Safe human-robot interaction in logistic applications for highly flexible warehouses

Title: Prototype demonstrator of AR based interaction concepts

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1 Summary

In this document we describe the first prototypes of various interaction strategies - AR navigation assistance, picking assistance and robot maintenance. Additionally we present the Virtual Reality (VR) environment purpose-built to serve as a scalable rapid prototyping tool, where we can perform large-scale tests with users and receive feedback.

This deliverable is strongly linked with deliverable *D4.4 Implemented and working concept for the localisation system [M30]*, as robust localization is required for proper data display. Additionally, some features of the AR device, such as live video streaming and two-way audio communication, will be presented in deliverable *D4.5 Prototype demonstrator of 2D/3D-GUI interaction concepts [M30].* Furthermore, the concepts and the reasoning behind them were presented in the deliverable *D4.3 Concepts of AR based interaction with the system [M18].*

2 AR-based navigation assistance

As a short summary, the navigation modalities identified in *D4.3 Concepts of AR based interaction with the system [M18]* were the following:

1. Displaying the path as a line on the ground.
2. Having an arrow point in the direction the worker should travel (e.g. forward, left, right, go back...).
3. Making a GPS-style 2D minimap of the surroundings with a path laid on top of it.
4. Giving sound instructions (either prerecorded voice or synthesised).

We have implemented all of them and decided that a layered approach results in the best and most intuitive navigation. The primary navigation modality is the line on the ground with an additional particle effect above the head. This was found as a low-impact solution which helps guide the user if they are not looking at the line on the ground. The implementation can be seen in Fig. 1 The arrow was found to be too intrusive, especially if implemented as head locked content. It was decided to keep it in body-locked form but only when the user is near the goal as an additional information source to identify the precise position.

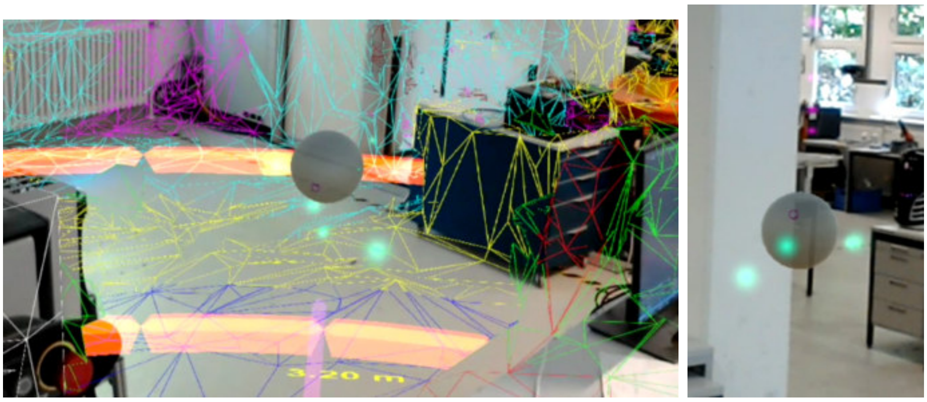

Figure 1: The line following on the left with incorporated distance to goal and the particle stream on the right (the pink particles above the spherical goal). The green particles were experimented as an additional way to make the goal more visible

Both 2D and 3D minimaps were implemented, however it was found that since the user generally doesn't need them they can be opened from a menu if the need arises. Sound instruction were dropped altogether, with the option to introduce a sound indication when the user needs to turn, and none of the other modalities are visible to her/him. Both minimaps can be seen in Fig. 2 The need for this will be evaluated following larger scale user studies.

The menu itself is based on pattern recognition from Vuforia, basically overlaying the menu on top of a heavily textured picture (Fig. 3). This method was used for testing purposes and will likely be changed in the future to be opened with a gesture.

The so called "x-ray" vision for robots was also implemented using occlusion shaders. The shaders work both to visualize robots behind other holograms as well as behind real world obstacles due to the spatial mapping presented on the Hololens, as visible in Fig. 4. Spatial sound was also implemented to give the information about the robots which are not in the field of vision of the user. The sound interaction will once again be evaluated in user studies and dropped if needed be. Jointly with the x-way vision, the path of the robot is displayed.

