CoRoSect

D6.7 : Safety concept for robotic systems (planning)

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AAS	Asset Administration Shell
AGV	Automatic Guided Vehicles
AI	Artificial intelligence
DIN	Deutsches Institut für Normung
EN	Europäische Norm
IEC	International Electrotechnical Commission
IPxx	Ingress Protection (followed by two numbers)
ISO	International Standardization Organization
JSON	JavaScript Object Notation
MQTT	Message Queuing Telemetry Transport
ONVIF	Open Network Video Interface Forum
RAMI 4.0	Reference Architectural Model Industrie 4.0
RTSP	Real Time Streaming Protocol
SIS	Safety Instrumented Systems
SLAM	Simultaneous localization and mapping
SLC	Safety Life Cycle
UNE	Una Norma Española
YOLO	You only look once

Executive Summary

CoRoSect includes in its core concept the coexistence of people and machines in enclosed spaces (insect farms). In such environments it is important to ensure that there is no danger to people while not affecting the overall performance of the factory. This deliverable alongside *D6.8 Safety concept for robotic systems (documentation)* due to M24 and *D6.9 Safety concept for robotic systems (final)* due to M36 describes all the measures taken in the project to ensure such coexistence. Current deliverable will focus on the theoretical planning of the safety concept while D6.8 will document the actual elements finally built for the project and D6.9 will include the conclusions obtained after its real use in the project´s pilots. Note that these new measures do not override or eliminate existing safety measures already existing (and in many cases mandatory by law).

Introduction

”Safety comes first”, this is the first directive in the industry. CoRoSect project has the objective of the automation of insect farms passing from current ”almost manual” operations stage to a fully automated operational stage. Such automatization created new risks in safety. In a fully automated farm, we will have autonomous robots moving “elements” and operating in a dynamic environment and making their own decisions. We should ensure that this does not create any hazard to the human beings, no matter their behaviour (e.g. even if they enter into ”no trespass” areas). On the other hand, we cannot override any existing security measures already in place for the machines (that usually make them stop). Finally, we want to improve the efficiency of the operation of these machines by preventing them to collide in advance (advance in time and distance) and at the same time keep them moving as much as possible to avoid interruptions, thus improving overall efficiency. This creates for us three key requirements that we should fulfil (in order or importance):

1 Humans must not be put in danger in any moment.
2 Existing safety measure must not be overridden (even if this provokes machine to stop working)
3 Operations, even if fully automated, should not be interrupted whenever possible, if adequate and guaranteed permitted situation consists. Stopping the machines should be always the last option.

Current deliverable, result of the *Task 6.3 Implementing safety control in robotic (planning)*, is the first of a three-document series. It will describe the planning made in CoRoSect for these safety related issues.

Section 1 will describe the standards that we need to consider for Safety in CoRoSect. Section 2 will include the description of the safety requirements that CoRoSect creates. Section 3 will describe our planned approach to the problem taking this requirement into account. Finally, Section 4 summarizes the document results in the conclusion.

1 Safety standards considered in CoRoSect

CoRoSect has to follow safety standards that could be mapped in RAMI4.0. This includes IEC 61511, IEC 62061 and ISO 13849. In this section we will make an overview of these standards.

1.1. RAMI4.0 safety standards

The Reference Architectural Model Industrie 4.0 (RAMI 4.0) also known as DIN SPEC 91345 [1] is a service-oriented architecture for the industry. It is also a standards-based architecture to enable the connectivity between components. At such, RAMI 4.0 has no “official set” of standards for safety, but use the accepted industry standards like IEC 61511, IEC 62061 and ISO 13849.

1.1.1 IEC 61511/EN 61511

An International Electrotechnical Commission (IEC) standard [2] for the safety of industrial processes by using instrumentation. This standard covers the application of electrical, electronic and programmable electronic equipment in many types of manufacturing processes. The standard covers the requirements for Safety Instrumented Systems (SIS) in all the Safety Life Cycle. Implementing a previous base standard, IEC 61508, it provides good engineering practices for the application of safety instrumented systems in the process sector.

