# D12.3 Second Annual Management Report
# Public part

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| **Dissemination Level** | | |
|---|---|---|
| **PU** | Public | **X** |
| **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 | | | |
|---|---|---|---|
| Participant Number | Participant organisation name | Short name | Country |
| 1 | UNIVERSITEIT MAASTRICHT https://www.maastrichtuniversity.nl/ | UM | NL |
| 2 | ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS https://www.certh.gr/ | CERTH | GR |
| 3 | HOCHSCHULE EMDEN/LEER https://www.hs-emden-leer.de/en/ | HSEL | DE |
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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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| List of Abbreviations and Acronyms | |
|---|---|
| AI | Artificial Intelligence |
| AGV | Autonomous Guided Vehicle |
| AR | Augmented Reality |
| CA | Consortium Agreement |
| DMP | Data Management Plan |
| DSS | Decision Support System |
| EU | European Union |
| IMS | Information Management System |
| IPR | Intellectual Property Rights |
| ORDP | Open Research Data Pilot |
| PSC | Project Steering Committee |
| UC | Use Case |
| SFM | Shop Floor Manager |
| VR | Virtual Reality |
| WP | Work Package |

# Executive Summary

This report provides a summary of the activities of the CoRoSect project partners during the second project year (January – December 2012). The summary has been written for a general audience. The report highlights the progress of the CoRoSect project that aims at making crucial contributions in securing sustainable food production from insects and in building innovative artificial intelligence and cognitive robotic systems for insect farming.

During the first months of the project, the CoRoSect partners focused on preparations, understanding urgent needs of insect farms, and defining technical solutions. Now, during the second project year, the CoRoSect partners invested most of their efforts into the development of solutions addressing the identified needs of insect farms. These efforts are summarised in this report. Some highlights of CoRoSect activities and solutions developed during the second project year and described in this report include:

- *Intelligent robots for insect farming.* The CoRoSect partners follow the innovative concept of developing dynamic robot cells for insect farms. These dynamic cells contain multiple robots that perform a variety tasks required to ensure the growth and wellbeing of insects. During the second project year CoRoSect made excellent progress in implementing the CoRoSect robot cell that is composed of a robot for heavy lifting, the D-Robot, and a robot for gentle insect handling and human-robot collaboration, the M-Robot. Both robots work closely for insect farming. They have been developed during the second project year and are now operational, but still require further software developments. Besides these first two robots, a third robot, an Autonomous Guided Vehicle (AGV), has been developed in CoRoSect. This robot has the important task to bring the insects to the dynamic robot cell and to carry the insects to their storage locations without help from humans.
- *Smart sensors and cameras for insect farming.* CoRoSect develops sensors for insect farming and software to allow cameras to detect insects, humans, and obstacles using artificial intelligence. Sensors and cameras are important to allow robots to react more flexibly to human co-workers and to ensure the quality and wellbeing of the insects. During the second project year the development of sensors and software for smart cameras has been almost completed so that in year 3 the CoRoSect partners can focus mostly on testing these sensors and cameras inside the insect farms of the CoRoSect partners.
- *Software for coordinating CoRoSect technologies and information management.* A powerful solution like the one provided by the CoRoSect partners that contains many complex robots, requires interfaces and software that allows human operators in insect farms to control all these robots. This is why CoRoSect build a shop floor management software during the second project year that can control all robots from a single computer. Besides, CoRoSect also successfully implemented software to collect data from all robots, sensors, and cameras so that human operators can better understand what is happening inside the insect farm and can keep optimising the workflow of CoRoSect technologies and human co-workers. Both software will be intensively tested during four major pilots at the CoRoSect farms in the third project year.
- *Exploring insect diets.* Several CoRoSect partners focus their efforts on developing and testing new diets for insects to understand how to best grow insects. These scientific studies led to first results and are being finalised during the third project year.
- *Improving Human-Robot collaboration.* CoRoSect is also developing and exploring new solutions to improve how robots and humans work together in insect farms. The CoRoSect partners develop interfaces using augmented reality to allow human co-workers to understand better which tasks

the robots are performing. A virtual reality environment is being prepared and explored that should help training human co-workers to collaborate with the CoRoSect robots. New interfaces and artificial intelligence are being prepared so that humans can teach the CoRoSect robots how to perform new tasks without having to learn how to program new software. All technologies will be carefully tested and further enhanced during the third project year.

To develop all aforementioned solutions, the CoRoSect partners have again been working together very closely. Together we came closer to realise our vision to provide versatile, powerful solutions for effectively rearing the three most important insects: Mealworms, Crickets, Black Soldier Flies.

# 1. Summary of the Context and Overall Objectives of the CoRoSect Project

## CoRoSect mission

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. This 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. 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.

## Project year 1

The CoRoSect project is carried out by 19 partners distributed over 12 European countries. During the first project year (2021), the CoRoSect partners closely worked together on evaluating the precise needs of insect farms. Several challenging use cases have been identified that, if successfully implemented, will substantially bring improve the efficiency of insect farms and the working conditions of human workers in insect farms. Several technologies required for these use cases have been prepared. For a public summary of the work during the first project year, kindly see the First CoRoSect Annual Public Report, **Deliverable 12.1**., which can be found on the CoRoSect web pages (https://corosect.eu/reports/).

## Project year 2

The present report documents the progress being made during the second project year (2022), where the CoRoSect partners focussed their efforts mostly on the development of innovative technological solutions meeting the most urgent needs of European insect farms. The CoRoSect partners came together at the insect breeding location of the CoRoSect partner Entomotech to perform a series of initial tests of the CoRoSect technologies. In addition, the CoRoSect partners conducted several studies on insect diets to provide a better understanding on how insects can be fed from by-products, food that humans no longer want to eat. By feeding insects from by-products, organic waste can be reduced and transformed into valuable proteins.

## Outlook on project year 3

During the third and final project year (2023) the CoRoSect partners are looking forward to testing all integrated technologies in 4 additional large-scale pilots in the insect farms of the CoRoSect partners

Invertapro, Italian Cricket Farm, Nasekomo, and Entomotech. The results of this work will be documented in additional deliverables to be published in 2023 and 2024.

### Organisation of this report

CoRoSect is a complex project, organised into 12 closely interlinked work packages. Each work package is divided into several tasks. In the following, a summary is presented that describes the work performed as well as the main results achieved during the second project year.

# 2. Work Performed in Year 2 and Main Results

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

## Work package 1: Ethical, legal and social implications of human-robot collaboration in industrial automation

### Work package 1: Objectives

Work package 1, led by the CoRoSect partner 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. For this KU Leuven prepares guidelines for a trustworthy Artificial Intelligence (AI) and assesses whether CoRoSect technologies comply with the ethical, safety and legal requirements. Following the practical experience gathered during the CoRoSect project, KU Leuven also determines gaps in the current legal and ethical landscape and provides recommendations for better policies.

### Work package 1: Progress being made

***Explanation of work performed at task level***

In the second project year, work package 1 fully concentrated on the following task:

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T1.3** | Ethical and legal oversight and implementation | M13-M30 | KUL | all | In progress |

*Description of activities*

The CoRoSect partners carefully monitor the ethical and legal aspects of their work. To help all partners in this responsible work, supportive materials such as organisational guidelines, presentations and a checklist to integrate the legal, ethical and social considerations in the development and use of the project's solutions have been developed. In addition, for training all CoRoSect partners, an internal workshop titled 'Law and Ethics of Artificial Intelligence and Robotics' has been provided. The aim of this workshop was to raise awareness on legal and ethical compliance and provide practical information to the consortium partners.

Moreover, work has been carried out to put in place a methodology to monitor the implementation and the evaluation of the project's solutions. Since artificial intelligence and robotics technologies interact with workers and function with a certain degree of autonomy, it is important that they function safely, securely and accurately. In addition, these technologies are trained with data relating to individuals or other type of data, which should be kept protected. A survey, including questions on thematic areas such as data protection, human oversight, safety and security has been developed. This survey reflects the ethics guidelines and the methodology produced by the High-Level Expert Group on Artificial Intelligence set up by the European Commission. The survey will be used to evaluate the contributions of the CoRoSect partners to learn how ethical and legal guidelines have been implemented and to provide insights for other technology developers.

# Work package 2: Use-cases, user requirements and system architectures

## Work package 2: Objectives

The overall aim of this work package is to collect and to carefully analyse the user requirements of insect farms for the project. This is to ensure that the developments of the CoRoSect technologies really meet the needs of insect farms. Based on the identified needs, the CoRoSect partners create the technical architecture, as well as the technical and functional specifications of the CoRoSect system.

## Work package 2: Progress being made

***Explanation of work performed at task level***

During the first project year, the CoRoSect partners had identified the requirements of the insect farms and most promising use cases for the CoRoSect technologies. Thus, during the second project year, the CoRoSect partners could fully concentrate on completing the architecture of the CoRoSect system:

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T2.3** | System architecture | M5-M12,<br>M18-M24 | ATOS | UM, CERTH, OAMK, TECNOVA,<br>AGVR, ROB, HSEL | Completed |

*Description of activities*

In the first phase of the project, the CoRoSect partners focused on studying and thoroughly understanding the specifics and needs of the insect farms. From the gained understanding the CoRoSect partners defined which technologies and innovation should be implemented by the project to solve key issues of scaling insect farming. The work and the resulting use cases of the CoRoSect technologies has been documented in the deliverable "Use Cases Definitions and Requirements". Functional Specifications served as basic guiding document for the work in the second project phase which focuses on the development of the technical solutions. It also supports the elaboration of the Plan for the implementation of the Pilots (object of the efforts of task 10.2.).

Since month 10, task 2.3 (System Architecture) is the remaining working line of work package 2. In month 12, an Initial System Architecture for CoRoSect's infrastructure was proposed.

During this second project year, this initial architecture was revisited, using the feedback collected from the CoRoSect progresses in terms of components' integration and operation. This Advanced CoRoSect's System Architecture (fully documented in the report D2.4) refers the steps, protocols and interfaces used to integrate and build the CoRoSect System, managed in work package 9.

# Work package 3: Biological, technical and economic aspects and parameters to insect rearing

## Work package 3: Objectives

The overall objective of work package 3 is to gain understanding on biological, technical and economic requirements for the rearing processes of three insect species and consequently understand how to improve them through management, sensoring and automation. This study focuses on three commercially valuable insect species, namely yellow mealworm, house cricket and black soldier fly. In particular, the goals are:

- To identify and describe biological, technical and economic factors which are critical for a successful and sustainable insect rearing process
- To test the use of printed sensors in monitoring insect rearing processes
- To develop sustainable insect diets for yellow mealworm, house cricket and black soldier fly by exploiting by-products from the food industry
- To present a model-driven support system for optimizing insect rearing. The support system will include a model that characterises the main biological and technical features of the rearing process and helps to describe biological and economic consequences of measures taken to control the rearing process.