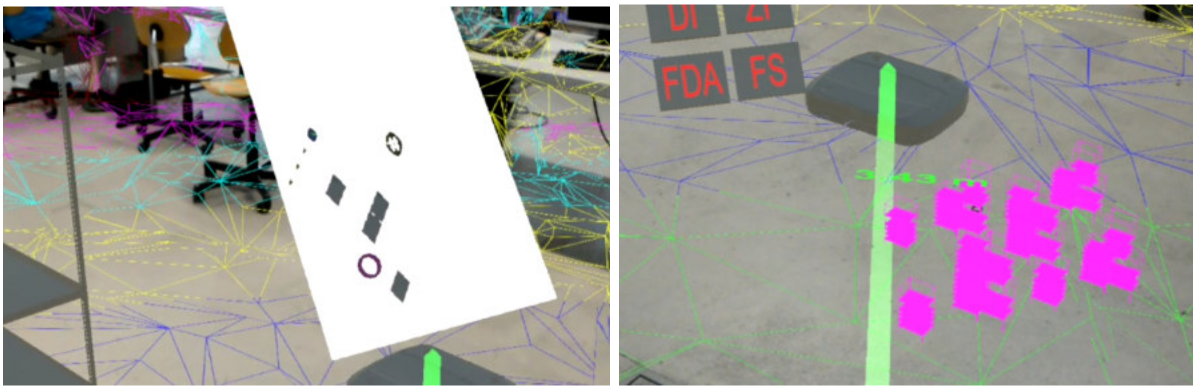

Figure 2: The 2D minimap on the left called from the menu.On the right the 3D minimap that automatically places itself on the floor infront of the user. Both minimaps can visualize robots, paths and allow a zoom in and out function

