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A new HW/SW architecture to move from AGVs towards Autonomous Mobile Robots

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***Abstract*—This paper proposes the basic concepts of a brand new HW/SW architecture, whose development is in progress through an academic/industrial collaboration, aimed at obtaining a mobile agent capable to merge in itself the standard characteristics of the Automated Guided Vehicles and some potentialities of the Autonomous Mobile Robots, with a particular care for safety issues. Its HW/SW features, together with its mechanical characteristics, make it potentially applicable both in industrial and research contexts.**

***Index Terms*—AGVs, Autonomous Mobile Robots, Hardware/Software Architectures**

I. Introduction

The industrial and service mobile robotics market has been significantly growing in recent years. The transition from Automatic Guided Vehicles (AGVs) to Autonomous Mobile Robots (AMRs) has shown the strongest pace change in this segment. Many publications and products that appeared in recent years had been focused on the ability to carry out high-level tasks, and on the extension and improvement of existing functions or on the integration of new ones, mainly from a software point of view [1], [2], but quite often using ad hoc HW solutions for lab or service applications.

In this work, we analyse the hardware/software architectures of the current state of the art, and introduce a new architecture, based on concepts and characteristics closer to the world of industrial robotics than to the traditional mobile robotics' one.

The proposed architecture, developed through the collaboration of COMAU and Politecnico di Torino within the HuManS (Human centred Manufacturing Systems) project, is designed to allow an easy integration of software or hardware extensions, like new software functionalities, the addition of sensors, as well as the inclusion of further motors to increase the number of degrees of freedom of the vehicle.

The first part of the paper offers an overview of the state of the art of the AGV architectures currently present in the research context and in the industrial everyday life. The second part sketches the main concepts of the new hardware/software architecture.

II. State of the Art

Mobile vehicles appear immediately after the Second World War, with the Machina Speculatrix [3], the first example of a mobile vehicle able to autonomously reach a target by finding its path.

From this first example, technology has evolved considerably, both from the academic and the industrial point of view. At the end of the 1980s, wire-guided vehicles began to be systematically used in the industrial context, and at the same time the interest of academic research on this kind of vehicles started to grow.

The state of the art of the hardware architecture of autonomous vehicles can be divided into two macro strands. The first one involves academic works and concerns the study of architectures suitable for mobile vehicles devoted to research or service applications. The second line concerns assembled industrial architectures with standard components from industrial AGV suppliers.

These two fields have some points of contact and some differences: for example, the positioning accuracy of the vehicle is a strong requirement for the industrial AGV, but it seems to be less relevant in the research world, which is mainly oriented to other navigation issues. An example of convergence of industrial and academic goals is related to the use of cheap sensors to improve the navigation system: in recent years some cameras and vision systems have been studied in academy (e.g. [4], [5]) and introduced in industry (e.g. [6]).

Another significant discrepancy between academic and industrial issues is the necessity for the industrial AGVs to be compliant to international and national norms and rules, which describe specifications and allowed behaviours. The UNI EN 1525:1999 norm in the European Union and the ANSI/ITSDF B56.5-2012 in the United States of America describe the safety requirements and the standard behaviour of an autonomous industrial truck.

A. Academic related works

The evolution of mobile vehicles within the academic world has distant origins in the past, but it is in the 90s, thanks to the development of sufficiently powerful mobile computing platforms, that AGVs research field expands considerably. Almost all the papers in literature mainly describe software architectures and algorithmic methods to perform specific tasks, leaving in the background the electronic architecture that supports, but at the same time constrains, the software solution. In the few academic articles about hardware architectures, typical solutions from the industrial and automotive world of those years can be identified.

More recently, in [7], the authors provide a comparison between the architecture of an automatic forklift, an autonomous electric car and an AGV. In the first and last case, it is shown how a CAN network combined with a PLC for vehicle management is sufficient to manage the single vehicle, a

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solution that could be extended to the electric car replacing the PLC with an embedded PC.