## WP3: Progress being made

***Explanation of work performed at task level***

During the second project year, in work package 3 the CoRoSect partners concentrated on the following tasks that will continue also during the third project year:

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T3.2** | Developing sustainable insect diets from agricultural wastes and sidestreams | M6-M36 | CIHEAM | LUKE, OAMK, TECNOVA, NASEKOMO, ENTOMOTECH, ENTOCYCLE, ICF, INVERTAPRO | In progress |

*Description of activities*

Feed is one of the most important factors affecting whether insect rearing can be considered sustainable. A preferred solution would be to use residues or by-products that are discarded from food industries to compose insects' feed, hence reducing the costs of rearing and finding new ways to utilise by-products such as left-over vegetables or residues of food processing that are not used for human consumption. Arguments favoring feeding by-products or residues to insects are based on benefits that can be obtained in terms of environmental sustainability, carbon sequestration, resource efficiency, food security and bio-conversion efficiency of insects. However, very little is known about the nutritional requirements of insects, and about the suitability of such diets in insect feeding. Because insect have the capacity to convert low-value by-products and residues from agriculture into valuable products, it is important to identify how suitable different by-products and residues are for insects and how diet's protein composition affects insects' performance.

During the second year of CoRoSect, experiments to test and develop standardized diets to feed the insects were designed, completed and reported. The by-products and feed materials selected for testing in yellow mealworm and house cricket diets included wheat bran, potato peels, tomato pomace, brewer's spent barley grain, and olive pomace, and chicken feed for house cricket. The by-products and feed materials selected for testing in black soldier fly included brewer's spent grain, kale, spinach, mashed tomato, potato, feed yeast, breadcrumbs, broad bean, potato protein, and apple, and two synthetic amino acids (L-tryptophan and DL-methionine) as supplements to achieve a balanced diet. Chicken feed was used as the control feed for house crickets and black soldier fly, and wheat bran for the yellow mealworm. Amino acid levels of the substrate were also tested in black soldier fly and a feed administration method in mealworm experiments. Two experiments were carried out with mealworms and black soldier fly and one experiment with house cricket. The results obtained were promising and indicated the potential of including by-products of agriculture and food value chains in insect diets. Sensors to collect data during the process were also piloted during some of the experiments.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T3.3** | Optimizing insect rearing (chain) through the development of a model-driven support system | M6-M36 | LUKE | CIHEAM, OAMK, TECNOVA, NASEKOMO, ENTOMOTECH, ENTOCYCLE, ICF, INVERTAPRO | In progress |

*Description of activities*

In order to produce insects efficiently and to maintain the high productivity and quality of insect rearing process, information on the desirable performance of insect rearing as well as information on when corrective actions in the rearing process should be taken are needed. 'When' means here, for example, when rearing box temperature or some other parameter exceeds the limits of acceptable natural variation so that a corrective action which prevents the deterioration of production performance is needed. During the second project year, an outline of a model that describes the main biological features of insect rearing and that can be used for optimizing the insect rearing process was developed. The model describes, for instance, how feeding and ambient conditions of the rearing room influence the growth rate and risk of mortality of insects. To develop the model, data on insects' nutrition, rearing conditions, life cycle, biology and performance with different feeds were collected during the second year of CoRoSect. Monitoring the rearing process with sensors was also given attention when collecting the data. Model development work of this task will be integrated with other work packages of the project through further workshops organised within the consortium. The final output of task 3.3 will be a model that support insect rearing process management decisions making based on the analysis of the current that of a batch of insects.

# Work package 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.

## Work package 4: Objectives

To ensure a successful operation of robots in insect farms, the CoRoSect partners develop several software systems to support human workers operating the insect farms. A shop floor manager is developed so that human operators of insect farms can control the activities of all robots. An information management system is implemented to support the operators in gathering relevant information on the growth and wellbeing of insects and on the performance of the robots. A decision support system uses gathered data to support the operators in optimal planning of the robots' activities.

### Work package 4: Progress being made

***Explanation of work performed at task level***

During the second project year, in work package 4 the CoRoSect partners concentrated on the following tasks that will continue also during the third project year:

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T4.2** | Shop floor management and decision support system | M1-M30 | HSEL | TECNOVA, ATOS, AGVR, NASEKOMO, ENTOCYCLE, ICF, INVERTAPRO, ENTOMOTECH | In progress |

*Description of activities*

The first version of the Shop Floor Management and Decision Support System was developed. Farm processes have been modelled by using Business Process Model and Notation.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T4.3** | Service-Oriented Information Management System | M6-M30 | ATOS | HSEL, TECNOVA, NASEKOMO, ENTOCYCLE, ICF, INVERTAPRO, ENTOMOTECH | In progress |

*Description of activities*

During this second project period, the CoRoSect partners worked together on a common and novel data model to be used by all the CoRoSect's system components. This new data model maps all the information (properties) each robot and software of the CoRoSect system shares, as well as all the different operations (commands) it implements. This model also supports the corresponding interface to operate with the real device behind the model. This is known as the Digital Twin of a physical component (such as a robot) and will enable the project's common way to read and manage the different CoRoSect components in a similar way, making it easier for the human operators of the insect farm to control all components.

## Work package 5: AI-enabled perception methods

### Work package 5: Objectives

The CoRoSect partners are preparing several technologies based on artificial intelligence (AI) to make robots better understand the environment they operate in, the humans they are working with, and the insects the robots take care of. These AI-based technologies are developed to improve the safety and efficiency when humans and robots work together and to safely train workers before they use the advanced CoRoSect technologies.

### Work package 5: Progress being made

***Explanation of work performed at task level***

During the second project year, in work package 5 the CoRoSect partners concentrated on the following tasks that will continue also during the third project year:

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T5.1** | Environment analysis and registration | M6-M30 | CERTH | UM, ATOS | In progress |

*Description of activities*

Given camera images that capture various types of insects rearing in a crate, the visual inspection task aims to identify each visible insect by automatically grouping the pixels of the camera images for each individual insect. Using the aforementioned pixel information, other types of information can be extracted such as the count, the average size, the health, the movement and the colour of insects which are important for insect farms. In general, systems capable of providing such solutions are based on the Artificial Intelligence (AI) technology, and in particular with the researching fields called object detection and object segmentation. Nevertheless, developing of an effective AI algorithm requires a comprehensive collection of frames depicting insects in various perspectives that describe real-case scenarios. Additionally, such datasets require annotations as a form of an additional information that highlights each individual insect within a frame.

Therefore, data 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. The most significant properties that describe the visual form of those livings 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 that exploits the colour difference between foreground (which are the insects) and 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 different AI techniques for utilizing the final AI models is also considered. Last but not least, in an attempt to alleviate annotation struggle and also achieve high performance on detection AI models, a new dataset was created capturing mealworms in a controlled and strict environment. The controlled environment and its uniform shape assisted and improved the detection accuracy.


*Figure 1. Controlled dataset on mealworms (tenebrio molitor)*

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 assisting the visual inspection task were found to be some state-of-the-art segmentation models that are used to detect all the essential information of an object of interest inside an image, such as its exact location of each individual insect on a pixel-wise level, thus allowing the extraction of high-level information such as the insect's size, thickness, bendability in a means of post-processing. Additionally, a system capable of detecting tiny faces in highly occluded and crowded scenes was utilized to detect insects instead, whereas another one was used to extract the distribution of the visible insects within a frame, indicating the regions of the image where insects are present. Current research on developing a novel approach involves the exploitation of spatial, colour, and movement visual properties to segment objects of interest, whereas usage of other state-of-the-art models is additionally explored so as to allow adaptation in case that the development of a novel system fail to reach the aims of achieving the optative accuracy.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T5.2** | Human motion analysis and prediction | M6-M30 | ATOS | CERTH | In progress |

*Description of activities*

For a safe collaboration of humans and robots it is important that the movement of humans can be detected and predicted. This allows, for example, predicting if a human will step in front of a powerful moving robot or will place a hand in the path of a robot arm. For this issue, in the second project period we have created a tool for the detection of people. The tool “follows” people and other elements (robots, etc) and, at the same time, is able to determine their distance to the camera and thus their position in the insect farm. By analysing their motion, the tool can predict the future movement of people and robots for the next few seconds knowing their current velocity and position. This information can then be used to predict and most importantly avoid collisions.

An example image showing the detected distance of people to a camera can be found in Figure 2.

*Figure 2. Distance of people to the camera (false colour)*

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T5.3** | Integration physics-based force feedback interactions in VR applications | M6-M30 | CERTH | - | In progress |

*Description of activities*

Virtual Reality is a rapidly evolving technology that that is used in CoRoSect to train human workers how to use advanced CoRoSect technologies. The training in the virtual reality allows human workers to train in a safe environment. In addition, because no robotic hardware is required, the work of the robots in the insect farms does not have to be interrupted for the training. Thus insect farms could safe a lot of costs by training their workers in the virtual reality.

The training of human workers requires more than a visual representation of the robot's behaviour. When, for example, a human worker instructs a collaborative robot how to perform a new task, the human worker touches and moves the robot. Thus for a realistic training in virtual reality, also in the virtual environment the human worker must be able to feel the virtual robot. For this we explore the combination of virtual reality and SenseGloves (shown in Figure 3), a wearable device that allows us to mimic force feedback when a human touches and moves a virtual object such as a robot.

*Figure 3. SenseGlove – Hand object interaction on virtual environment*

In the second period of the CoRoSect project, the CoRoSect partner CERTH implemented a virtual environment and an experimental setup for exploring and capturing the interaction of humans with real-world and virtual objects. This work is a step towards simulating virtual robots and other objects that a human can touch and feel and is generally useful to improve the interaction with virtual object in virtual reality. To capture the interaction of humans with real-world objects, CERTH used two cameras as shown in Figure 4 and Figure 5, SenseGloves, and additional hand tracking equipment. With this equipment, a dataset has been created that contains the interaction of a number of humans grasping deformable objects. This dataset is now being explored.

*Figure 4. Camera Setup to capture hand and object for both angles*

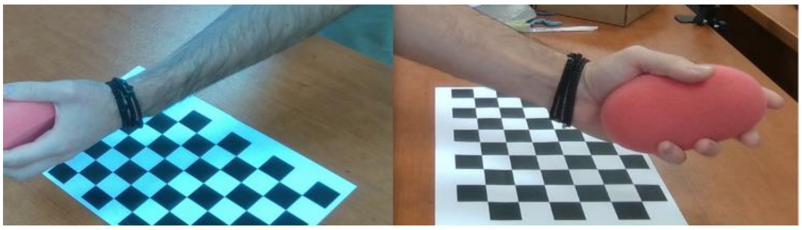


*Figure 5. Hand Object interaction capturing example*

# Work package 6: Robotic actions planning and control

## Work package 6: Objectives

CoRoSect develops software to safely control robotic arms that autonomously handle insects and material required for insect rearing. CoRoSect also develops software so that autonomous guided vehicles (AGVs) can autonomously navigate in insect farms to transport large amounts of crates filled with insects without requiring help from a human. For the robotic arm, the aim is to develop and provide safe handling of insects, crates containing insects, and other materials. For the autonomous guided vehicles, the objective is to provide a navigation 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 to avoid potential collisions.