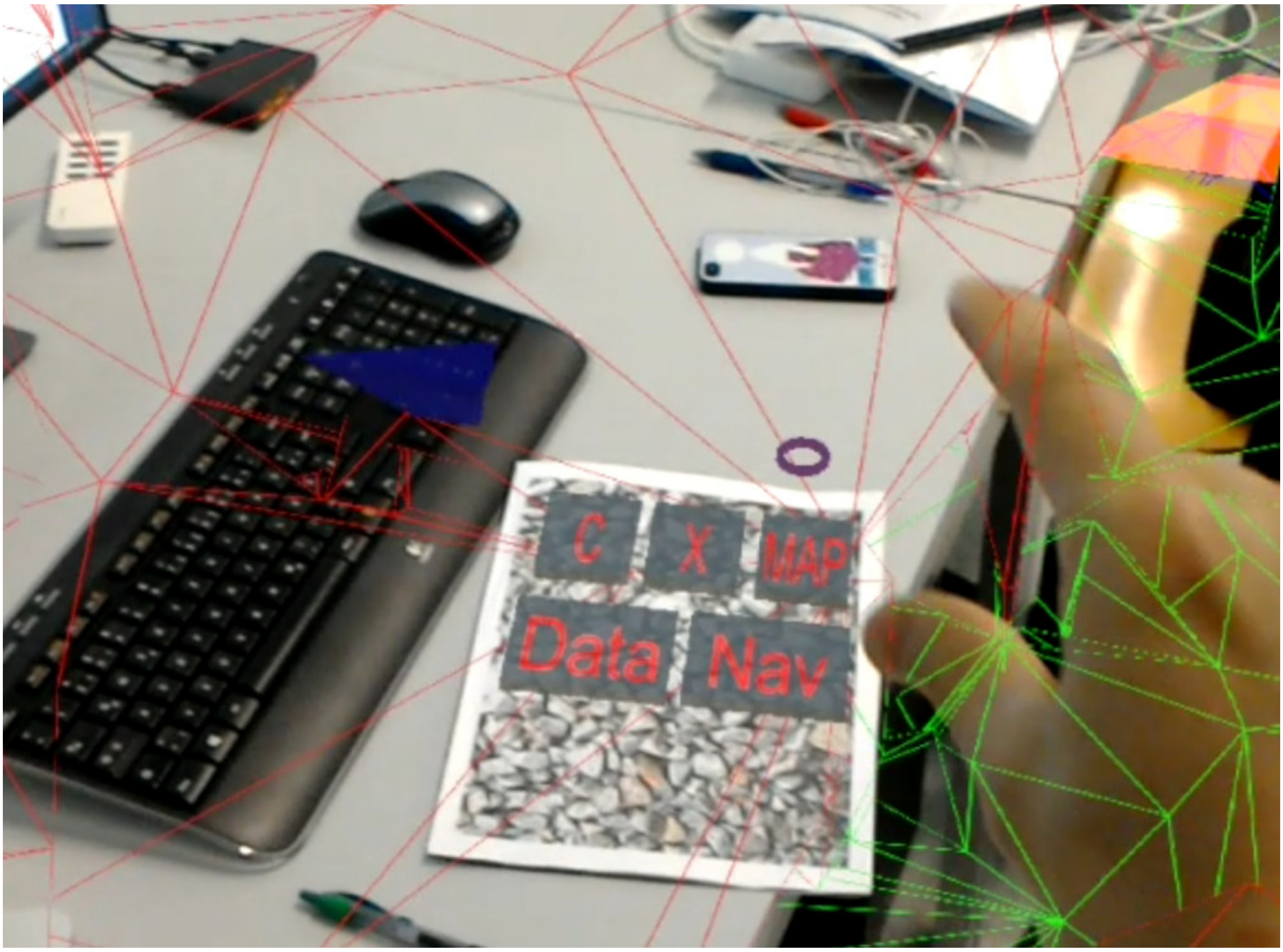

Figure 3: The first version of the menu overlayed on top of a piece of paper.