In [8], an hardware architecture for mobile robots is designed to guarantee extensibility and reconfigurability. It is stated that this extensibility "*is performed through a myriad of protocols including i2c, SMBus, RS232, RS485, USB, Firewire, and Ethernet. Cables to the host CPU are minimized by employing only high-bandwidth hot-pluggable protocols: USB, Firewire, and Ethernet*".

In the hardware and software architecture, developed in [9] to control a mobile robot equipped with an anthropomorphic arm, the system is based on the use of an embedded PC interfaced mainly through three methods: an Ethernet bus for communication with vision systems, a CAN bus for communication to the servo drives, and a set of wired I/O for management of the gripper and simple actuators.

Also in recent works, explicitly devoted to the use of AGVs in the Industry 4.0 scenario (e.g., in [10]), the hardware architectures are often not compliant with real industrial needs, but strongly oriented to an easy prototyping.

B. Industrial solutions

Mobile robots have been used in industry for many years. A patent [11] that hypothesizes the use of mobile vehicles for the transport of automotive bodies had already been registered in 1977. An example of implementation of that patent is the Fiat Ritmo production line [12], in which videos of the time highlight the usage of wireguided AGVs for bodies transportation. A much more recent example of AGVs used in industrial environment is represented by the production line of the Lamborghini Urus [13].

AGVs in the industrial sector are typically produced according to two philosophies: the first one is based on the adoption of software libraries and hardware suppliers that do not deal with the construction of complete vehicles, but provide Commercial Off-The-Shelf (COTS) components; the second one typically concerns suppliers providing turnkey solutions equipped with software, hardware and mechanics.

Among the suppliers of single components, different levels of provision can be found, from those who supply all the necessary electronic components, such as Kollmorgen [14], to companies like Navitech [15] that sell only the control PC.

Kollmorgen provides a whole ecosystem of devices (Figure 1) connected together by a CANOpen Bus, completed by a software environment for the configuration of the vehicle in all its aspects.

Other suppliers, such as Navitech Systems, provide only the control PC hardware (see Figure 2), equipped with all the ports necessary for communication with the drivers and with the laser scanners, and the vehicle management software.

Other types of industrial AGVs are instead supplied turnkey, complete systems, equipped with their own proprietary architecture and their hardware and software solutions. Examples of this type of AGV are built by companies like Otto Motors [16] or Fetch Robotics [17].

If you want to create your own AGV with the COTS components of a pure supplier, it is however necessary to consider also the safety aspects, besides the mechanical issues. These safety aspects involve practically all the AGV components, from motor encoders to safety laser scanner management.

Fig. 1. Hardware ecosystem for AGV from Kollmorgen [14]

Fig. 2. Hardware for AGV from Navitech Systems [15]

For safety management, specialized companies like SICK [18] or PILZ [19] produce ad hoc certified boards with the appropriate safety levels.

The complete hardware architecture thus becomes a double architecture: the first layer consists of non-safe components and communication buses necessary for the functionality of the vehicle itself; the second layer is devoted to the safe control of the state of the vehicle. Such a control is necessary for a safe interaction, for example between man and machine, as well as to address safety norms.

A typical double-layer architecture is represented in Figure 3, where the usage of non-safe drives is supported by safe relays for power control. This solution respects the functionality and security requirements necessary for modern industrial products, but at the price of a greater complexity, and heterogeneity of communication protocols and programming environments, with a consequent greater difficulty in integrating additional axes on the AGVs.