1.1.2 IEC 62061/EN 62061

IEC 62061 is an IEC standard [3] for the safety of electrical, electronic and programmable electronic control systems. In the same way as with IEC 61511, it is an implementation of IEC 61508, in this case for machinery. It provides requirements applicable to the system level of all kinds of machinery safety-related electrical control systems.

1.1.3 IEC 61508

This international standard from IEC is the basic functional standard for safety valid for all industries. It defines the Safety Life Cycle (SLC) as an engineering process based on industry best practices. Additionally, it includes a statistical failure approach for the safety impact of failures. Critical for the standard, Safety Life Cycle is defined as all the phases starting ”from initiation and specifications of safety requirements, covering design and development of safety features in a safety-critical system, and ending in decommissioning of that system”[1]

1.1.4 UNE-ISO 13849

This standard of the International Standards Organization (ISO) is a safety standard for machinery control systems designed for safety functions (the so-called safety-related parts of the control system). It provides principles for design, provides safety requirements on the principles of design and integration of safety-related parts of control systems (both hardware and software) and for its validation. The process of design described in the standard is based in a risk assessment of the machinery.

1.1.5 Applicability of RAMI 4.0-complaint safety standards

The approach described in this document, based on Task 6.3, does not include the use of information coming from robots or any other mobile asset. Current approach is purely based on observational data coming from cameras. This approach limits applicability of safety standards to RAMI4.0.

[1] https://www.wikiwand.com/en/Safety_life_cycle

In any case, the detection subsystem described in this document is part of a bigger system of Safety Control (see *D2.3 Initial system architecture* for details of this system). This full system includes data coming from robots and other Asset Administration Shell (AAS) driven modules. Inside this full system, the safety standards can be addressed as RAMI 4.0 complaint. This system will be described in *D8.2 Autonomous and human-aware robot trajectory planning for safe and efficient HRC* due to M32.

2 Safety hazards requirements in CoRoSect

CoRoSect project aims to automatize and digitalize the working environment of insect farms. This creates a full set of requirements related with safety hazards that we need to consider. In this section we will describe what is planned for the project and what are these requirements created by the project and its planned tasks.

2.1 Overall objective

To focus the discussion, lets describe first the overall objective of CoRoSect for the automation/digitalization. Note that this automation/digitalization is just one of the objectives of the full project.

The objective that we consider here is to include autonomous robots able to move autonomously and continuously in the insect farm factory with the mission of moving and managing the insect crates between different "stations" and for different operations (clean, feed, etc) related with insect rearing. It goes without saying that the human being will direct these machines in the different operations.

2.2 Environment

The first element we need to consider is the environment where we will deploy the robots deployed for the project. This environment is an insect farm where insects are grown and fed following different stages (different depending on the insect). There are always some common environmental factors in all the farms considered for the project:

- Farms (in our pilots) are typically rectangular closed naves with "main working areas" typically between 10 to 20 meters of side. Usually, there are no physical separations (i.e. rooms) inside each of these "main areas". The full space considered is divided into different stations (for each phase of operation). The aisles allowed for movement are created by these stations and the piles of insect crates. This creates different roads available for movement that should be shared between all participants (people and machines).
- Physical environment has high humidity and temperature with, in some operations, low light conditions (due to the necessities of rearing the insects in some phases)

This provides us with our first hazard-related requirements: **Shared areas of pass, fixed layout without walls, high humidity and temperature** and **low light conditions**.

2.3 Operations

Without entering in full details of the operations, the operations of the farm that interest us from the point of view of the requirements for hazard avoidance, consist typically on the manipulation of the "insect crates" and the movement of the piles of crates between stations. This adds two requirements of **movement of piles of crates** around the factory and **local manipulation of crates**.

Additionally, the movement of the machines should avoid any collision, no matter the "object" creating the issue (people or any unexpected element in the aisle). This gives us another requirement; **avoid collision with any obstacle** at all times.

2.4 Automation intended

One of the aims of CoRoSect is to automate/digitalize the operations described. We want to add autonomous robotic arms to manipulate the crates and Automatic Guided Vehicles (AGV) able to transport piles of crates deciding and following their own routes (there are, of course, more element, like conveyor belts, etc, but they can be considered part of the factory static layout since they don't share the areas of pass or has their own movement). Moreover, we want these elements to be able to provide continuous operation without any interruption. This means that any potential collision should be avoided, whenever possible, by modifying trajectories without stopping the machines. It goes without saying that, stopping the machines completely, will be always included as a "last resort" measure to avoid any danger to people or to machines (in the case of collision with unexpected obstacles).

