements with the help of VR SenseGlove sensors. Next, using the aforementioned dataset, a game engine to simulate 3D virtual reality environments similar to the physical ones and as well as data-driven system, the appropriate force and haptic feedback will be predicted.

3.4. Soft robotic end-effectors for insect and material handling

Autonomous material handling by a robot is a challenging task that requires sophisticated tools. Handling insects that can move around and are soft is even more challenging and require proper control and tools that adapt to various situations required for handling insects. CoRoSect develops novel instrumented (soft) robotic end-effectors for insect and material handling. These end-effectors allow for precise manipulation of soft structures like insects. The end-effectors are designed in such a way that they allow for a gentil touch that ensures the well-being of the animals.

3.5. Versatile force-adaptive control for handling crates and insects

When handling insects but also other material, no situation is exactly the same as the situation before. Thus, an artificial system handling insects must learn to adapt to new situations. When acting the system must be quick but also careful to avoid harming any of the animals. CoRoSect develops new control methods for robotic manipulators for precise and adaptive control. To achieve a new generation of cognitive robots that can adapt to handling new materials and situations without human intervention, CoRoSect investigates and develops machine learning and optimization approaches. With these approaches machines can learn autonomously and improve their skills over time. Learning allows machines to adapt to new situations that they have not encountered before and to find appropriate behaviour without human intervention.

3.6. Printed sensors for intelligent crates

Quality management in insect farms requires observing the well-being of insects in hundreds or thousands of crates simultaneously. For this CoRoSect develops novel, mass-manufacturable, cost-efficient, and accurate printed sensoring and identification techniques for efficient, automated insect rearing. Using printed electronics technologies provides developing and innovation capabilities that go well beyond what the typical traditional, rigid sensor systems can do. For example, using novel printed technologies the environmental impact of smart structures and components can be significantly reduced.

3.7. Machines learning from human input

Human behaviour is a rich source of inspiration for robot behaviour. Also, when enabling a robot to learn from human demonstrations, skilled factory workers can teach a robot new behaviour without having to write new program code. Learning from demonstrations is not an easy task for a robot. First, the robot must guess the human intentions. For this, a robot can observe a human through a camera. Alternatively, a human can guide the robot by touching and moving the robot. From the observed behaviour then the artificial intelligence inside the robot must generalise the human behaviour and map it back to its own robotic skills. A robot will e.g. have different arms and grippers than a human and thus must learn to perform the same task but with its own skills. The key to accomplish this task is learning. Thus, CoRoSect partners develop machine learning and optimization techniques to allow a robot to learn from human demonstration.

3.8. Human-machine interactions with AR for situation awareness and training

In the context of task 8.3, research involving the wearable optical see-through device HoloLens 2 will be conducted. As part of the research, an egocentric task-depended dataset will be composed, where a subject will perform specific tasks while wearing the HoloLens 2. HoloLens 2 will be recording different data streams, like audio, RGB-D, eye-tracking and hand-tracking and accelerometer, gyroscope and magnetometer values as provided by the device. Furthermore, data like the subject's heart rate or even blinking rate could be used. The aforementioned dataset will be used to train deep learning models with different architectures. After the features of the models have been decided, multiple architectures will be tested in order to find the model that offers the best overall accuracy on evaluating the attention levels of the HoloLens 2 operator.

Subsequently, the model could help provide safer better human-robot collaboration by evaluating, the attention levels of workers in farms and generally in industries, different actions could be taken in order to avoid accidents because of human carelessness that occurs either by lack of rest or other reasons. This will result in a higher percentage of workers feeling safe and more importantly being safe during a human-robot collaborative task. Consequently, the effectiveness of human-robot collaboration will increase.

3.9. Smart integrated platform for insect farms and manufacturing industry

CoRoSect develops a novel way of integrating the different assets such as robots, intelligent crates, artificial intelligence, and smart software that are participating in the production of insects. The project focuses on using DIN SPEC 91345 RAMI 4.0 and the Asset Administration Shell Methodology to digitalize and network the various assets of CoRoSect. This approach not only decouples the assets from each other, but at the same time offers benefits like flexibility, facilitating rapid change in configurations, and real time data access. This brings transparency and helps in optimizing the production process with the data exposed from these assets. The use of Asset Administration Shell technology also ensures that the data and information exposed from each of the assets is represented in a standardized manner, resulting in interoperability and high scalability of the solution as such.

4. Conclusions

CoRoSect is a complex project with high ambitions working towards secure and sustainable food production. During the first year, CoRoSect partners have worked together closely to successfully build the foundations for achieving the ambitious project goals. Crucial milestones have been accomplished: CoRoSect partners with a variety of backgrounds such as experts on insect rearing, engineers, AI experts formed a common understanding of the requirements of a next generation of robotised, AI-supported, digitalised, and networked insect farms. Sophisticated robotic hardware, artificial intelligence, and software have been designed, partially developed, and evaluated.

In the coming 12 months during the second project year, CoRoSect partners will be completing and integrating the first generation of CoRoSect technologies. These technologies will then be shipped to and tested at the location of our insect farm partners. Based on the lessons learned during these tests, a second generation of technologies will be built and tested during the third project year.

CoRoSect

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