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Interacting with a Multi AGV System

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Abstract—This paper introduces a novel Human Machine Interface (HMI) that allows users to interact with a fleet of Automated Guided Vehicles (AGVs) used for logistics operations in industrial environments. The interface is developed for providing operators with information regarding the fleet of AGVs, and the status of the industrial environment. Information is provided in an intuitive manner, utilizing a three-dimensional representation of the elements in the environment. The HMI also allows operators to influence the behavior of the fleet of AGVs, manually inserting missions to be accomplished.

I. INTRODUCTION

In order to heavily reduce costs, to avoid unsafe conditions for human operators, and to increase the efficiency, goods production flow in manufacturing plants has been largely and deeply automated in the last decades. Despite the automation of production, logistics is still marginally automated and typically requires manual operations performed by human workers and hand-operated forklifts.

It is worth remarking that, typically, manufacturing plants need warehouses for storing both raw materials and final products, at the beginning and at the end of the production line respectively. Therefore logistics, which is not fully integrated in manufacturing processes, is a source of inefficiency. Moreover, it is one of the main causes of risks for workers [1]. Factory logistics is then crucial for the overall production flow, and its weaknesses affect the production efficiency and the quality of goods delivery, especially in terms of product traceability. Bottlenecks and problems in warehouse logistics heavily impact on factory competitiveness on market.

A modern solution for these drawbacks is represented by Automated Guided Vehicles (AGVs), that will lead to obtaining an integrated system for the complete handling of logistic operations in factories of the future (Fig. 1).

Nowadays these autonomous systems have a market share of about few thousands vehicles sold every year and they are not yet ready to be widespread in manufacturing plants. In fact safety, efficiency and plant installation costs are still open problems and technologies are not mature enough to fully support a pervasive diffusion of AGVs. Therefore, innovations to address weaknesses of AGVs and automated warehouse systems will boost capabilities of these logistic solutions bringing them toward a pervasive diffusion in modern factories [2]–[4].

AGV systems have been extensively studied in the literature: a comprehensive survey is presented in [5], where



Fig. 1. Automated warehouse with AGVs

authors describe the main technologies adopted for localization and guidance of AGVs in industrial environments. The work in [6] describes the use of multiple AGVs for cooperative transportation of huge and heavy loads. Generally speaking, AGV systems are used for automatically moving goods among different locations in an industrial environment [7], [8]. Typical operations performed by AGVs consist in picking up a pallet of goods from the end of an automated production line, and bringing it to the warehouse, or from the warehouse to the shipment. Each movement operation is generally referred to as a *mission*. The AGV system is handled by a centralized controller, usually referred to as Warehouse Management System (WMS), that is in charge of assigning each mission to be completed to a specific AGV. The WMS coordinates the motion of the AGVs through the industrial environment, in a centralized manner [9]–[13]. In order to simplify the coordination, and to enhance safety of operations, AGVs are typically constrained to move along a predefined set of roads, referred to as *roadmap* (Fig. 2).

While the system is controlled in an automated manner by the WMS, human intervention is often necessary, to solve unforeseen situations. Therefore, it is necessary for human operators to have an interface with the system, that allows them to assess the status of the industrial plant and of the fleet of AGVs. Moreover, operators need to have the possibility of defining custom missions to be performed.

The paper is organized as follows. The state of the art is summarized in Section II. Subsequently, in Section III we describe the proposed Human Machine Interface, that is used both for informing the operator about the status of the system (see Section III-A) and for letting the operator interact with the system (see Section III-B). Concluding remarks are given in Section IV.