This adds the requirements of **use of autonomous machines creating its own routes,** of **continuous operation keeping the movement** whenever possible and of **not override current safety measures** already in place.

2.5 People behaviour

We consider that there will be people in the factory, no matter how autonomous the machines or the operations will be. For people we should consider the necessity of keeping them safe at all times no matter the actions or restrictions in place. We cannot think that, for example, since the robotic arm has a "closed area" no one is going to invade this area. The requirements for people are; thus, **people will access all areas** (even if dangerous of forbidden) and **people has to be safe at all times avoiding all collisions and near-miss**.

3 Plans for safety concept in CoRoSect

Taking into consideration all the described requirements what we have obtained from CoRoSect operations, we have this table (Table 1):

Table 1 - List of Requirements

Environment	**Shared areas of pass**
	Fixed layout without walls
	High humidity and temperature
	Low light conditions
Operations	**Movement of piles of crates**
	Local manipulation of crates
	Avoid collision with any obstacle at all times
Automation	**Use of autonomous machines creating its own routes**
	Continuous operation keeping the movement (for the machines)
	Not override current safety measures
People	**People will access all areas**
	People has to be safe at all times avoiding all collisions and near-miss

Additionally, there are other operational requirements (Table 2):

Table 2 - List of operational requirements

Operational	**Full control of the area of interest**
	Avoid blind areas
	Use of Wifi
	Use of cameras able to stream video
	Need to have all elements positioned (use of coordinates)

To cover all these requirements, we are planning the use of fixed cameras combined with artificial intelligence (AI) algorithms with the result of detecting potential collisions with people and any other obstacles while avoiding machines to stop working.

The planned work has been divided in two: planned physical layout (section 3.1) including the physical elements considered (cameras) and planned software layer (section 3.2) that includes all the software analysing and using the cameras footage.

3.1 Planned physical layout

Considering the requirements, the planned physical layout will consist in the use of many cameras (typically three, but depending on the geometry of the factory) able to cover all the area with the following conditions:

- All cameras together should cover the entire area of interest
- Any possible place in the area of interest should be visible, no matter the obstructions (e.g a pile of crates). We cannot afford to have any "blind areas", so we will try to avoid them as much as possible using many cameras

- Cameras should be fixed in order to control the space. This implies that the "effective distance" covered by any camera should be typically less than 20 meters and that the cameras should be calibrated for improving the measurement precision. The "effective distance" means the distance at which the AI algorithms can detect "objects" with high reliability considering the camera resolution and the AI model used. In layman terms, this for example means that we cannot guarantee detecting a person at 30 meters with high reliability.
- Using the cameras, we should know the coordinates of every possible element (fixed or not) in the area of interest. For the camera itself, this implies that each camera needs to be calibrated.
- Cameras should be IP66 at least to stand high temperature-high humidity conditions
- Cameras should have infrared led lights to enhance vision in low light conditions
- For operational reasons, we also need the cameras to be able of WiFi connectivity and "ONVIF capable", that is, able to stream the footage using RTSP protocol or similar
- All cameras used will be "monocular" in principle (that is, having just one objective)

An example of a typical layout that we are considering can be seen in Figure 1:

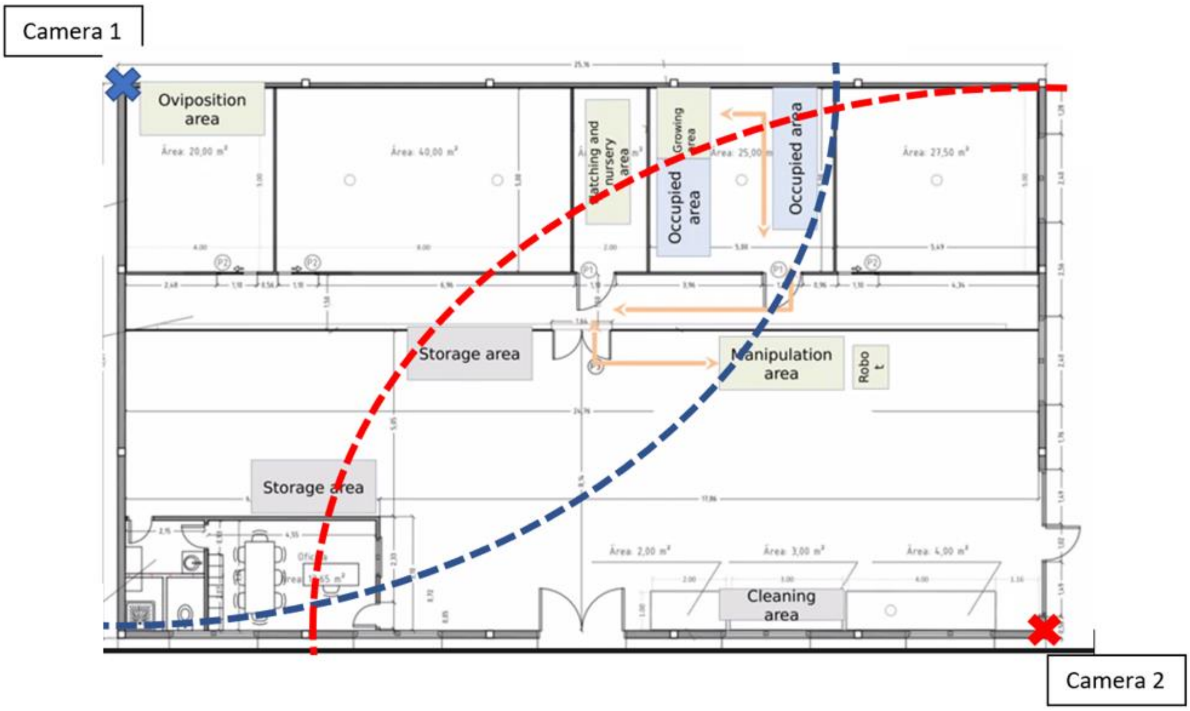

Figure 1 - Example of disposition of fixed cameras in a factory

3.2 Planned software layer

These cameras will provide footage in streaming that will be consumed in real time (soft real time) by the software layer. This software layer will have different layers for the determination of the factory space, detection of people and its distance, detection of any obstacle and its distance, coordination between cameras and sending of obstacles detected to the main control.

Note that, at this stage, this planned software approach has not been tested, integrated and fully validated. It is possible that, during their development and integration we will need to change some of the algorithms considered and here described.

3.2.1 Establishment of the factory space in 3D

The first element that we need, before analysing the space in real time, is the establishment of the space of the factory and its fixed elements to determine the coordinates of all elements.

This establishment has to be done before any other operation and will consist in the use of two different AI algorithms:

- Use of a SLAM algorithm or similar to determine the space of the factory. We will need to use a camera passing through all the factory space to determine the coordinates of all "fixed" elements, that is, the bare factory without any "obstacle" in the aisles. This will create a baseline that we will use to determine the position of any object or people acting as an obstacle.
- Use of 3D reconstruction of the space in order to create a human-friendly perspective of the space. This projection will be synchronized and coordinated with the SLAM (Figure 2). This will create a baseline 3D reconstruction of the space.

The result of this previous phase will be to have a map of the factory with a clean baseline of "fixed" elements and a set of coordinates that will allow us to situate all elements in the area of interest.