## Work package 6: Progress being made

***Explanation of work performed at task level***

During the second project year, in work package 6 the CoRoSect partners concentrated on the following tasks that will continue also during the third project year

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T6.1** | Versatile force-adaptive control for handling crates and insects | M6-M39 | UM | Robotnik, TECNOVA, CERTH | In progress |

*Description of activities*

To enable insect farming at large scale, fast and safe handling of insects as well of crates and other materials required for insect farming must be achieved. During the second project year, the CoRoSect partners advanced the software for controlling the robotic cells that are being developed in the CoRoSect project. These robot cells are being developed in work package 7.

Partner Robotnik developed the required software for handling crates that are used to store and rear insects. The crates a being handled by a robot shown in Figure 6 (left). For this a well-known control framework called MoveIt is being used. Software has been developed to automatically pick and place crates. This allows the content of the individual crates to be handled and to stack crates in such a way that these crates can be stored efficiently making sure that tons of insects can be grown simultaneously.

Researchers from Maastricht University focused on the exploration of state-of-the-art methods to let a robot automatically discover how to grasp objects including objects that the robot has not seen before. The robot that is developed as part of work package 7 is shown in Figure 6 (right). Two types of methods for enabling a robot to pick objects have been explored: (1) methods that use a mathematical approach to find best grasping positions by analysing the surface of an object (see Figure 7 for an example) and (2) machine learning approaches that allow a robot to try out and learn how to best grasp an object. The work is still in progress. If the methods can be made reliable, they would allow robots in factories such as insect farms also to handle new objects that these robots have not been pre-programmed to handle. Thus, workers in insect farms and other factories could teach robots to handle new objects without the need of employing someone who develops additional software. A details report can be found in deliverable 6.3 "Insect handling – advanced approaches".

*Figure 6: (left) Robot for handling crates. Here a crate for rearing crickets is shown. (right) Robot for handling insects. Here the robot is shown handling material for insect rearing inside a crate.*

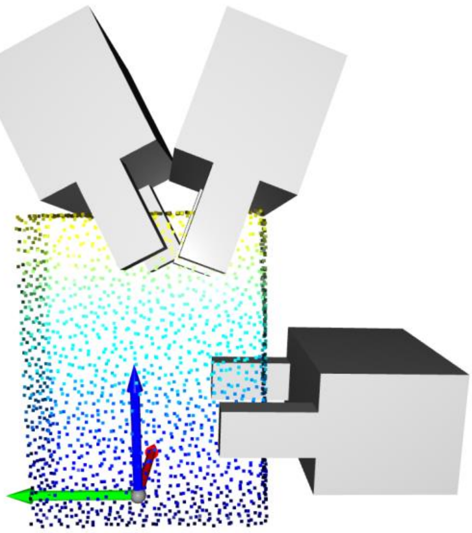


*Figure 7. An object has been scanned with 3D vision. From this scan a 3D point cloud is shown. An algorithm calculated multiple possible grasping positions to grasp the object. 3 possible grasping positions are shown in form of 3 grippers.*

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T6.2** | SLAM/Navigation of AGVs | M1-M36 | AGVR | Robotnik, ATOS, HSEL | In progress |

*Description of activities*

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. To navigate autonomously inside insect farms the AGV must be able to determine its own location inside the farm, to build a map of its environment and to find optimal pathways to a destination. This process of self-localization and building a map is called Simultaneous Localization and Mapping (SLAM). During the second project year, the CoRoSect partner AGVR developed the necessary software so that the AGV is now able to successfully perform SLAM. The software is documented in the report D6.6. The software will be used inside the insect farms during the third project year.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T6.3** | Implementing safety control in robotic planning | M06-M30 | ATOS | UM, TECNOVA, Robotnik, AGVR, HSEL | In progress |

*Description of activities*

Safety is a key feature required to operate robots in insect farms. We are addressing the task of providing safety control on robotic planning as part of the more general task of the detection of moving and static “obstacles and people” in the factory space in order to avoid potential collisions with the robots. For this task, we follow two main directives:

- Avoid any collision between robots and “obstacles”. This is especially important for people. We should avoid any hazard for people even if they enter in forbidden areas.
- Keep the robots moving as much as possible avoiding them to stop.

In the second project year we developed the software modules for this general task. We focus on the detection of “moving” or static obstacles present in the factory floor. The moving obstacles can be other robots or people, and the static obstacles can be any element blocking the pass (a crate or a fallen box for example). An example of the detection of people in camera images can be found in Figure 8.

We have created a dedicated module able to detect these obstacles. This module uses as input the images of a camera. The module, using Artificial Intelligence algorithms is able to detect all kind of “objects” (that can be people, robots, etc) and place them in the factory map. Additionally, this module is able to determine the position of these potential obstacles and can calculate its future position. With all these elements together, we can detect the potential obstacles than any robot moving on the factory floor can find in its trajectory in advance. Thus, we can recalculate the robot route (using another module called “Routes Manager”) to avoid these obstacles.

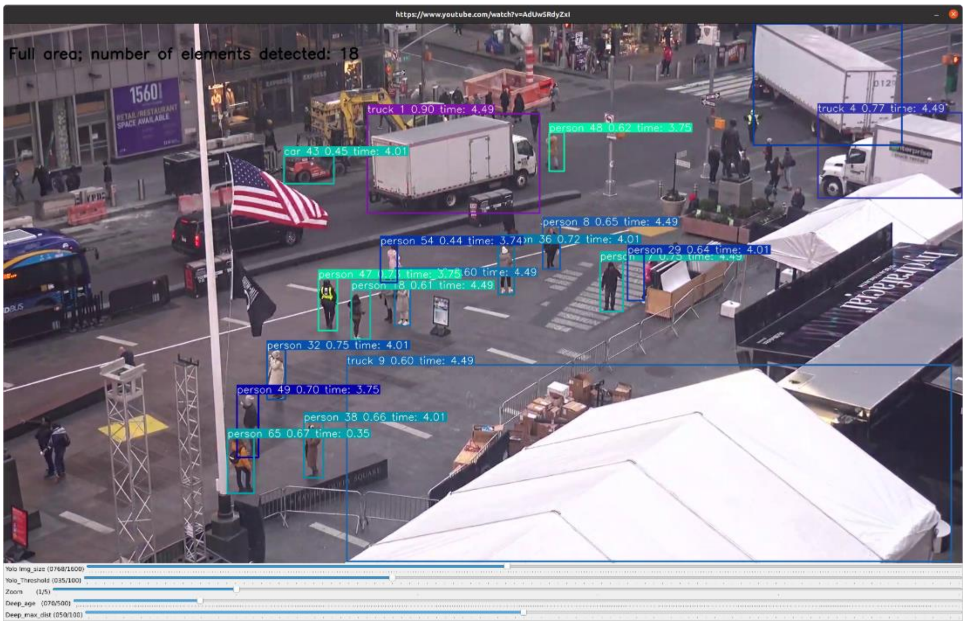



*Figure 8. Detection and tracking of objects*

# Work package 7: Cognitive robots and smart mechatronics

## Work package 7: 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, an autonomous guided vehicle (AGV), and two robot cells. All robots and sensors cooperate closely for the automation of insect farming.

- The sensors to be placed inside the crates are made to 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.
- 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 robot cell for handling insects (M-Cell) fulfils the required tasks for supporting the wellbeing 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.

## Work package 7: Progress being made

***Explanation of work performed at task level***

During the second project year, in work package 7 the CoRoSect partners concentrated on the following tasks that will continue also during the third project year:

| Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| **T7.1** | Printed sensors to monitor insect environment, intelligent crates | M4-M30 | OAMK | LUKE, CIHEAM, TECNOVA, NASEKOMO, ENTOMOTECH, ENTOCYCLE, ICF, INVERTAPRO | In progress |

*Description of activities*

CoRoSect develops, manufactures, and tests the sensors that can be integrated into insect growing crates to measure the critical environmental variables which must be monitored to ensure a successful and efficient production process. The result of this task are sensor solutions (standalone and integrated to form so called "intelligent crates") which support and improve the automated insect rearing process.

During the second project year, the work has continued from the implementation draft done in the beginning of the project. The first integrable prototype structure with temperature sensoring capability was tested in several different use cases. Development work on this structure focused on finding the best suitable materials and manufacturing parameters to enable the best functionality of the product with reasonable costs and mass-manufacturability. The sensor structure includes a temperature sensor, micro-controller with wireless communication capabilities, printed Bluetooth antenna and very thin, printed battery. This sensor is thin and flexible, credit card form factor as seen in Figure 9 (sensor with label "CoRoSect"). The basic structure can be used also together with other sensor types.

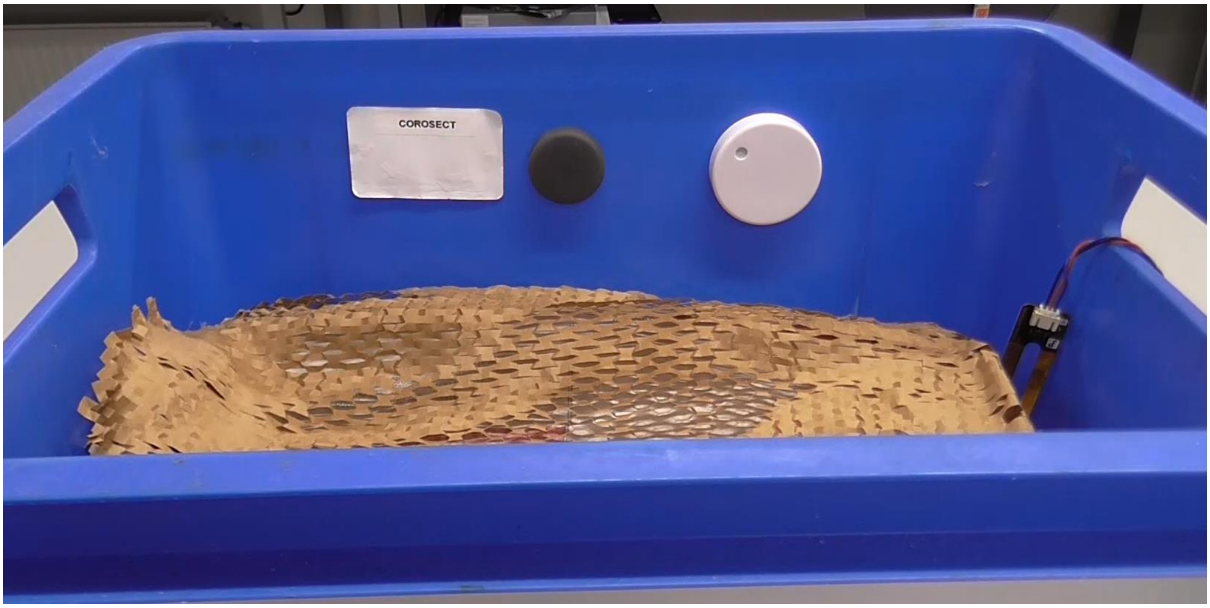



*Figure 9. Sensor prototypes in a crate. Left: thin, flexible sensor, middle: button type sensors, right: wired sensor*

Other type of sensor structures includes for example larger button type, as seen in Figure 9 (round black and white sensor in the centre of the crate). These structures have sensors for temperature and humidity. There are also wired sensors as seen in the right corner of Figure 9. This sensor is for measuring the moisture of the substrate in the crate. Wired sensors are in some cases needed to increase the reliability of the system, because wireless communication can be severely attenuated if sensor structure is covered by the substrate, as in the case of substrate moisture sensor for example.