III. The proposed architecture

The proposed architecture is mainly based on two concepts: the standardization of communication protocols and the most radical simplification of the components possible. By analogy,

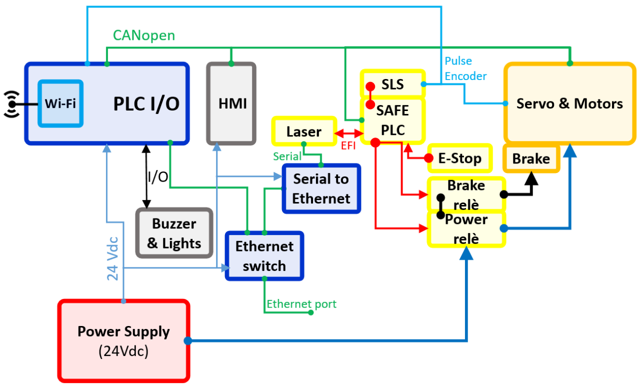

Fig. 3. Standard Architecture

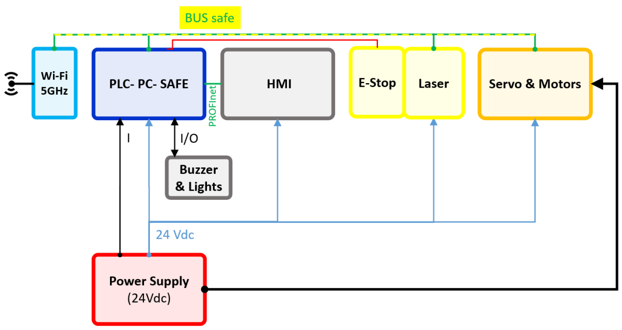

Fig. 4. Proposed Hardware Architecture

we want to bring the hardware design of an AGV closer to the hardware solutions used since the early 2000s in industrial robots controls: a single communication bus that carries both safe and non-safe information, and intrinsically safe encoders and drives.

This architecture is sketched in Figure 4: every communications go through a single bus, while every other connection is merely for power supply purposes. There is no need anymore for hardware redundancies, power cuts via relays or similar discrete solutions.

This new architecture is therefore based on the adoption of safe encoders, which interface on safe drives, capable of speed control, stop ramp, safe stop and, if necessary, integrated and safe power cutting. All the data present on the drive reach the control card via a realtime bus, which allows both safe and non-safe packets to pass.

The control board, which collects all the data (both safe and non-safe) from the peripherals, is made of three subcomponents: a safe PLC for safety control, a non-safe PLC and an industrial PC, all merged in the same element.

Thanks to the reduction of the connections complexity and of the number of employed devices, the wiring operation is significantly simplified, leading to a reduction of the construction time, and hence of the cost of the vehicle. Furthermore, the achieved simplification reduces the risk of mistakes during the assembly phase and improves the maintainability of the vehicle. All these aspects combined with the increase of the safety performance level make this architecture interesting

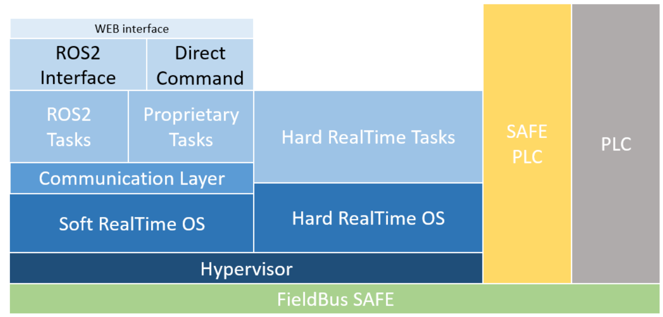

Fig. 5. Proposed Software Architecture

from an industrial and commercial point of view.

In parallel to a new concept of simplified hardware architecture, the software has been designed with the purpose of extending the normal capabilities of an industrial AGV.

The software architecture sketched in Figure 5 is aimed at being modular and open, so to be suitable both in industrial environments, including safe needs, and for academic and research purposes.

The software architecture aims at answering to three main needs:

- to ensure the safety of the AGV application;
- to allow the addition of external software components;
- to allow the extension of the vehicle's degrees of freedom through a simple integration management.

The safety of the AGV is ensured by the presence of a software safe PLC that includes the logic developed, tested and certified by the producer.

