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CoLLaboratE

Co-production CeLL performing Human-Robot Collaborative AssEmbly

D5.3 – Design and Deployment of CoLLaboratE Automated Guided Vehicles (PU)

Due date: M32

Abstract:

The present document is a deliverable of the CoLLaboratE project, funded by the European Commission's Directorate-General for Research and Innovation, under the Horizon 2020 Research and innovation programme (H2020). This deliverable presents the outcome of the CoLLaboratE consortium's research on the modifications of a standard AGV for serving the objectives of the CoLLAborate co-production cell.
Specifically, the magnetic guidance technology which determines the vehicle's routes within the shopfloor is endorsed with autonomy features to allow free, yet safe robot's perambulation, taking advantage of the entire shopfloor operational area. To achieve this, the vehicle is integrated with laser range finders in order to create a map during its travel and SLAM techniques. In addition, human aware navigation strategies have been implemented. To do it a system that identifies the zones most visited by the workers and integrates this semantic information in the navigation maps has been developed. This way the AGVs are aware of the areas with the most traffic of workers and may avoid them when the routes are planned. In addition, an iterative algorithm to calculate the path of the AGV avoiding these restricted zones and obstacles has been developed. Finally, a new AGV voice interface has been implemented to interact with whatever type of AGV.

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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EXECUTIVE SUMMARY

This document is a deliverable of the CoLLaboratE project that presents the results of task 5.2 "Design and Deployment of CoLLaboratE Automated Guided Vehicles". The task aims at modifying a standard AGV for serving the objectives of the CoLLAborate co-production cell.
Specifically, the magnetic guidance technology which determines the vehicle's routes within the shopfloor is endorsed with autonomy features to allow free, yet safe robot's perambulation, taking advantage of the entire shopfloor operational area. To achieve this, the vehicle is enhanced with additional sensors and strategies for autonomous and human-aware navigation.

This document is a short version of the deliverable D5.4– Design and Deployment of CoLLaboratE Automated Guided Vehicles.

This deliverable is accompanied by a video which is accessible from the URL: https://youtu.be/Rb_i2VTjo_M

The presentation of the conducted research is divided in 5 sections. Starting from the introduction (Section 1), an outline of the developed methods is presented along with their scientific contribution.

Section 2 is dedicated to the development of an AGV with greater navigation flexibility. Simultaneous Localization and Mapping techniques are included to allow continuous robot navigation in the operational environment.

In Section 3, we integrate the voice control and provide a mechanism to control and interact with the AGV using voice commands. For the industrial world, one of the most efficient way to interact with the machines is by using voice commands. This keeps our hands free to perform other tasks, eliminates the need to be next to the machine to control it and makes the interaction easier and more natural.

In Section 4, semantic information in navigation is introduced in AGV to prevent dangerous situations. This safety system identifies the zones most visited by the workers and integrates this semantic information in the navigation maps. This way the fleet management system is aware of the areas with the most traffic from workers and can consider this information when the routes and orders are scheduled. That is, the areas with highest traffic of people are configured in the map as restricted zones. The AGV also can take into account these restricted zones to when the path is calculated.

Finally, in Section 5, we present the safety system, that allows the AGVs to stop their movement in the presence of obstacles in the path. Moreover, multi-sensor systems are used to improve the navigation of AGVs in these variable environments. AGVs should be able to distinguish between the possible obstacles they sense in their path and react accordingly: sometimes it may be enough to simply change their route; other times they must stop, especially if they are in a person's path.

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ABBREVIATIONS AND ACRONYMS

Partner's short name	Partner's full name
AUTH	ARISTOTLE UNIVERSITY OF THESSALONIKI
CERTH	CENTRE OF RESEARCH AND TECHNOLOGY HELLAS
ARMINES	ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPMENT DES METHODES ET PROCESSUS INDUSTRIELS
JSI	INSTITUT JOZEF STEFAN
IDIAP	FONDATION DE L'INSTITUT DE RECHERCHE
UNIGE	UNIVERSITA DEGLI STUDI DI GENOVA
KU Leuven	KATHOLIEKE UNIVERSITEIT LEUVEN
LMS	UNIVERSITY OF PATRAS
CRF	CENTRO RICERCHE FIAT SOCIETA CONSORTILE PER AZIONI
BOR	BLUE OCEAN ROBOTICS
ASTI	AUTOMATISMOS Y SISTEMAS DE TRANSPORTE INTERNO SA
KOL	KOLEKTOR ORODJARNA NACRTOVANJE IN IZDELAVA ORODIJ TER ORODJARSKE STORITVE D.O.O.S
ARCELIK	ARCELIK A.S.
ROMAERO	ROMAERO S.A.
UBU	UNIVERSITY OF BURGOS

Abbreviation	Definition
WP	Work Package
D	Deliverable
EC	European Commission
EU	European Union
AGV	Automatic Guided Vehicle
UWB	Ultra-Wide Band
SLAM	Simultaneous Location and Mapping
LIDAR	Light Detection And Ranging
FCS	Fleet Control System

1 INTRODUCTION

This deliverable reports the work performed in T5.2 – “Design and Deployment of CoLLaboratE Automated Guided Vehicles” that started in M6 and was completed in M30. The task aims to modify a standard AGV for serving the objectives of the CoLLaboratE co-production cell.