During the period tests were conducted at the pre-pilot in real insect growing environment. The purpose of the tests was to find out the selected technologies functionality in real environment and to find out any needs for improvement. After the pre-pilot the development work has continued to improve the sensor performance and to make the usage of the sensor solution more suitable for the project purposes.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T7.2** | Robot cell for handling crates | M1-M30 | ROB | UM, AGVR | In progress |

*Description of activities*

The CoRoSect partner Robotnik is developing a robotic cell for handling crates, the D-Cell. The cell includes a 6-axis industrial robotic arm, custom compliant gripping tools to grab all types of crates present in the CoRoSect project and vision sensors to overcome small deviations in crate positioning. The D-Cell's main task is to individually de-stack crates transported by the AGV and to place them on a table where the robot (M-Robot) for handling insect proceeds with its tasks. After the M-Robot carries out crate handling, crates have to be stacked back for the AGV to transport them out of the cell to their storage location.

During the first project year efforts were focused on transforming the use cases and end-user requirements into technical specifications for the robotic cell. A Kuka KR70 2100 arm was selected to handle the crates. Initial gripper designs and gripper basic mechanism prototype testing was carried out in a workbench to test the viability of the initial design when grabbing crates with filled with the required weight.

During the second project year the design of the robotic cell for handling crates has continued, with the definition of the layout, the gripping system, and the sensors for visual servoing.

During the past months gripper designs have been further developed and functional gripper prototypes for crate handling have been manufactured. After carrying out gripper prototype workbench testing during the first year, it was determined that two grippers were going to be developed, one suitable for all small crates (Nasekomo, InvertaPro, Entomotech) and one for the big ICF crate. After extensive research, the Schunk PSH52 pneumatic gripper has been selected as an actuator for both gripper designs, custom compliant jaws to handle both the small crates and the big crate have also been developed and integrated with the actuator. The hardware integration of the pneumatic gripper to the KUKA arm has also been developed.

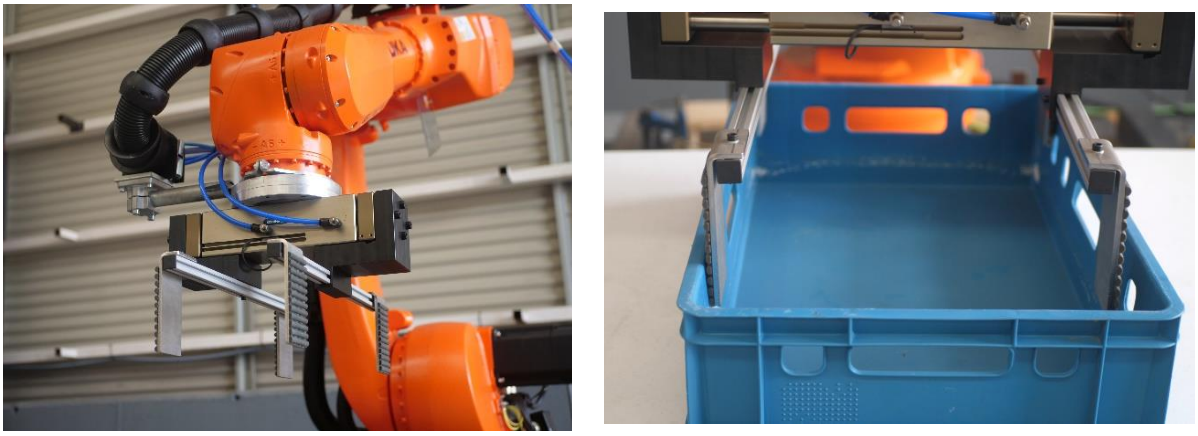


*Figure 10. Big (top pictures) and small (bottom pictures) crate grippers.*

Efforts have also been carried out regarding the visual servoing used to correct crate positioning by performing fine positioning of the gripper. Tests with different visual sensors, including lidar lasers and RGB-D cameras, have been carried out. Different sensors placed at different positions have been tested for each gripper. At software level different algorithms have also been tested to check the robustness of the crate localization. Further testing will be carried out during this next year.

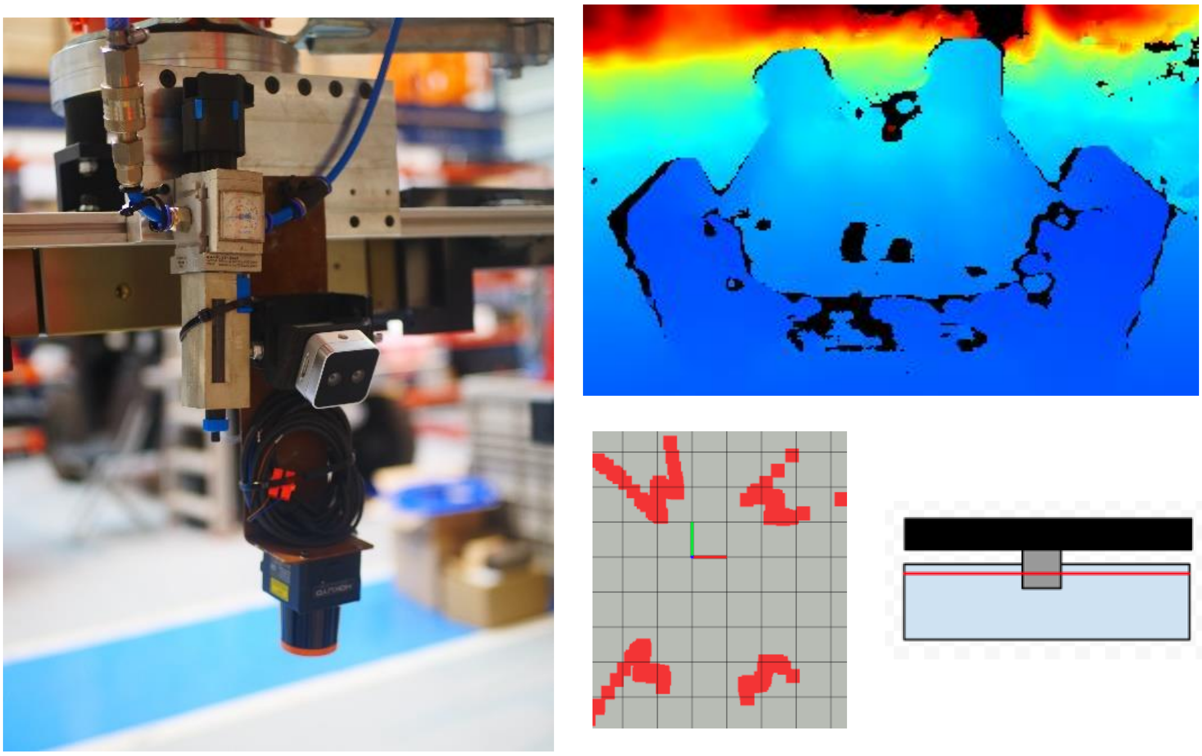


*Figure 11. Sensors for crate servoing*

At software level Robotnik has developed a manipulation application based on ROS and MoveIt that enables the robot to robustly and accurately de-stack and stack crates filled with insects. MoveIt is an open-source tool that allows robot trajectory path planning taking into account the modelled robot environment, which is used for collision avoidance. During this next year, efforts will be made regarding the integration of the D-Robot's cell functionalities with the CoRoSect's Manufacturing Execution System (MES) at software level.

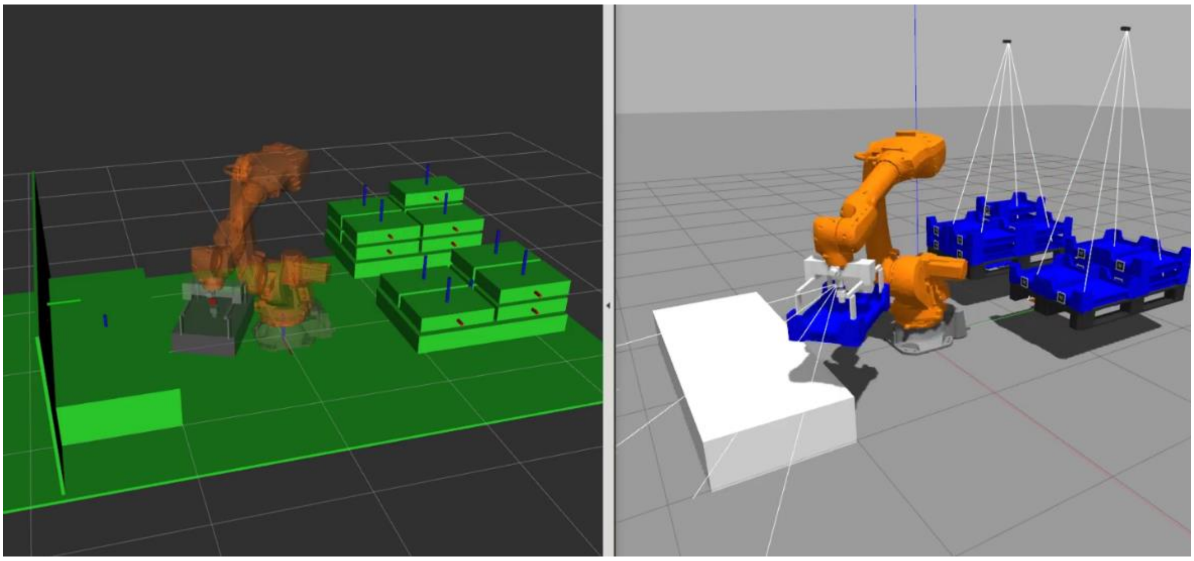


Figure 12. D-Robot ROS manipulation application

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T7.3** | Robot cell for handling insects | M1-M30 | UM | HSEL, TECNOVA | In progress |

*Description of activities*

During the second project year the robot cell for handling insects (M-Cell) has been developed further to meet the needs of the insect farms. The robot cell consists of a KUKA LBR iiwa robot arm (Figure 13) mounted on a support structure. The robot was selected to be the core of the M-Cell as it allows for a safe collaboration with humans. The support structure was designed so that the autonomous guided vehicle can autonomously bring new material to the M-Cell and remove waste if necessary. This will reduce workload for the human workers in the insect farm. For more reach and improved speed of operation, the KUKA robot arm has been extended. Furthermore, a new gripper has been developed that allows for superior flexibility in handling material. This was required since insect farming requires the handling of a variety of materials to fulfil the many needs of the insects. The new gripper will be mounted on the robot arm extension. With this configuration, the robot can service a variety of crates from all CoRoSect insect farm partners and is now almost fully ready to perform the various tasks required by the insect farms.