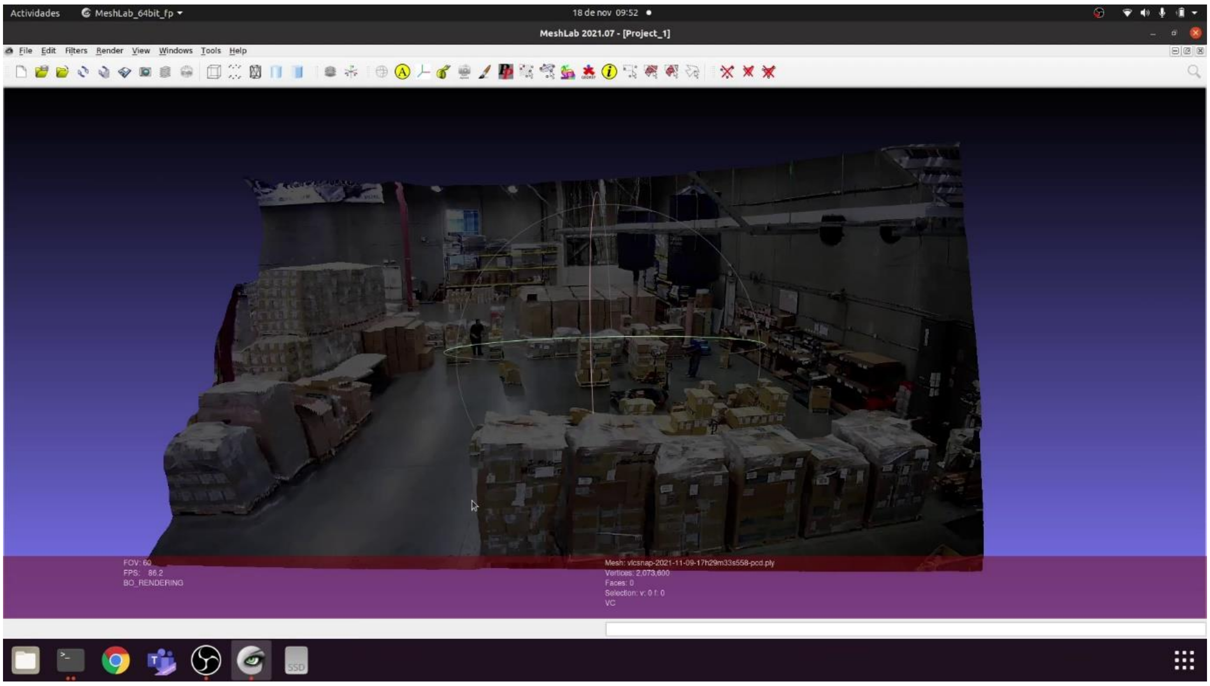

Figure 2 - Example of 3D reconstruction

Now that we have clear the area of interest and the possibility of setting coordinates of every element, we can now detect "obstacles" like people and "unexpected objects" (like a box fallen in the middle of an aisle) and place them in the coordinates space.

3.2.2 Detection of people in the factory space

For the detection of people and the determination of their position relative to the camera, we will use:

- Algorithms for the detection people using latest state of the art detector for people in less than 20 meters as seen in Figure 3. This could be for example YOLO v5.

Figure 3 - Detection of people

- Algorithms for the detection of the position of the people in the space, that is, their distance relative to the camera as can be seen in Figure 4

Figure 4 - Distance of people

Note that in these detections of people and its position, the estimation of the position provided can change from frame to frame. This problem will have to be corrected using different procedures. For correction, we have considered that we will need to use:

- Calibration of the cameras
- Use of Kalman filter to “smooth” the trajectory and distance avoiding “leaps”. This will provide continuity to the measures
- Use of “ground truth” elements in the real factory to determine real distances and correct deviation of values. This will be marks in the floor with its real distance known
- Use of tracking algorithms to follow the people in order to avoid “leaps” (see Figure 5 for an example with people). This will provide continuity to the measures for the same “items” detected