1.1 OUTLINE

Due to the fact that the shopfloor environment is very dynamic, including frequent changes on stored products location and human presence, simultaneous localization and mapping techniques are included to allow continuous robot navigation in the operational environment. Moreover, human comfort and safety are considered by developing human aware navigation strategies that respect the worker’s personal space and ensure safety when operation in cluttered areas is necessitated. To achieve such social aware robot navigation feature, integration with human motion anticipation is considered, which emerges respective AGV’s reaction.

The interface of the AGV is improved by a new AGV voice interface developed to interact with every type of AGV. The system is generic enough to be used with different types of AGVs and brands.

Based on the methods developed in T3.6, the intentions of the human workers are assessed by the AGV and it reacts accordingly, taking into consideration not only practical, but also social factors investigated in WP2.

In addition, specific regions are enhanced with semantic information such as frequently congested or free ones, in order to create a hyper map that is utilised for the robot’s global and local planning, expediting AGV’s movements within the shopfloor, while at the same time avoiding unnecessary crossings with humans.

AGV’s navigation strategy takes into consideration the vehicle’s kinematics constraints. Collaboration among AGV and human workers is established by adding peripheral sensors such as microphones where the human has the capacity to pass direct orders (through speech and gestures) to the vehicle.

2 CoLLaboratE Automatic Guided Vehicle

Automated Guided Vehicles (AGV) are unmanned transport vehicles currently used in the industrial sector to substitute manned industrial trucks and conveyors. This kind of mobile robots usually navigates by following long marked lines or magnetic tapes on the floor [1]. Recent advances have allowed these mobile robots to move in a more autonomous way, without the need for marks on the floor. These autonomous AGVs allow greater flexibility in the production structure, as they do not need to drive in a predefined area.

A standard Automated Guided Vehicle (AGV) produced by ASTI has been modified for serving the objectives of the CoLLAborate co-production cell, Fig 1. Specifically, the currently employed magnetic guidance technology which determines the vehicle's routes within the shopfloor has been endorsed with autonomy features to allow free, yet safe robot's perambulation, taking advantage of the entire shopfloor operational area. To achieve this, the vehicle has been integrated with additional sensors, such as laser range finders in order to create a map during its travel that will provide the means for autonomous navigation within the environment. The mapping is carried out in manual mode. Once the map is created the AGV navigates with it.

Figure 1: SLAM AGV

We carried out a comparative study with other guiding systems to analyse the pros/cons. Fig 2. shows some results of this study.

	Slam	Laser-guided	Magnets & Gyro	Wire-guided
Installation/modification	+	=	–	–
Precision	+	+	=	=
Speed	+	+	=	–
Manual/automatic	+	+	–	–
Cost of infrastructure	+	=	=	–
Cost of maintenance	+	+	=	=

\+ Positive = Neutral – Negative

Figure 2: Comparison between different guiding systems

This AGV also has been updated to receive the gestures detected by the gesture recognition system of ARMINES and the destination provided by the production planner of LMS.

The Fig. 9 shows a demo of the gesture interface where an Intel Real sense camera is on the AGV to perceive the position of the human. There is a specific set of gestures that are detected and converted into commands.

Figure 3: Gesture recognition architecture

3 CoLLaboratE AGV Voice Interface

The world of robotics is growing and reaching all areas of our lives. New technologies are being applied to cars, houses, televisions. But the way we communicate with them has not changed much. We need to communicate with technology in a simple and natural way. For the industrial world, one of the most efficient way to interact with the machines is by using voice commands. This keeps our hands free to perform other tasks, eliminates the need to be next to the machine to control it and makes the interaction easier and more natural. Thus, an AGV voice interface has been developed to interact with AGVs. The system is generic enough to be used with different types of AGVs and brands.

The set of words that are considered as key words can be configurated by a dictionary. This way it can be used for different applications and languages. In addition, the translation from words to orders is also easily editable through a file.

The application has been developed entirely in Java with Android Studio and has been validated on a SONY Smartwatch 3 with Wear OS system of Android 6.0.1 version, a system created by Google to adapt the Android operating system of their cell phones to their smartwatches. These devices have microphone, Bluetooth, Wi-Fi and GPS, and some of them even with NFC and the option of inserting a SIM card to connect to the internet.