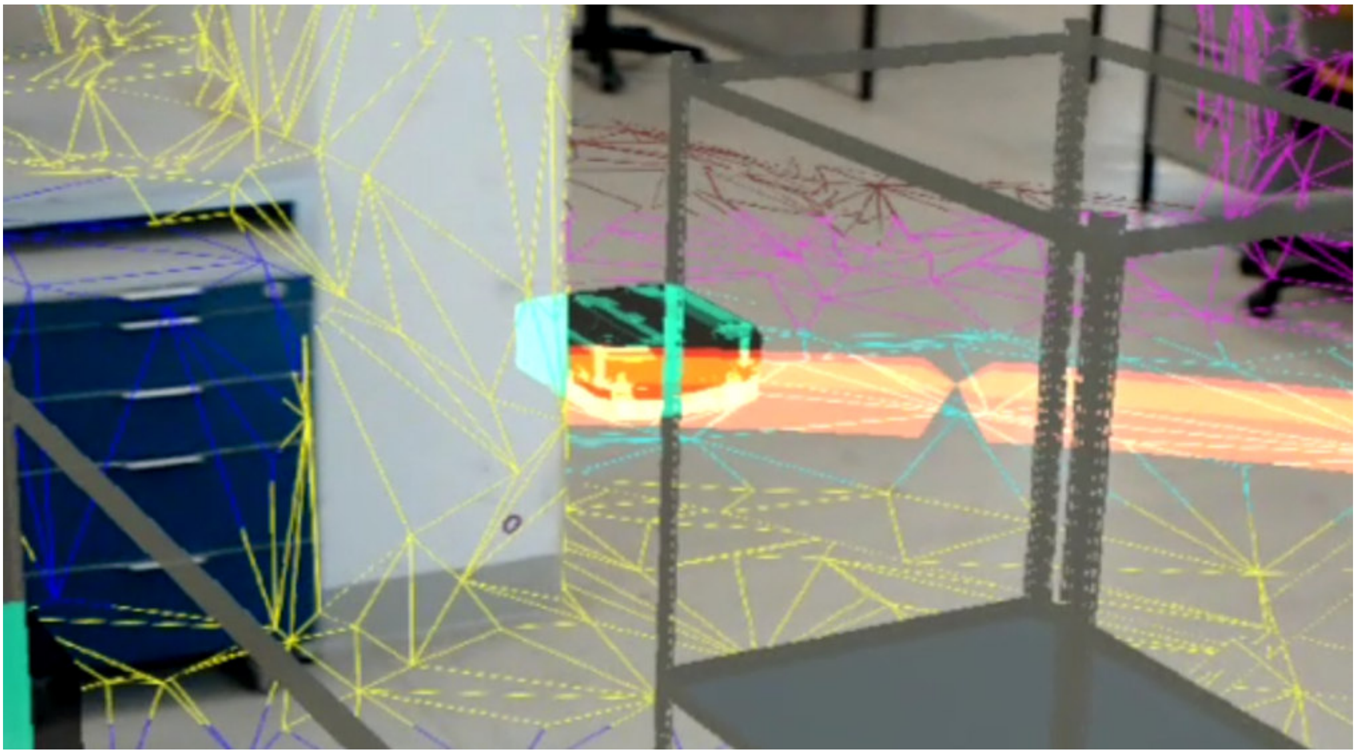

Figure 4: Oclusion of the robot both behind real obstacles and holograms.

No large scale user studies were yet performed; however, many demos were given to people from industrial, scientific and civil sectors. General comments were very positive with indications that the strategy was indeed intuitive. The biggest hurdle to performing large scale studies is an appropriately large environment where it can be tested, and that's easily accessible to the general public and students. Additionally, navigation in the presence of the robots would give the best feedback. This is however impossible before the safety system in SafeLog is officially certified. To alleviate these problems, a VR environment was developed and is being polished, where large scale tests with users can be made. These tests would include all the interaction presented in this deliverable in a relatively realistic setting which includes mobile robots. More about this environment will be presented in Section 4. Further smaller scale use studies will be conducted during the planned IROS 2018 Demo. However this will be quite small scale, where most of the modalities listed above will be disabled, with only the line and the arrow used for navigation.

3 AR-based picking assistance

The picking assistance is designed to provide a portable alternative to the current state-of-the-art, namely pick-by-light. Although mainly designed to serve in the warehouse where pick-by-light is not usable, the goal is to make the assistance system more or at least as efficient as pick-by-light, thus providing an alternative at the picking stations also.

The first implemented concept can be seen in Fig. 5 on the left. A line is connecting the Hololens and the position of the rack where the object to pick is located. Next to the line the distance and the location (in front or behind) is displayed. On the rack itself a visual indicator shows the part of the rack where the object is located. This implementation was deemed to be impractical due to the cluttered field of view. The final concept is shown in Fig. 5. The line was exchanged for an arrow, and the position information was colour coded (red for in front and blue for behind). The indicators on the rack were kept however the colours were changed to make it more intuitive.

Figure 5: The original version of the picking assistance to the left and the new one to the right

Figure 6: First test of object recognition without barcodes.

Figure 7: First test of object placement.

Once the worker picks the object, object detection confirms if it's the right object or not. An example of the object detection can be found in Fig. 6. If the picker is located at the picking station, the assistant then also provides the location where the object needs to be placed. This can be seen in Fig. 7

During various demos people found the picking interaction to be intuitive, though a specific user study still needs to be carried out. Likewise the interaction was demonstrated on a virtual rack only due to the delays in the rack delivery. At IROS 2018 we intend to present a demo integrating all of the steps in a realistic environment, with real racks and objects to interact with. As the expected number of visitors is high, this should provide us valuable feedback about the intuitiveness and performance of the system.