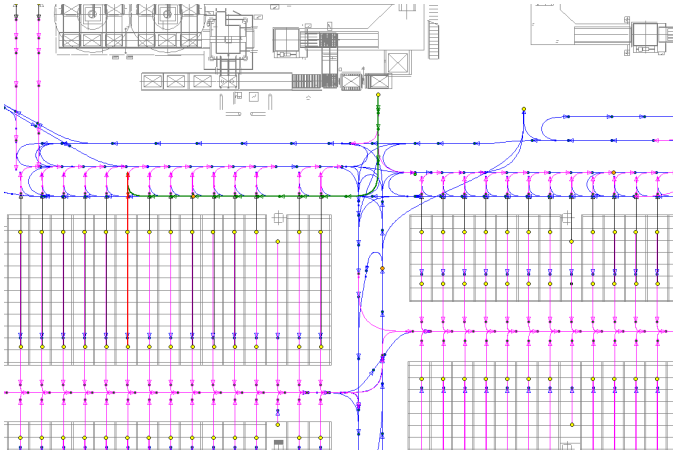


Fig. 2. Portion of the roadmap of a plant

II. STATE OF THE ART

Fleets of AGVs are typically controlled in an automated manner, in industrial applications. In particular, the WMS is in charge of defining missions based on production requirements, and assigning each of them to a specific AGV for completion. Subsequently, the WMS coordinates the motion of the AGVs along the roadmap, in such a way that the overall completion time is minimized, as well as energy consumption. The control strategy needs to take care of avoiding collisions and deadlocks, and to manage the traffic in an efficient manner [14]–[18].

It is worth noting, however, that industrial plants are highly dynamic environments, generally shared among AGVs and human operators. Subsequently, they define a very complex system, that cannot always be controlled in a fully automated manner. In fact, disturbances on the nominal behavior of the system may appear, such as the presence of obstacles on the AGVs' path, or necessity to change missions for the AGVs. A limited set of disturbances can be dealt with in an automated manner: a typical case is represented by the presence of obstacles. As described in [19], sensing devices can be exploited for recognizing and measuring obstacles, and for computing local deviation paths for avoiding deadlocks.

However, several cases exist in which the system is not able to automatically recover from disturbances, and human intervention is then mandatory. Hence, it is necessary for the system to provide human operators with an efficient supervision interface, to let them effectively assess the behavior of the overall system.

When dealing with large fleets of vehicles, providing the system with an effective supervision interface is a complex issue, since the amount of information to be considered is very large. In particular, in order to make the interface well usable by a human supervisor, it is necessary to present information in an aggregate manner, thus reducing the necessary cognitive load.

Generally speaking, the definition of an information interface for assessing the status of a fleet of autonomous vehicles is a hard problem, that involves several difficulties [20]. The standard approach consists in having a separate interface for

each robot, which provides detailed information on the status of each vehicle and a first-person camera view from the vehicle itself [21]. However, since this kind of approach provides too much information to the user, it becomes rapidly difficult to use, as the complexity of the multi-vehicle system increases. The main problem is in the fact that the operator has difficulties in maintaining situation awareness about the overall system.

As described in [22], [23], a user interface for situation awareness for multi-vehicle systems needs to provide the following features: perception of the elements in the environment, comprehension of the current situation, projection of future status. Along these lines, we will hereafter describe an interface that provides the operator with a constantly updated three-dimensional view of the overall system, and thus gives him/her the possibility of being aware, in an intuitive manner, of the behavior of the multi-vehicle system. The operator also has the possibility of modifying this behavior, defining custom missions to be executed.

III. THE HUMAN MACHINE INTERFACE

The proposed Human Machine Interface (HMI) was developed with the purpose of providing complete information about the status of the industrial environment in an intuitive and effective manner. In particular, the HMI provides the operator with a constantly updated three-dimensional representation of the environment, as well as the static and dynamic elements that populate it. Therefore, the HMI represents both infrastructural elements (e.g. walls, doors, racks), and dynamic entities (e.g. AGVs, pedestrians, objects).

The HMI was developed based on the V-REP [24] software platform (Fig. 3). V-REP is a powerful robot simulator, which provides an integrated development environment. It is based on a distributed control architecture, where each object can be individually controlled, also from a remote client. Hence, V-REP is very versatile, and represents a natural choice for multi-robot applications. Exploiting these features, we also implemented a control interface in our HMI, that allows the user to interact with the system giving the possibility to manually define new missions to be accomplished.

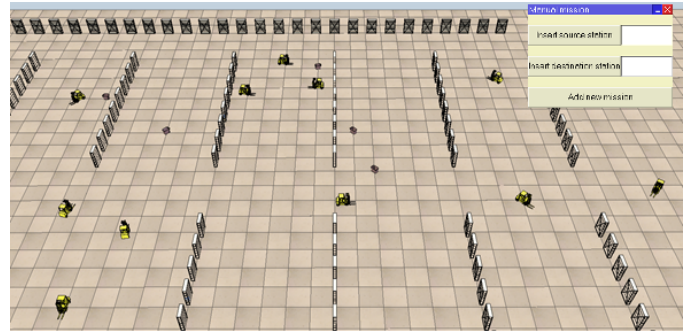


Fig. 3. Portion of the three-dimensional representation of the industrial environment

A. From the system to the operator

We assume the AGV system to be equipped with an advanced sensing system, composed of two main elements: on-board sensors, and infrastructure sensors.