The system is open and can be extended at the software level in two ways. The first one is based on the presence of a ROS2 interface [20] within the AGV control; this interface allows to move the vehicle via an external control. The second openness is allowed by the non-safe portion of the PLC. This component, which is reserved to the user, allows the insertion of customized code to manage the simplest logics or to integrate additional axes.

The extendibility of the vehicle's degrees of freedom is allowed by the mutual possibility to implement PLC code or a ROS2 node to control the new device.

This solution is qualified to evolve along three lines, as sketched in Figure 6. The first line is the possibility of improving the single vehicle. The management of the ROS modules and the presence of a second hard Real-Time OS lead to an *open* architecture, which allows expert users to easily add further sensors and to simply integrate the code developed for research or prototyping purposes, as well as to benefit from an enhanced environment in which various control schemes can be developed and tested.

The second line concerns the possibility of including the control of additional axes, or even complex chains. The usage of the AGV with a common lifter or a simple axis can be easily managed in any case by the PLC with its typical features. The possibility to add a complex system, for example an articulated sequence of axes, to bring the AGVs closer to a mobile robot, is provided by the RealTime environment on the PC board.

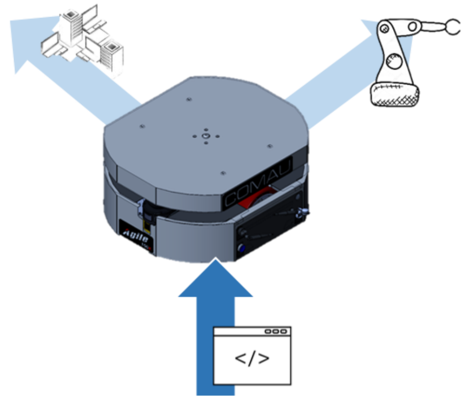

Fig. 6. Evolution path of the proposal architecture: algorithmic and control proprioceptive improvement, ease of integration, openness to speak different languages and compatibility with different systems

The third possibility of improvement is in the potential ability to interface with different fleet managers, depending on the purpose of the application in which the vehicle is involved and the needs of the end customer. This feature is aimed at potentially allowing the usage of the vehicle no longer as a single unit, but as a part of a swarm that shares a common task.

These capabilities align a normal AGV to an AMR, enabling the proposed architecture to be used in new industrial production paradigms, for example like in [21], where the AMRs are proposed as meta-sensors spread in the plant to identify the human presence along the normal route of AGVs.

The proposed mobile agent could be successfully employed in both industrial and research scenarios, thanks not only to the potentialities of its HW/SW architecture, but also to its mechanical characteristics. The compactness of the vehicle, having a maximum horizontal width of 650mm and a height of about 400mm, makes it suitable for typical university spaces without the extent of an industrial floor. At the same time, a load capacity of around 250Kg and a towing capacity of around 1800Kg make it an industrially interesting object for small general purpose logistics or components transportation in the automotive sector.

The compact shape and the high towing capacity make the proposed architecture particularly efficient in cooperative applications employing several vehicles. In this scenario more units of the same type can contribute to the execution of a single task, like in [22], where two or more vehicles cooperate to handle a single object. Through the proposed architecture we aim at implementing this operating principle into an industrial environment.

IV. Conclusion and Future Development

Currently the design of this new AGV/AMR is in the conceptual and material procurement phases. According to the schedule, the first prototype is expected to be available by summer 2019.

Already in this initial phase of development, this new platform is adopted as means to share competencies between academia and industry, particularly in the modelling of the vehicle for the development of control schemes; an even closer collaboration between COMAU and Politecnico di Torino is expected in the near future.

This collaboration will give to the researchers the chance to transfer advanced solutions into a real industrial scenario, and to the company a basis for conceiving and implementing the concepts of industry and production line in a new and different way, thanks to the versatility and simplicity of integration of the proposed architecture.

In the development roadmap of this platform it is expected to integrate an articulated system on board, so to extend the degrees of freedom of the vehicle and allow it to perform more complex and interesting tasks, both in the industrial and research context.

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