4 AR robot maintanence assistace

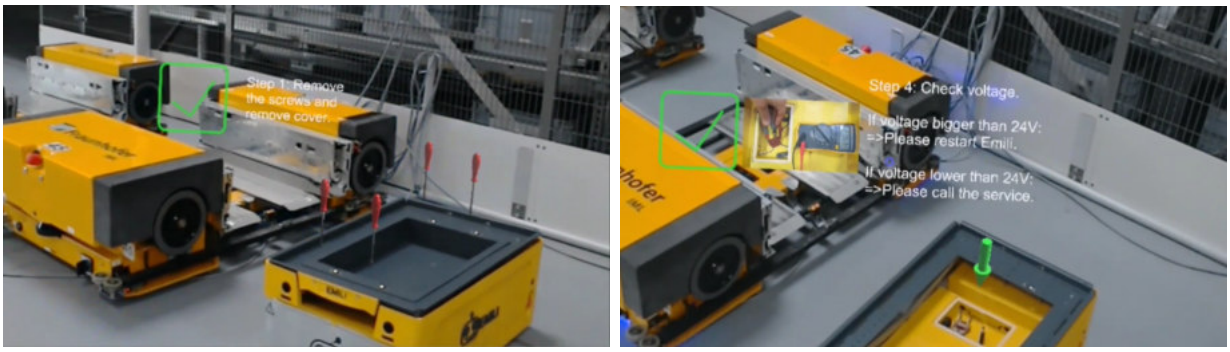

Figure 8: Some steps from the Hololens Robot repair demo on the Emili robot. Here one can see the first step of removing the screws on the left and the last step of checking the battery on the right.

Among the possible use cases why a person would enter the warehouse is on-site robot maintenance and repair. Here we intend to provide step-by-step assistance to both professional maintenance workers or even to pickers without experience, though this will be quite limited, as in most cases tools are needed to successfully repair the robot. Some pictures from the first implementation on can be seen in Fig. 8. The system currently works with IML Emili robot and will be extended to SLA Carry-pick system in the near future.

The demo will also be shown on the already mentioned IROS 2018 demo, however with the Emili robots due to the ease of transportation. It should still provide quite adequate feedback for the interaction strategies.

5 VR-based rapid prototyping system

As mentioned at the end of Section 1, performing large scale user studies in a realistic environment is very difficult, and with robots included impossible at the moment. Due to this constraint we have implemented a Virtual Reality environment where such tests can be performed. This also serves as a rapid prototyping tool where interaction can be tested in large-scale environments and possible errors identified. Additionally we can inject errors into the system, meaning we can get a good estimate on how high the localization error of the Hololens needs to be for specific interaction to become unusable and unintuitive.

We implemented this framework in the Unity 3D engine, using HTC Vive for the VR Glasses. Currently the guidance of the worker through the warehouse (Fig. 9 on the left), the robot x-ray vision (Fig. 9 on the right) and the picking assistance are all implemented (Fig. 10). We also implemented a field of view (FoV) reduction for objects which are considered holograms to the 30° horizontal and 17.5° vertical of the Hololens itself. The Hololens' pointer was also implemented the same way as on the Hololens, thus emulating entirely the real experience. The only difference being that controllers are used for system input instead of gesture. All of these features are also visible in the figures bellow (Fig. 9, Fig. 10). We plan to extend the framework to encompass all AR interactions including object detection. As work is still progressing on the fleet planner and the communication interfaces, a method was devised to emulate it. We place the desired number of robots randomly in the warehouse at the start of the experiment. Each robot then selects one of the reachable adjacent nodes at random and continues selecting nodes in such a manner, except that it is not allowed to return to the node visited in the previous step. If another robot already selected the same node in the same time step, it stops and waits for it to pass. This works well at emulating a fleet of robots moving around the warehouse without collisions. However it should be noticed that the density of the robots is expected to be higher near the picking stations, something which the approach does not emulate. It still provides an adequate representation for the proposed use case of testing the AR interactions.