During the beginning of the third project year, the M-Cell will be finalised and then intensively tested in the insect farms of the CoRoSect project throughout the rest of the year. Tools to be handled by the M-Cell to perform the various tasks in the insect farms will be optimised and software to fully integrate the M-Cell into the CoRoSect system will be finalised.

*Figure 13. Robot cell for handling insects (M-robot). Left: KUKA LBR iiwa robot arm with extension and gripper picking a drinking device for insects from a crate. Right: KUKA LBR iiwa robot arm with extension and gripper handling material on a pallet.*

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T7.4** | Autonomous Guided Vehicle (AGV) for transporting crates | M1-M30 | AGVR | ROB | In progress |

The Autonomous Guided Vehicle (AGV) used in the CoRoSect project is shown in the Figure below. The AGV is based on a standard product, the crawl under CU600. For usage in the insect farms, the CoRoSect partner AGVR adapts the hardware and software of the AGV. Software modifications are for instance part of Task 6.2 (SLAM/Navigation of AGVs) where an improved localisation software for the AGV is being developed.

The integration of the AGV in the CoRoSect platform is part of work package 9. Several interfaces are developed to communicate with central CoRoSect software systems for the coordination and monitoring of the movements in the insect farm.

In general the 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 second project year has been used to finalize the mechanical design, make the electrical design and actually build the AGV. Due to delayed component deliveries the build has been postponed a couple of months. At the end of the second project year the AGV was mechanically and electrically completely build.

Figure *14. Autonomous Guided Vehicle for transporting crates*

In project year 3 the software configuration and testing of the AGV will be performed.

## 2.1. Work package 8: Human-robot collaboration schemes

### Work package 8: Objectives

For a successful operation of robots inside insect farms, robots need to be able to effectively work together with humans. For this CoRoSect develops several technologies:

- The CoRoSect partners aim to enable the collaborative robot of the CoRoSect M-Cell to learn the correct execution of new tasks from humans. This should allow the robot to learn new tasks without the development of new software.
- Technologies are being developed to ensure that AGVs can autonomously plan and change their paths in the insect farms to avoid moving too close to humans.
- An interface is being developed that uses Augmented Reality to make human workers aware of the robot's actions to improve human-robot collaboration.

### Work package 8: Progress being made

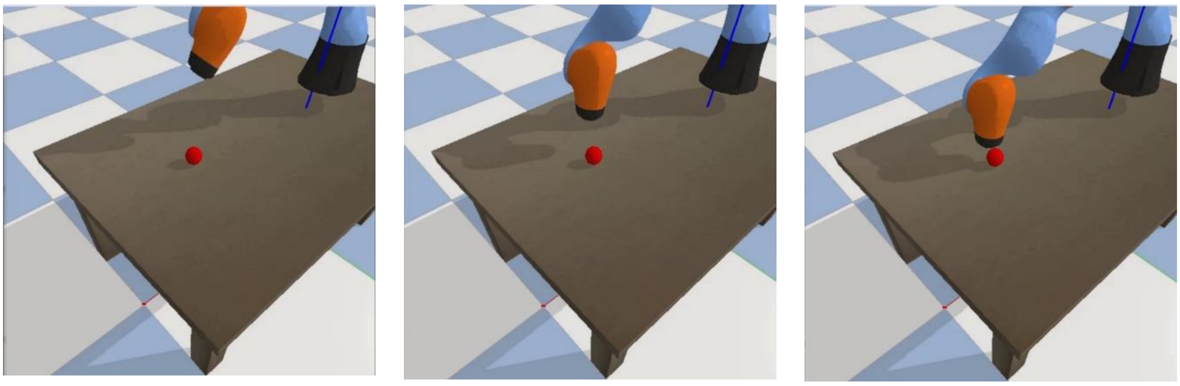
***Explanation of work performed at task level***

During the second project year, in work package 8 the CoRoSect partners concentrated on the following tasks that will continue also during the third project year:

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T8.1** | Learning from human input | M6-M30 | CERTH | UM, Nasekomo, ICF, Invertapro, Entomotech | In progress |

*Description of activities*

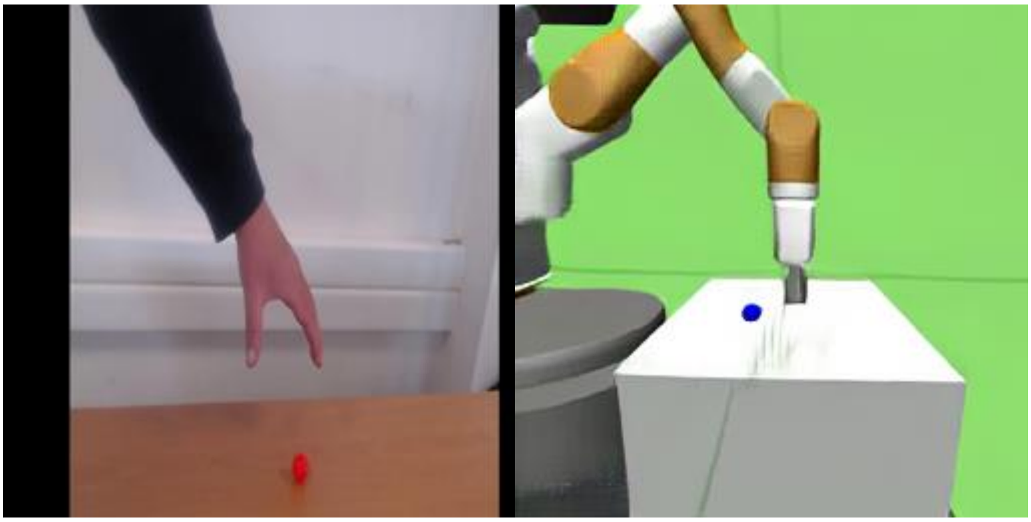
Within this task, the existing literature has been researched, and relevant techniques have been identified. Techniques using artificial intelligent algorithm with information from images were tested in basic tasks producing meaningful results. Next steps will include the design of specific scenarios, 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. Figure 15 shows an example of solving the reach problem of a randomly placed object using imitation from observation.



(a) (b) (c)

*Figure 15. Trained policy for reaching a randomly placed object. Each subfigure (a-c) shows the movement of the robot across time*

To teach a robot to learn to complete a task from a human such as picking and placing materials for insect rearing, we created a software that uses artificial intelligence. The software takes as input a sequence of images of a human and of a robot performing a task. The software then tries to match the actions of the robot to those of the human and predicts the optimal action that the robot needs to do in the next step. Figure 16 shows an example of an image from the human and the converted one in the robot. The state of the work so far is still preliminary and will be finalised and tested on the actual CoRoSect robot for manipulating insects in the third project year.



(a) (b)

*Figure 16. (a) Is the input image from the human environment and (b) is the output image converted in the robot environment*

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T8.2** | Autonomous and human-aware robot trajectory planning for safe and efficient HRC | M16-M32 | ATOS | NASEKOMO, ENTOCYCLE, ICF, INVERTAPRO, ENTOMOTECH | In progress |

*Description of activities*

To guarantee a safe environment for humans and robots where they can co-exist without any danger of collision, we have created, a dedicated tool able to create and manage safe routes for autonomous guided robots (AGVs) in an insect farm.

This tool has two missions:

- Create, under demand, new routes for the robots (route creation). These routes are then sent to the AGV to be followed until the route ends.
- Follow step by step the route followed by the AGV (route managing). If a new obstacle is detected on the route, the route is recalculated to avoid the detected obstacles.

The tool includes a simulated floor plan for the propose of testing the routes and the recalculation of them in case of obstacles detection (as can be seen in Figure 17)

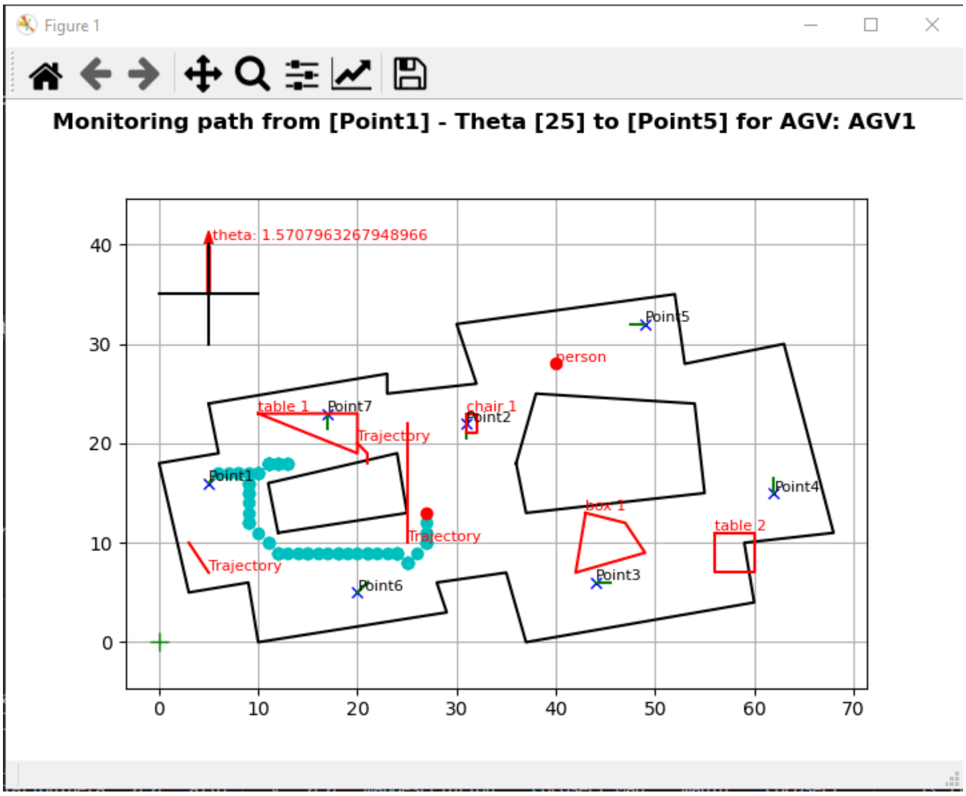



*Figure 17. Simulation of a route with obstacles*

The objective of this routes managing is to avoid collisions and, at the same time, prevent the robots to stop making them re-route around any possible obstacle instead. This last point is very relevant to make the robots usage more profitable by avoiding any unnecessary security stops whilst guarantying a safe environment for people.