Regarding the on-board sensors, safety regulations impose each AGV to be equipped with safety laser scanners. Moreover, we assume safety laser scanners to be complemented with advanced sensing systems, capable of providing capabilities to monitor the entire 360° region around the vehicle. In particular, the on-board perception system is considered to be composed of multiple laser scanners, positioned around the AGV, together with an omnidirectional stereo vision system consisting of two omnidirectional lenses and two cameras mounted on the top of the AGV, as described in [25].

On-board sensors are then complemented by additional sensing systems installed on infrastructural elements. The idea is similar to the use of hemispherical mirrors mounted above the intersections, that are used by the workers to *look around the corners*. Along these lines, as proposed in [26], we consider the presence of laser scanners, installed on specific locations of the environment, used to provide an efficient monitoring of the black spots.

Information about the status of the environment is then acquired by different sources. In order to opportunely merge them, a centralized data fusion system, referred to as the *Global Live View* of the environment, was introduced in [27] that contains constantly updated information regarding all the entities that populate the industrial environment. In particular, the Global Live View contains information regarding the static infrastructural elements (e.g. rack, walls, doors, etc.) of the environment, as well as information regarding dynamic objects gathered from the sensing systems.

Information contained in the Global Live View is exploited for automatically controlling, in an optimized manner, the fleet of vehicles. Besides that, in order to provide human operators with effective supervision capabilities, data contained in the Global Live View need to be visualized into the HMI. Therefore, the proposed HMI contains a constantly updated three-dimensional graphical representation of the main data contained in the Global Live View, namely infrastructural elements, AGVs, static and dynamic objects.

The architecture of the HMI system is depicted in Fig. 4. In particular, the HMI process is in direct communication with the Global Live View process, that contains a constantly updated database, where all the dynamics elements of the environment are included. In particular, dynamic elements are acquired by on-board and infrastructure sensors: hence, the Global Live View process is connected to the Electronic Control Unit (ECU) that handles each sensor, and that is in charge of implementing local detection and pre-processing.

Information regarding the objects to be represented is then extracted by the HMI system, and sent to the V-REP rendering engine. In particular, each dynamic object is handled by a separate object visualization process, that is in charge of managing the category, shape, position and velocity of the object within the V-REP scene.

Information regarding the infrastructural elements of the industrial environment are collected in the layout, and are then visualized in the V-REP scene as well.

Examples of scenes related to real industrial environments are depicted in Figs. 5, 6, 7, 8, 9 and 10. In particular, Fig. 5 depicts an AGV approaching a box to be handled.

Moreover, Fig. 6 shows two AGVs that move, in a row, towards a rack. Two AGVs coordinating their motion in a cluttered environment are depicted in Fig. 7. The simultaneous presence of three AGVs is shown in Figs. 8 and 9. Finally, Fig. 10 represents an AGV moving in the presence of a human operator.