Before the development of the application, a study to identify available speech recognition libraries was carried out. After several tests, finally the Google Speech To Text (STT) Library [2] was selected. This library utilizes Google's most advanced deep learning neural network algorithms for automatic speech recognition (ASR). Furthermore, it supports over 125 different languages and dialects.

The APP has been developed in a modular way. Therefore, it is very easy to replace the Google Speech To Text library by a different one if needed. The latencies of the system has been measured and results around 1 second per word have been obtained.

If the speech does not match with any word in the dictionary any order is sent to the AGV, and it continues with the execution of the tasks assigned by the fleet management system (FMS). If the system perceives the speech incorrectly two different events can happen: the perceived word is not in the dictionary or the perceived word is in the dictionary. In the first case nothing happens, in the second case an incorrect command may be executed. In any case, if a command is incorrectly interpreted the user can say other words to indicate a new command. This new command substitutes the old one.

4 Integration of Semantic Information in Navigation Maps

The deployment of autonomous vehicles and automated guided vehicles (AGVs) in workplaces is growing more and more. This has made workers and robots share the same workspace. This can lead to loss of efficiency in the intralogistics and the production but also safety issues. So, it is a must to avoid having AGVs harming people or damaging infrastructure.

To prevent these dangerous situations, a safety system is proposed. It first identifies the zones most visited by the workers and integrates this semantic information in the navigation maps. This way the AGVs are aware of the areas with the most traffic from workers and may avoid them when the routes are planned. That is, the areas with highest traffic are configured in the map as restricted zones.

In order to obtain information about the flow of people, different sensors can be used: UWB-tags, Bluetooth-tags, cameras together with computer vision algorithms to track the people's movement, etc. These devices provide information about the workers' positions, and the information is stored in a database. These positions (spatial coordinates) are sorted based on day and time. Every hour, the computer system processes the information of the positions obtained during the last hour and generates the restricted zones for the robot.

In order to obtain these forbidden areas, the data are classified into clusters. Then the hot spots are obtained. These areas are frames in an ellipse and sent to the robot..

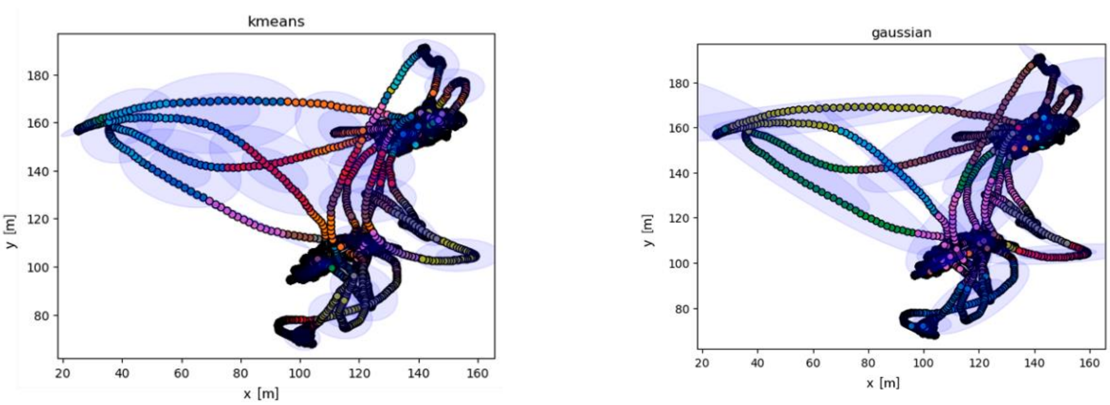

Figure 4: Left: Results of the K-means algorithm with 33 clusters. Right: Gaussian algorithm with 33 clusters.

5 DEVELOPMENT OF NAVIGATION STRATEGIES

Autonomous AGVs share the workspace with humans, manned industrial trucks and other mobile assets. Thus, in order to guarantee their safe operation, AGVs must be equipped with a safety system to stop their movement in the presence of obstacles in the path. Moreover, multi-sensor systems are used to improve the navigation of AGVs in these variable environments. Among others, encoders, gyroscopes, ultrasound sensors, infrared sensors, LIDARs (Laser Imaging Detection and Ranging), RADARs (RAdio Detection And Ranging) or cameras are commonly used for safe indoor navigation of AGVs. Ultrasound sensors are low-cost solutions but their range and reliability are not usually sufficient for industrial applications. LIDARs provide high reliability but they are expensive. Furthermore, they have several major drawbacks. They cannot cover 360º around the AGV, which forces two LIDARs to be installed per vehicle, increasing the cost of the system even more. Additionally, LIDARs only provide two-dimensional (2D) information about an obstacle at a specific height from the floor, usually a few centimetres above the floor. Thus, in many cases additional vertical safety LIDARs must be installed, making the final cost of the safety system very expensive. The AGVs should be able to distinguish between the possible obstacles they sense in their path and react accordingly: sometimes it may be enough to simply change their route; other times they must stop, especially if they are in a person's path. UWB sensor can help in this task. Impulse Radio UltraWideband (IR-UWB) is considered the most promising technology for indoor positioning [3]. IR-UWB is based on the transmission of radio signals that occupy a very large bandwidth. This technology performs robustly in multipath channels. Its high accuracy in the time-of-flight estimation has made it really attractive for estimating the position of a node. Thus, this technology has been tested to detect the position of humans in the environment of the AGVs.