This tool, in combination with the ones developed for Task 5.2 and Task 6.3 uses a different approach to the routes management than the one used in current state of the art solutions. Current solutions are based on the use of binocular cameras integrated in the same hardware device (e.g. a binocular camera on top or a robot). In our approach the solution is based on the use of already existing monocular (normal) cameras that can already be found in every factory. These cameras are fixed in the walls and are now used for surveillance tasks. With our approach, we use these cameras footage to analyse the scene, detecting element on it and estimating position and movement of elements present.

This new use creates the extra-challenge of estimating depth (equivalent to estimate distance with just one eye open). With this approach, we try to create a new way of managing routes using already existing infrastructures.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T8.3** | Human-machine interactions with AR for situation awareness and training | M6-M30 | CERTH | UM, NASEKOMO, ICF, ENTOMOTECH | In progress |

*Description of activities*

CoRoSect aims at increasing safety and efficiency when human workers and robots work closely together. For this CoRoSect uses augmented reality so that e.g. human workers can see the planned actions of a robot before the robot is executing these actions (see Figure 18). This provides a better understanding to human workers and allow for training human workers to work together with a robot arm in an insect farm or factory. The human worker will be provided information about the robot's next steps, notifications and advice, farm floor assignments and issues such as robot failure that necessitate human intervention. Microsoft's Hololens 2 is used to visualize simulated trajectories and an augmented-based safety net around the robot arm as shown in Figure 19. Warning messages are also provided to the worker regarding the safety distance to the robot so that collisions with the robot can be avoided (see Figure 20).

U

*Figure 18. 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.*

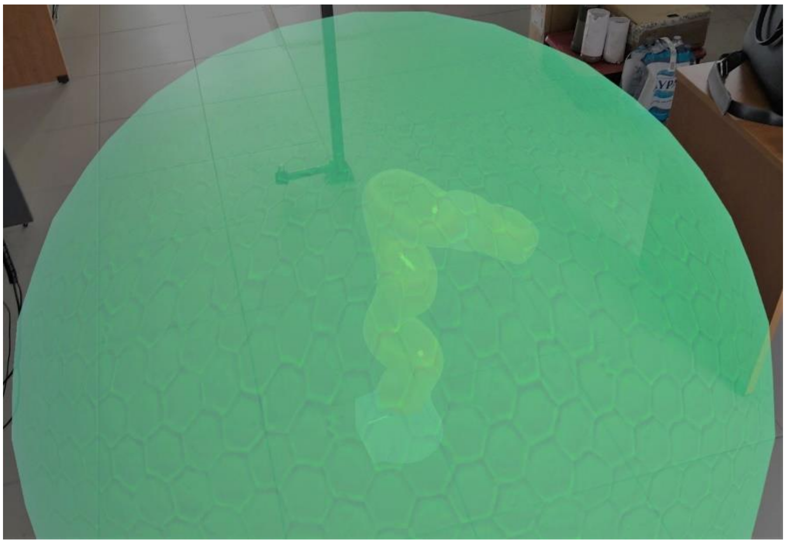


*Figure 19. Green 3D Safety-Sphere around the KUKA displayed in augmented reality makes a human co-worker aware of the area in which the robot might be moving.*

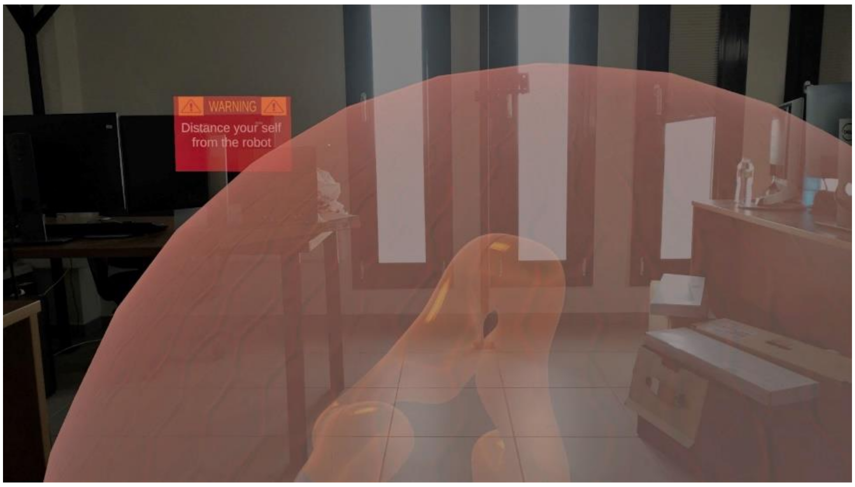



*Figure 20. Red 3D Safety-Sphere and warning message is provided when the human co-worker is getting too close to the movement range of the robot*

Furthermore, a critical role in human-machine interactions and collaboration is the human attention level. The attention level can affect cooperation either negatively or positively. For that purpose, an experiment was set up using the HoloLens 2 in an augmented manner to gather data required for AI training to predict the attention level of humans during the performance of a task. The experiment's task was the supervision of a robotic arm and the marking of the mistakes it made while different types of distraction occurred, as can be seen in Figure 21.

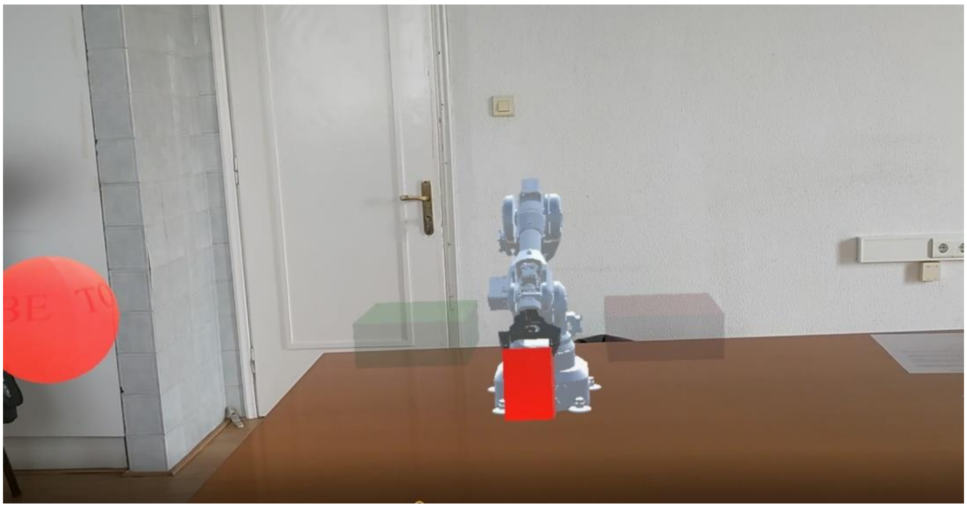


*Figure 21. Augmented experiment on HoloLens 2*

# Work package 9: Secure platform integration

## Work package 9: Objectives

CoRoSect aims to provide a fully integrated system where the different technologies being developed work well together. 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.

## Work package 9: Progress being made

***Explanation of work performed at task level***

During the second project year, in work package 9 the CoRoSect partners concentrated on the following tasks that will continue also during the third project year:

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T9.1** | Integration plan and platform interfaces | M1-M24 | HSEL | UM, CERTH, ATOS, TECNOVA, ROB, AGVR, OAMK, LUKE, CIHEAM | In progress |

*Description of activities*

During the second project year, together with the other CoRoSect technology developers, CoRoSect partner HSEL developed all the interfaces required to integrate all robots and software into the CoRoSect system. For this, the CoRoSect partners followed a state-of-the-art reference model for industrial applications: the reference architecture model Industry 4.0 (RAMI 4.0). As a result of these efforts, CoRoSect will become able to provide insect farms with a fully integrated solution where operators of insect farms can control all robots and observe all data generated by the sensors, robots, and software in the CoRoSect solution from a central interface, making the solution more user-friendly and easier to use.

To this end, there have been developments from the CoRoSect technology providers. Tests to integrate all developments have started and will be finalised at the beginning of the third project year.

The approach of the integration of the developments and the definition of their interfaces are detailed in the report D9.1.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T9.2** | Integration and ROS | M13-M34 | ATOS | UM, CERTH, TECNOVA, ROB, AGVR, HSEL, OAMK | In progress |

*Description of activities*

This first stage of Task 9.2 (M13-M24) has produced a first version of the CoRoSect System that integrates all the CoRoSect components and enables the interoperation between them, as well as the data sharing. For these purposes, it relies 1) on the Advanced CoRoSect System architecture provided by WP2 as the skeleton to set each component and define the data and commands flows according to the selected Industrial and Internet of Thinks protocols (D2.4); 2) the standard interfaces defined by Task 9.1 to program this communication between components (D9.1); and 3) the Digital Twins (data models) developed within task 4.3 to support the data and commands management.

The task has also provided a cloud implementation of the this first CoRoSect platform, focused on the project's Information Management System (IMS) and the interfaces for Industrial (OPC-UA) and Internet of Things (MQTT) protocols. The target of this first implementation is enabling all the project's components providers to test their corresponding digitalization and integration within the CoRoSect system, by testing data uploads/downloads and commands requests, following the Industry 4.0 standards. This cloud instance is all based on open-source code and uses a Kubernetes (an orchestration system for automating software deployment, scaling, and management) framework to compose and update the instance.

This is all detailed in the report *D9.2 – Integrated CoRoSect Platform Release (Version 1)*.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T9.3** | Testing, optimization, and technical validation | M20-M25, M30-M36 | ATOS | UM, CERTH, TECNOVA, ROB, AGVR, HSEL, LUKE, CIHEAM, NASEKOMO, ENTOMOTECH, ENTOCYCLE, ICF, INVERTAPRO | In progress |

*Description of activities*

Starting in August 2022, task 9.3 is identifying and defining the different tests to evaluate the first release of the CoRoSect's Platform. This is essential to ensure that all components (such as robots and software components) properly work together. The initial planned tests will be oriented to:

- Test interfaces and connectors developed in Task 9.1 and Task 9.2, to ensure proper integration of CoRoSect components. These tests will make sure that data can be gathered from the robots and software components and is properly stored in the CoRoSect Information Management System. Additional tests ensure that the robots properly understand commands from human operators.
- Test performance, such as the response times of software components.