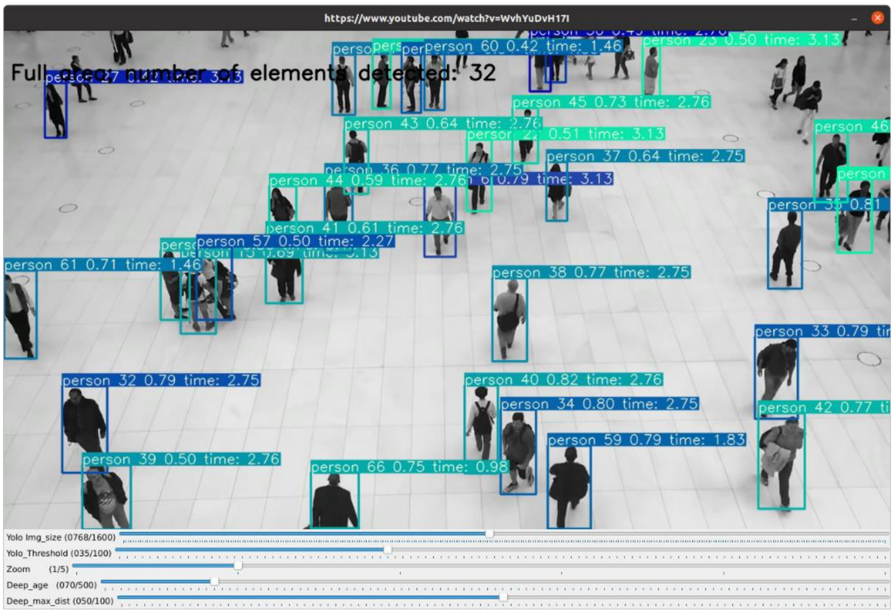

Figure 5 - Tracking of people

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

3.2.3 Detection of any object in the space

We will have to detect the position of “any” object that was not previously present in the map baseline, no matter if is “static” or is moving. This broad category will include from unexpected obstacles (e.g. a crate that has fallen in the middle of an aisle) to moving robots.

For this task, we will use an AI algorithm able to detect “objects” (generic) and its trajectories. Additionally, we should be able to place these objects in our coordinates space (see Figure 6). As an alternative to this AI algorithm, 3D subtraction of the baseline space (created in 3.2.1) is also being considered for this task.

Many details of the algorithm that will be used and its positioning precision capabilities are still in study.

Note that it is possible that we will need a Kalman filter approach to determine the projection of the trajectory of the moving elements following the same reasoning we followed for people trajectories.

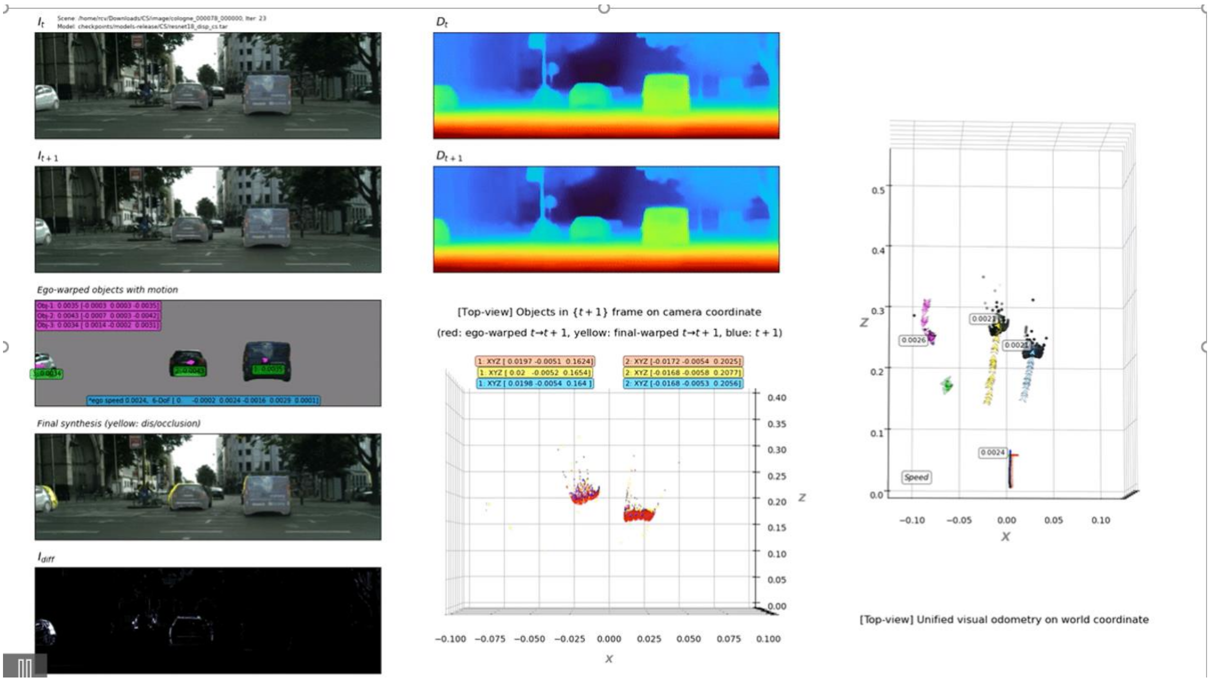

Figure 6 - Position of generic objects (from [4])