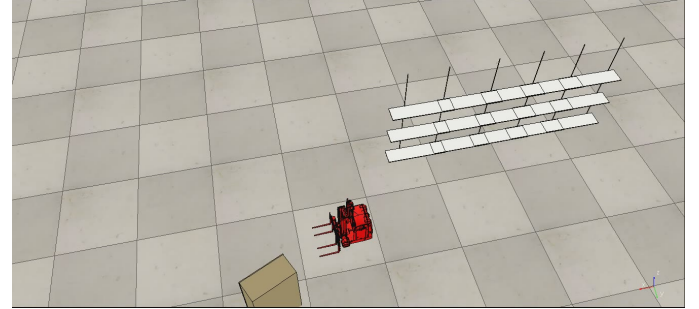


Fig. 5. An AGV approaching a box to be handled

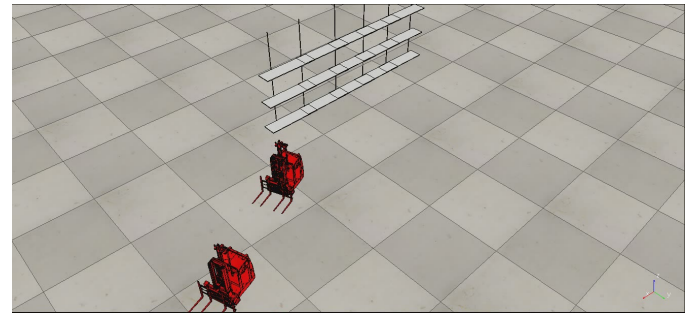


Fig. 6. Two AGVs that move, in a row, towards a rack

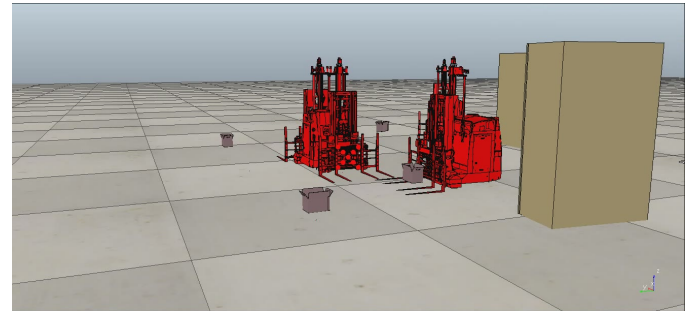


Fig. 7. Two AGVs coordinating their motion in a cluttered environment

B. From the operator to the system

An intuitive control interface was developed for letting human operators define custom missions to be accomplished. The control interface is represented in Fig. 11. A new mission can be easily defined by a user manually specifying in the text boxes the ID of the source and destination stations or, alternatively, selecting with the mouse the corresponding warehouse elements in the scene.

Data regarding custom mission are then communicated to the Warehouse Management System (WMS), that appends it to the current list of pending missions, and schedules its assignment to an AGV for completion.