- Test interactions between different robots and software components.

All these tests are still in definition process and will be detailed (tests and results) in the report *D9.3 – Test Cases for the CoRoSect Ecosystem*.

# Work package 10: Pilot studies demonstration and evaluation

## Work package 10: 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.

## Work package 10: Progress being made

***Explanation of work performed at task level***

During the first project year, the pilot scenarios, on which the CoRoSect technologies will be tested, have been defined. During the second project year, in work package 10 the CoRoSect partners concentrated on the planning and preparation of the pilots. In addition an initial pre-pilot has been implemented on which some of the CoRoSect technologies have been tested.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T10.2** | Pilot preparation and planning | M7-M20 | TECNOVA | UM, ROB, AGVR, HSEL, NASEKOMO, ENTOMOTECH, ENTOCYCLE, ICF, INVERTAPRO | Completed |

All CoRoSect partners have been intensively working on the organizational and technical preparations for the implementation of the defined Use cases and pilot scenarios and their demonstrations at the CoRoSect insect farms. The information has been compiled in the report *D.10.2 Pilot preparation and planning.*

The final decisions taken about the use cases that will be deployed by the CoRoSect partners are:

| Insect farm | Use case/pilot scenario |
|---|---|
| Inverapro in Norway | • Quality Management and Intervention to ensure the growth, quality, and wellbeing of Mealworms<br>• Ovipositioning management (management of adult beetles and eggs) |
| Italian Cricket Farm in Italy | • Quality Management and Intervention to ensure the growth, quality, and wellbeing of crickets<br>• Cricket Management (including automated feeding of Crickets) |
| Nasekomo in Bulgaria | • Quality Management and Intervention to ensure the growth, quality, and wellbeing of Black Soldier Flies<br>• Ovipositioning management (management of adult flies and eggs) |

| | |
|---|---|
| Entomotech in Spain | Here we again run use cases for Black Soldier Flies as well as for Mealworms. |

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T10.3** | Pilot deployment | M21-M36 | TECNOVA | UM, CERTH, ATOS, ROBOTNIK, AGVR, HSEL, OAMK, LUKE, NAKESOMO, ENTOMOTECH, ENTOCYCLE, ICF, INVERTAPRO. | In progress |

*Description of activities*

While the 4 main pilots of the CoRoSect project are planned for project year 3, in the second project year the CoRoSect partners already performed a first pre-pilot at the insect farm Entomotech. This pre-pilot was used to test and optimise many of the CoRoSect technologies and to gather valuable insights on the insects for which the technologies are being developed. We tested the identification, detection and measurement of the insects' larvae and adults with the visual cameras which helps us to classify the different abnormalities needed for the insects inspections. We also performed initial test with the CoRoSect robot for handling insects as well as with the CoRoSect sensors.

Furthermore, at the pre-pilot the CoRoSect Information Management System was tested and connected to sensors and simulations of the CoRoSect robots. These tests allowed us to identify where further improvement could be made. The insights generated during the pre-pilot helped the CoRoSect partners to prepare well for the main pilots of project year 3 and to ensure that the technologies will be ready when required.

# Work package 11: Dissemination, communication and exploitation

## Work package 11: Objectives

CoRoSect aims to maximise 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.

## Work package 11: Progress being made

***Explanation of work performed at task level***

During the second project year, in work package 11 the CoRoSect partners concentrated on the following ongoing tasks:

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T11.1** | Dissemination and Communication Plan | M1-M36 | FSH | ALL | In progress |

*Description of activities*

The second year of CoRoSect implementation has brought a very dynamic and upgraded set of activities for dissemination and communication of project goals and results. This has been achieved through the visual identity of CoRoSect. The online presence was established with a landing page, social media accounts (LinkedIn, Twitter, Facebook, Youtube) and branding material. The recognizable image and awareness around the project set up during the first year of the project has been significantly enhanced during the second project year.

The CoRoSect partner FSH has updated its strategies regarding reaching out to the CoRoSect audience. We have entered the second phase of dissemination and communication actions, meaning that in this period we have focused on providing content that is more personalized (content tailored according to the audience that follows CoRoSect), educative (to provide knowledge), informative (to inform about the project's developments and achievements) and tangible (to show practical side of the project through videos and pictures). Hence, our audience and potential adopters can better understand the purpose of the CoRoSect solutions.

Furthermore, the CoRoSect website got a slight makeover, making it more accessible and easier for our users. Within the website, the Newsroom tab got a new look. In this section, FSH has added a Media Corner tab, where all CoRoSect branding material can be downloaded. Furthermore, FSH created a niche for more interactive communication with our audience. The aim is to enable our visitors a chance to share opinions, ask questions, and start a discussion about different areas of the CoRoSect work.

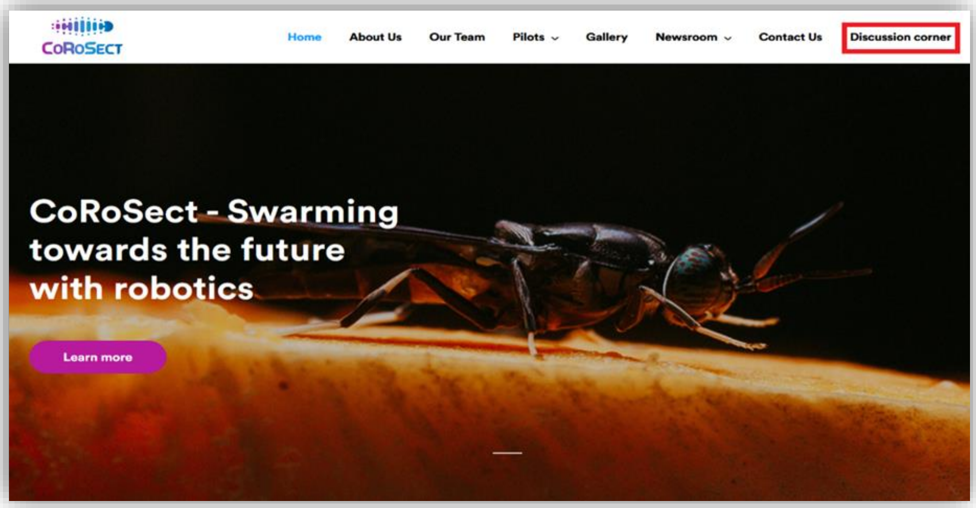



*Figure 22. Discussion corner tab on the CoRoSect Home-page*

FSH designed the Discussion Corner, in the way to be appealing, intriguing, informative and encouraging. The aim is to inspire visitors to ask questions regarding our work. On the left side of the window, the CoRoSect audience can see previously asked questions – the purpose is to encourage them to ask questions, and to assure them that they will be answered. However, on the right side of the window, users will have a chance to fill in the form and send us inquiry about what interests them.

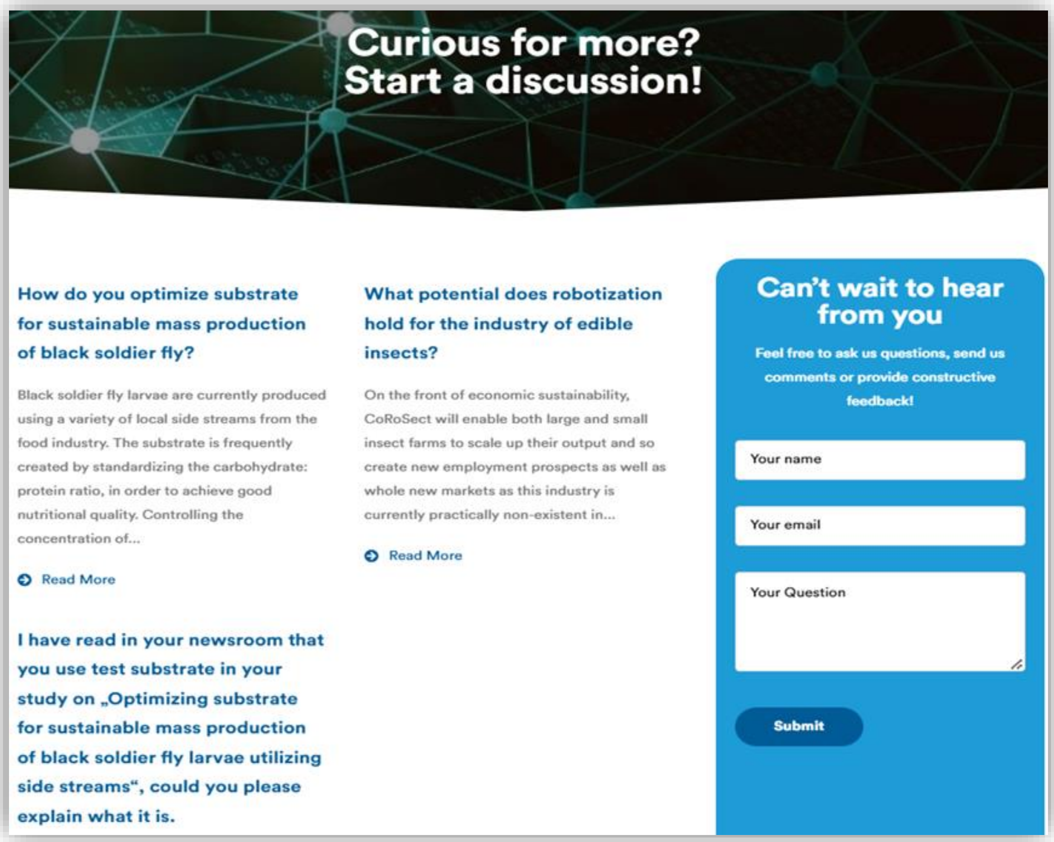



*Figure 23. Discussion Corner*

Having in mind that results are coming to the surface, hence FSH has also significantly upgraded Communication and Dissemination Activities.

| | Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T11.2** | Communication and Dissemination Activities | M1-M36 | FSH | ALL | In progress |

*Description of activities*

Through our communication and outreach activities, we are preparing the market and the ecosystem for the 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.

Furthermore, with emerging results, the CoRoSect website is regularly updated with the news, and scientific developments of our partners under the "Insect farming stories you won't find anywhere else". This particular part of the CoRoSect website is dedicated to the insights and outcomes of the innovations tested in real-time environments.