3.2.4 Coordination between cameras to avoid blind areas

During the detection of people and "any" obstacle in the coordinates space it is necessary to coordinate the cameras to confirm detections in case there is any partial occlusion (for example created by any pile of crates). This will be done by using the transport protocol that we are using in CoRoSect (RabbitMQ MQTT) with specific messages. Note that, for this process to work properly, the space and all its elements (including the cameras) needs to be positioned with known coordinates and all the detections should be placed with the maximum precision as possible.

3.2.5 Sending obstacles detection message

During all the detections described we will need to transform coordinates between cameras, map and objects to obtain the "real" position of the obstacles in the factory space. This corrected set of coordinates will be sent using RabbitMQ using a JSON message to the central area of the CoRoSect as a "detection" event. The JSON describing this event is not yet defined. This JSON will follow standardized data models.

In the central area of CoRoSect, this information will be used to determine if a possible collision can happen.

3.2.6 Open issues

There are many open issues that we will need to solve during the creation phase of all the elements described:

- We will need to put all detections, that comes from different AI models, in the same coordinates space and with a precision good enough (e.g. we cannot place a person "inside a wall of crates"). Also, we will need to smooth the detections to make the trajectories coherent and continuous (without leaps). Note that the AI models used are creating predictions that are “per frame” without any continuity. We will need to add this continuity. All these constraints will imply different procedures:

    - Use of calibration for the cameras in the real space.
    - Correction of the detected position using known marks in the real space
    - Use of Kalman filters to smooth trajectories
    - Coordination between detection of different cameras
    - Use of tracking algorithms to follow the “objects” or people to avoid positional “leaps”

- The algorithms that we plan to use for all elements need to be tested and validated. It is possible that this will imply the change of any or even all of them if they are not good enough or a better alternative is found
- The management of the baseline for the map is also an open issue. We can easily set a first baseline of “empty factory” before starting the detection, but we need to find a way of re-setting this baseline in case some new elements are added as “fixed” (the factories are not static, sometimes a new element is added, or the previously “fixed” elements are moved)

4 Conclusion

This deliverable is the first of three dedicated to the safety planning for robotic systems. In it, we have described the plan for the detection of ”obstacles” and people. In this stage, this is just a plan of the software-hardware that we are starting to implement. This means that many of the elements described, especially in the software, will surely evolve and will be modified for many reasons like lack of precision, problems with coordinates, etc. In the second version of this document *D6.8 Safety concept for robotic systems (documentation)* due to M24 we will describe this evolution and the resulting software elements finally created.

Finally, all these hardware and software solutions will be put into real use in the pilots. This will surely further modify the software. The final version will be described in *D6.9 Safety concept for robotic systems (final)* due to M36.

References

[1]. Nagorny, K., Scholze, S., Colombo, A. W., & Oliveira, J. B. (2020). A DIN Spec 91345 RAMI 4.0 Compliant Data Pipelining Model: An Approach to Support Data Understanding and Data Acquisition in Smart Manufacturing Environments. *IEEE Access*, *8*, 223114-223129.

[2]. Gall, H. (2008, March). Functional safety IEC 61508/IEC 61511 the impact to certification and the user. In *2008 IEEE/ACS International Conference on Computer Systems and Applications* (pp. 1027-1031). IEEE.

[3]. Smith, D. J., & Simpson, K. G. (2010). *Safety critical systems handbook: a straight forward guide to functional safety, IEC 61508 (2010 Edition) and related standards, including process IEC 61511 and machinery IEC 62061 and ISO 13849*. Elsevier.

[4]. Lee, S., Im, S., Lin, S., & Kweon, I. S. (2021). Learning monocular depth in dynamic scenes via instance-aware projection consistency. *arXiv preprint arXiv:2102.02629*.

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