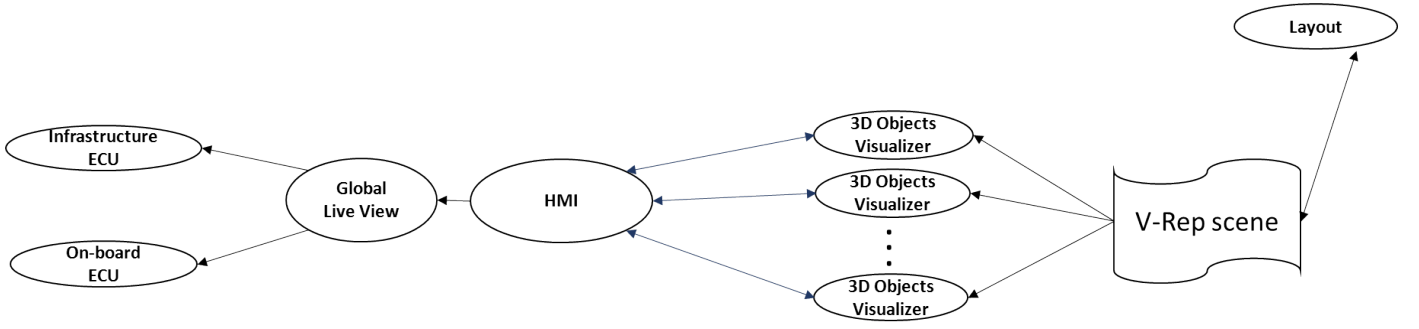


Fig. 4. HMI system architecture

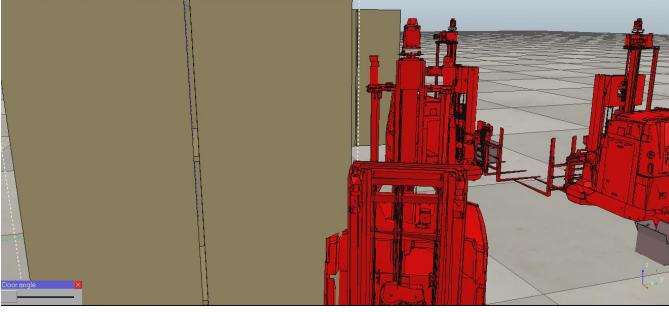


Fig. 8. Simultaneous presence of three AGVs

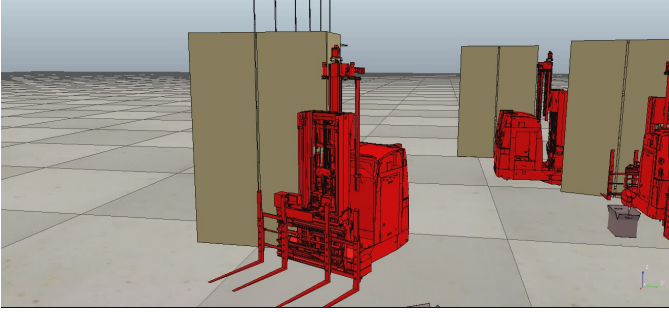


Fig. 9. Simultaneous presence of three AGVs

The algorithm for the definition of custom missions is hereafter represented utilizing standard UML notation. In particular, Fig. 12 represents the UML state machine diagram, and highlights the state transitions in response to events. Moreover, Fig. 13 represents the UML sequence diagram, which highlights its dynamic behavior and focuses on the sequence of messages exchanged among all entities involved.

The first state transition occurs when the user defines a new custom mission through the HMI. The mission is then validated, to check its compliance with the required format, and the HMI transmits it to the mission manager, interfaced with the WMS. The WMS is then in charge of updating the database of missions, allowing the assignment of the new custom mission to a specific AGV, according to the regular mission assignment policy.

IV. CONCLUSIONS

In this paper we proposed a novel Human Machine Interface, to let human operators supervise a fleet of autonomous

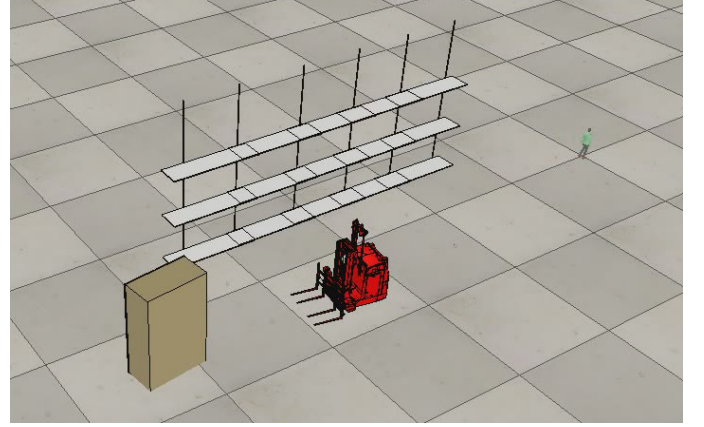


Fig. 10. An AGV moving in the presence of a human operator

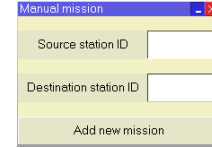


Fig. 11. Control interface, for the specification of custom missions

vehicles used for industrial logistics. The HMI contains then an information part, which provides a three-dimensional visual representation of the status of the fleet and of the industrial environment. For this purpose, the HMI is interfaced with a centralized data fusion system, referred to as the Global Live View, that leads to obtaining a constantly updated visual representation of both static and dynamic elements in the environment.

A control interface is provided as well, that allows operators to define custom missions to be accomplished. The control interface is very simple, and leads to an intuitive interaction with the system, that is then possible also for untrained users.

Future work will aim at extensively testing the interface, to assess its usability over a large pool of potential users.

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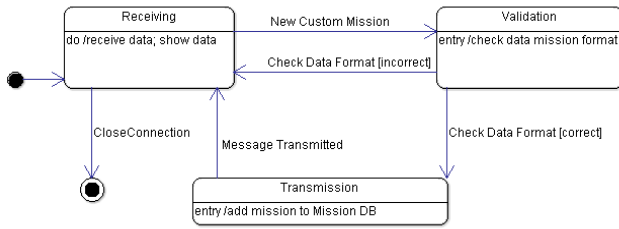


Fig. 12. State machine diagram of the control interface

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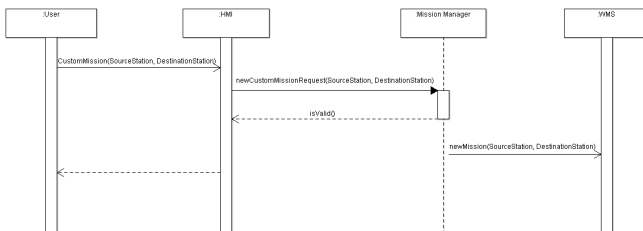


Fig. 13. Sequence diagram of the control interface