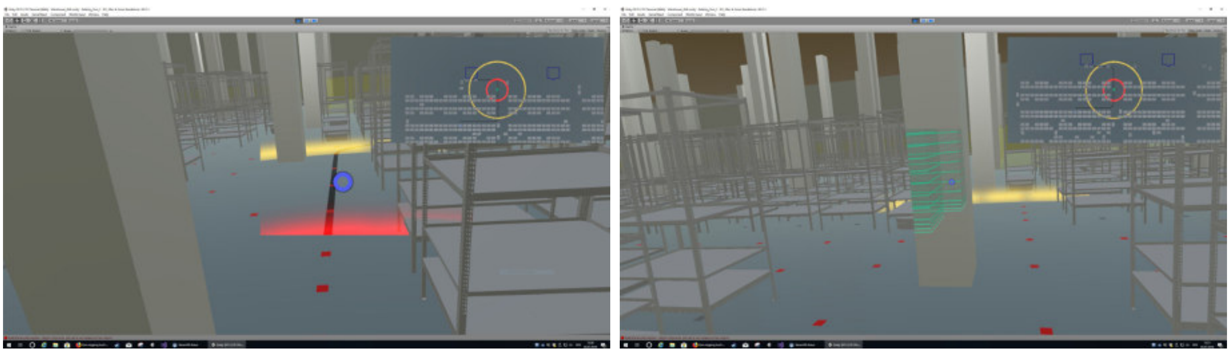

Figure 9: The two safety levels visualised and the line navigation on the ground on the left image. The x-ray vision of the robots on the right one. Note that the map in the upper right corner is not visible to the users although they can enter a top-down view - the same as on the hololens.

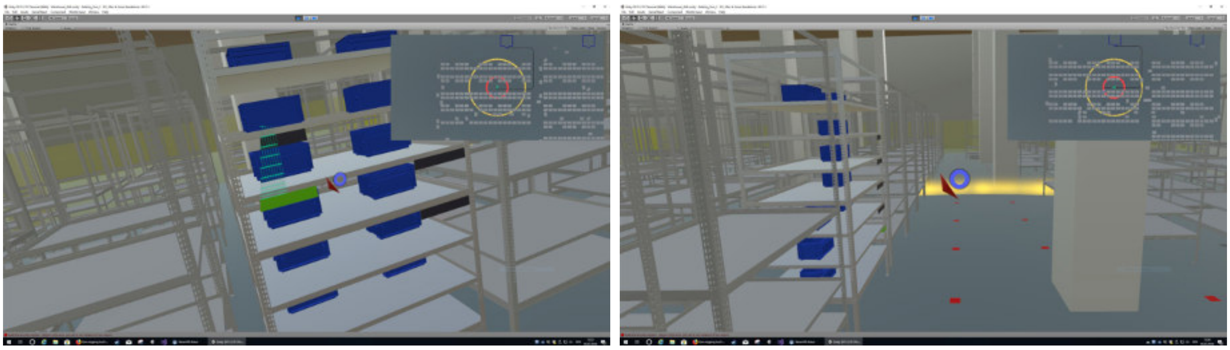

Figure 10: The picking assistance implemented in VR. Note that the FoV restriction for the Holograms still apply as on the Hololens. Also to note is the cut x-ray image of the robot on the left image. This is due to the robot just entering the visualisation zone.

Future work includes communication with the path planner, which will also be beneficial for the testing of the replanning capabilities if the worker deviates from the trajectory prescribed by the FMS. It will also be part of the IROS 2018 demo and will allow visitors to experience the SafeLog system in a full-scale warehouse.

6 Conclusion

So far all the proposed concepts for the AR-based system interaction have been implemented and demonstrated on the relevant AR device - the Microsoft Hololens. Although no large scale studies were made, the feedback from the numerous small demos illustrate that the interaction strategies seem sound. Due to the impossibility of large-scale user-studies in a large relevant environment, a VR environment was developed to serve as a test and rapid prototyping platform. The environment successfully emulates the Hololens and the AR interaction therein.

The next milestone is the integration of all of the proposed components into a single framework, as well as performing relevant user studies. Both of these milestones will be achieved in time for IROS 2018 - 01.10.2018, and subsequently reported at the next review meeting. Furthermore, user-studies can and should also continue using the VR framework discussed before. This means that future interactions of the AR-based assistance system, based also on the feedback from the IROS demo, will have the opportunity to be tested in user studies.