In addition to the advanced detection of people in the surroundings, in order to guarantee the safety and the productivity of the installations, it is also crucial to define advanced path calculation strategies to avoid zones with obstacles, conflict zones, or restricted areas, as the ones defined in the previous section. For this purpose, an iterative algorithm has been implemented and validated.

The AGV is equipped with a safety lidar sensor which detects if there are obstacles in the path. This sensor provides information of the distance and angle from the front of the AGV to the elements around the AGV. These (distance, angle) measurements, polar coordinates, are transformed into cartesian coordinates relative to the AGV (X,Y). This obstacle safety information is complemented by other information sources such as the information provided by UWB sensors.

Additionally, the information about the relative position of the tags from the AGV could be sent to the fleet control system (FCS). This way, the FCS could employ the information it receives from all the AGVs in the production plan to exploit low occupation zones and optimize the fleet movement. This will improve the intralogistics thereby increasing the productivity of the plant.

Once the obstacles, persons or restricted zones are received by the AGV, no matter the source from the LIDAR sensor, the UWB device or from the FCS, they are encapsulated into a bounding box and a new trajectory able to avoid this bounding box is computed. This new trajectory is defined by either a spline or a clothoid where some edges of the boundary box are used as passing points of the trajectory. This process is iterative, if the new trajectory intersects an obstacle, the bounding box is enlarged to include this new obstacle.

The path to avoid the obstacles is defined as clothoids. A clothoid is a curve whose curvature varies linearly with its arc length; hence the curvature is continuous along it. This continuity in the curvature avoids discontinuities in the centrifugal force, thus it is a transition curve commonly used to design roads. This improves the safety and reduces the tire wear. This property also makes them very suitable as trajectory segments in mobile robot path planning.

Fig 5 shows some examples of the execution of the path calculation algorithm to avoid the obstacles for 1 to 2 obstacles.

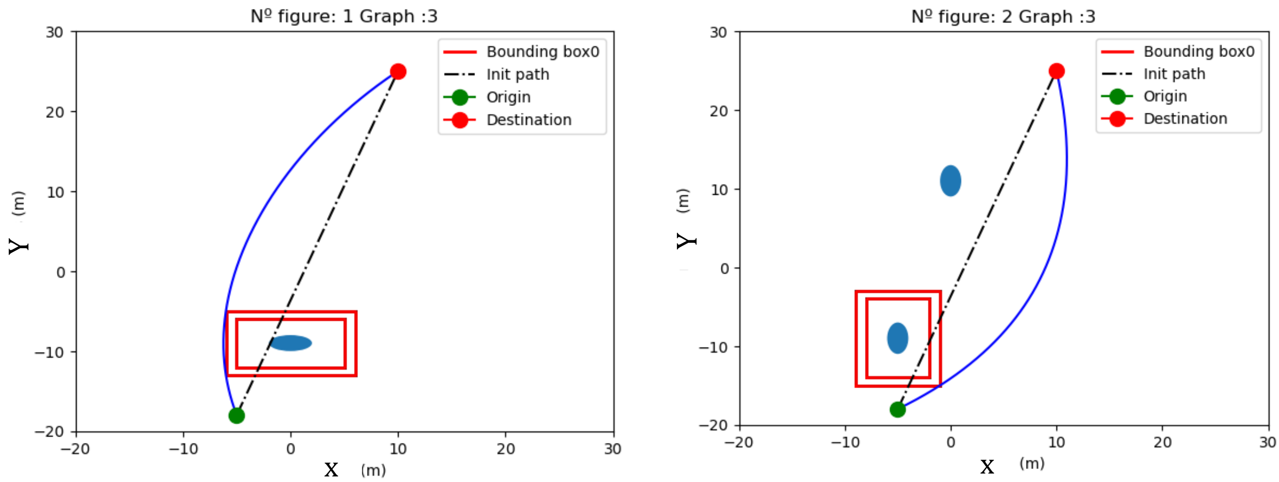

Figure 5: Left: Execution of the algorithm with 1 obstacle. Right: Execution of the algorithm with 2 obstacles.

6 REFERENCES

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