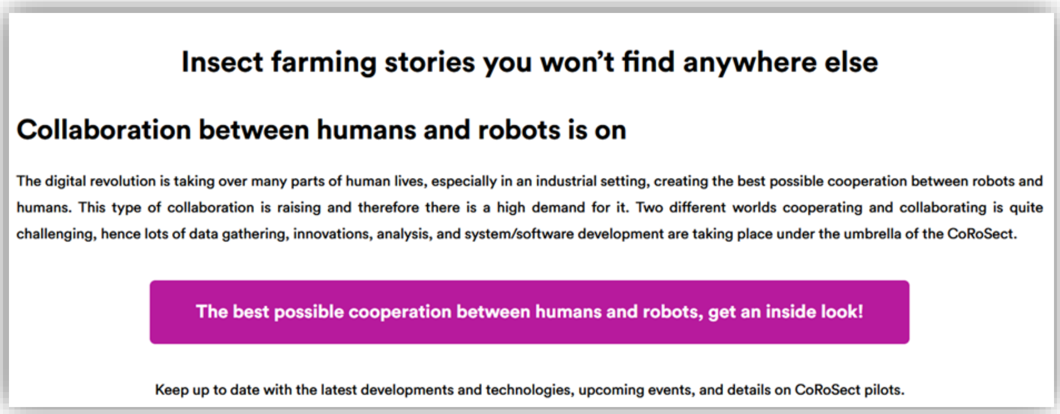



*Figure 24. Insect farming stories you won't find anywhere else*

Moreover, to enable our audience possibility to be the first one to receive the most recent information and updates, FSH created Sign-up Button on the LinkedIn profile, which leads directly to the Newsletter subscription.

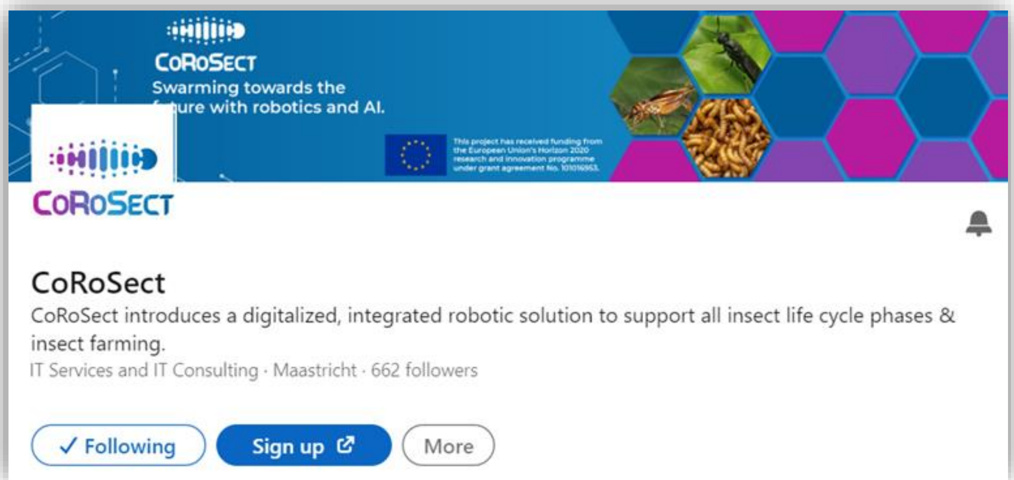



*Figure 25. Sign-up Button on the CoRoSect LinkedIn profile*

To further inform our audience, FSH has launched several campaigns of informative and promoting character. The first one aims to educate and inform our audience of the CoRoSect goals, mission, and vision, and most important to show transparency and accountability of our work. The latter serves the purpose of promoting and celebrating the success of our partners, especially the outcomes of the pre-pilot activities.

The best way to convey messages, updates, developments, outcomes and achievements is to utilize Social Media tools. For this reason, FSH designed visuals appropriate for each campaign, to bring CoRoSect closer to the audience.


*Figure 26. Example of informative campaign*


*Figure 27. Example of the promotional campaign*

| Task | Duration | Lead | Contributors | Status |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **T11.3** Community Building | M1-M36 | AFL | FSH | In progress |

*Description of activities*

During the second year of the CoRoSect implementation, CoRoSect has participated in various online and offline events. The community building is of great importance not only for promotion and presentation of the project's outcomes, but also connection with important ecosystem stakeholders, insect farmers, tech providers, and other actors. The overall aim is to increase networking among stakeholders, while also provide better understanding on the benefits of the dynamics of our work. This will further serve the purpose of reaching our stakeholders for post-project exploitation.

In the second project year, CoRoSect was involved in over 20 different activities, such as conferences, exhibitions, workshops, etc. The CoRoSect's role was not only to present its achievements, but also to actively participate and co-organize them. Most events, where CoRoSect participated are introduced further in the text.

At Advanced Factories event CoRoSect presented an appropriate option for industrial application in indoor environments like factories or warehouses, where transport is one of the most demanded operations. Furthermore, since insects are the missing puzzle in the modern food chain, CoRoSect used the opportunity at the 73$^{rd}$ Annual Meeting of the European Federation of Animal Science to shed light on the insect digital twin developed by one of the CoRoSect partners.


*Figure 28. CoRoSect at EAAP2022*

INSECTA 2022 is the place where science and industry engage in fruitful knowledge exchange encompassing newcomers and experts. The aim of the conference is to build a strong ecosystem, and connect companies and research institutes that play a major role in insect production and application, so the prospective aspects of insect technology could be discovered and implemented. Hence, CoRoSect presented its work within the project framework entitled „Optimizing substrate for sustainable mass production of black soldier fly (Hermetia illucens) larvae utilizing side streams". This provided the chance for CoRoSect, to show how important is to have control over insects' diets, in order to ensure larvae growth and well-being.

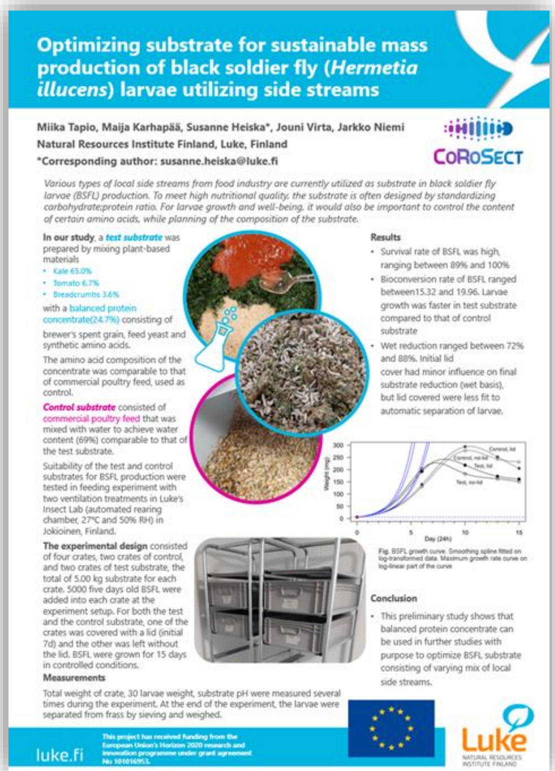



*Figure 29. CoRoSect at INSECTA 2022*

Technological developments were presented at FIWARE Summit. The two-day Fiware Summit featured cutting-edge innovation, increased teamwork, and networking opportunities. FIWARE offers support to people who want to use well-known Open Source technology to change this world for better, predict the future, or disrupt the market. CoRoSect's Information Management System (IMS) and the Route Manager components for the safe human and robot collaboration (HRC) environment was in the spotlight.


*Figure 30. CoRoSect at FIWARE Summit*

| Task | | Duration | Lead | Contributors | Status |
|---|---|---|---|---|---|
| **T11.4** | Exploitation strategy, business plan and IPR | M1-M36 | AFL | ALL | In progress |

*Description of activities*

In the second project year, as the WP leader, FSH organized IP (intellectual property) workshop in April 2022. The workshop aimed to provide all partners proper explanation of potential IP issues. Before the workshop was conducted, FSH developed an in-depth survey with the purpose to get a full picture of the partners' perceptions of IP rights in CoRoSect. The survey enabled us to get an overview of the basic IP situation/strategy of CoRoSect partners at that particular moment and in the future (e.g., if they plan to protect any asset).

After this cycle of the survey, it was agreed among core work partners, the future steps regarding the exploitation strategy and business plan. For the best benefits and outcomes of the CoRoSect project, the following plan will be executed. A business plan for the overall CoRoSect system will be created, which will include market analysis, business model, organization structure, IP issues, marketing, financial projections, customers, competitors, etc. Moreover, individual exploitation strategies for individual components will be analyzed and created, under the umbrella of the CoRoSect system, and this will be exploited by the partners.

For the best benefit of the project, core tasks' partners will repeat the survey after each piloting, in order to fine-tune the strategies. Additionally, with emerging tangible results the commercial perspective of the CoRoSect system will be sharpened. The focus will also be on the identification of the components of the CoRoSect solution that can be further available and exploited. As the use cases are developed and deployed, there are still a few ongoing issues, questions, and discussions that need to be addressed. Therefore, core tasks' partners will conduct the survey and collect inputs within January 2023. After thorough analysis of the survey, a roundtable and one-on-one session will be arranged within January 2023, to better define partners' interests.

# 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 analyse whether, and to what extent, the ethical guidelines for trustworthy AI and any other relevant tools 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 gentle touch that ensures the well-being of the animals.

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

When handling insects and materials in insect farms, many unforeseen changes can happen. The colour of the food might change daily. Large groups of insects form different contours and might make it impossible to see the food. 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 no less than trying to help securing a sustainable food production. To achieve this goal, CoRoSect works with a holistic approach, taking into account the needs of insect farms, their workers, developing robotic technologies, sensors, artificial intelligence and software to coordinate the many components within the insect farms. CoRoSect will provide not only several innovative technologies but is working also towards an integrated solution where all of CoRoSect technologies harmoniously work together with human workers, keeping the human workers in control.

During the second project year, together, CoRoSect partners made substantial progress in the development of the many technologies required for insect farming, achieving several key milestones. Important steps have been taken towards the integration of the CoRoSect technologies in parallel to the development of the individual components. Several components are finalised or close to finalisation. A first successful test in the insect farm of our CoRoSect partner Entomotech in Spain has been realised.

During the third and final project year 2023, the CoRoSect partners will be dedicating their efforts towards the demonstration and testing of the CoRoSect technologies. During 4 large-scale pilots at the insect farms of Nasekomo, Invertapro, Entocycle, and Italian Cricket Farm the integrated CoRoSect technologies will be piloted and evaluated. For this the CoRoSect partners have carefully planned during the second project year so that in the end well-integrated and well-tested solutions will be delivered for enhancing insect farming.

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