7 Consortium

Role of KIT

KIT has two roles:

1. KIT will be coordinator of SafeLog. Coordinating person will be Björn Hein. The department FORScience of KIT will handle all management issues (s. previous paragraph, section *Management structure and procedures* and *WP8 Project Management* in document Part 1).
2. Regarding research and innovation KIT will mainly focus on the human-system interaction and assistive technologies in the envisioned flexible and collaborative warehouse *WP4 Assisting technologies for a collaborative and flexible warehouse system* with the corresponding relations to the other work packages.

Role of SLA

Swisslog provides expertise in automation and logistics ranging from industrial robot applications, electrical overhead monorails, transport AGVs and goods-to-man systems. Swisslog will handle the demonstrator based on a fleet of mobile goods-to-man robots. For this system prior work exists comprised of fleet-manager, standard safety infrastructure and also a 2D emulation environment. Swisslog will take the lead of WP1 and WP6.

Role of CVUT

CVUT will lead *WP3 Planning and scheduling for a heterogeneous fleet manager*. The target of the workpackage is to realize a planning module that will provide coordinated plans for robots and humans in the warehouse CVUT will also significantly contribute localization activities in *WP2 Integrated safety concept for detecting and localizing of humans* as well as specification and requirement analyzis *WP1 Requirements and Specifications* and integration *WP6 Integration and Demonstration*.

Role of UNIZG-FER

UNIZG-FER will lead *WP2 Integrated safety concept for detecting and localizing of humans*. The target of the workpackage is development of a holistic safety concept that will allow safe collaboration of humans and robots in the warehouse. UNIZG-FER will also contribute in human aware planning in *WP3 Planning and scheduling for a heterogeneous fleet manager*, localization and human intention recognition in *WP4 Assisting technologies for a collaborative and flexible warehouse system*, specification and requirement analyzis in *WP1 Requirements and Specifications* and integration in *WP6 Integration and Demonstration*.

Role of IML

IML has a comprehensive knowledge about a multitude of interlogistic applications as well as a deep knowledge about development of embedded eletronic components and robotic solution.

In this position IML will contribute to the overal integration of the different concepts by leading the *WP6 Integration and Demonstration*. Furthermore IML will bring in the expert knowledge in embedded systems and communication technologies to contribute majorly to the safety concept and hardware development of the vest as part of *WP4 Assisting technologies for a collaborative and flexible warehouse system*.

Role of KEEI

KEEI will lead *WP5 Development of a Safety Vest*. The goal of this work package is to develop a Safety Vest which enables humans to safely enter and work in a flexible warehouse system with AGVs. Special attention shall be given to safety certification of the safety west and the Safety Concept developed in *WP2 Integrated safety concept for detecting and localizing of humans*. KEEI will contribute to the Project with its experience in embedded systems design and in development and certification of safety critical control systems for railway applications.

8 Glossary

AGV

Automated Guided Vehicle: An Automated Guided Vehicle is a mobile robot that follows markers or wires in the floor, or uses vision, magnets, or lasers for navigation. They are most often used in industrial applications to move materials around a manufacturing facility or warehouse. Application of the automatic guided vehicle has broadened during the late 20th century.. 12, 13

AR

Augmented Reality: Augmented reality is a visualization technique where a direct (e.g through glasses) or indirect (through a camera and screen) view of the real world is supplemented by sensory input and data to achieve a better and more informative understanding of the scene.. 4, 5, 10, 11

FMS

Fleet Managment System: The Fleet Management System cares about scheduling and computing trajectories for mobile robots based on orders given by the WMS. The present system will be updated with real-time replanning, human avoidance planning, and heterogeneous fleet planning features.. 11

GPS

Global Positioning System: The Global Positioning System is a space-based navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The system provides critical capabilities to military, civil, and commercial users around the world. The United States government created the system, maintains it, and makes it freely accessible to anyone with a GPS receiver.. 5