Mobile Robotics Experimentation in Industrial Environment

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Abstract

This paper provides an overall vision of the current state of the mobile robotics deployment in manufacturing industry. The main features that mobile robotics solutions should implement need to be obtained from the perspective of potential users, considering the requirements from the key actors involved in the deployment of this type of solutions and defining indicators related to these requirements to validate them. An experimentation environment and use case are defined to characterize these industrial scenarios.

Keywords

Mobile robotics, industrial robotics requirements, industrial experimentation

1. Introduction

The Industry 4.0 (aka Connected Industry) is the stage of the industry in which both connectivity and collaborative robotics are consolidated in the industrial processes. Within this framework workers and machines work in a safe common environment sharing information that can be used to improve these processes and related decision making. Considering the high relevance of this information exchange, the adoption of mobile robots and manipulators brings an autonomous and flexible industrial automation which is required in the creation of Smart Factories, where additional technologies such as the Internet of Things (IoT), Artificial Intelligence (AI) and Big Data are integrated improving the resources' management and increasing the overall productivity. This ICT soup integrates smart technologies allowing mobile robots to expand their industrial capabilities adapting to heterogeneous working environments [1]. The main objective of this paper is to provide a comprehensive vision of the adoption of mobile robotics solutions in SMEs, putting a slight focus on the ceramic tile manufacturing. Actors, requirements and Key Performance Indicators (KPIs) are presented to measure the impact of the adoption. An experimentation environment and a use case are proposed as well. Main insights as conclusions and future work are finally exposed.

2. Mobile robots in the production environment

While mobile robotics is being incorporated in every segment, there will be a gap in the 21st century between technologically advanced enterprises and the rest of companies. Indeed, most people are not aware of the extent to which robots are already present in their lives [2]. Mobile robots are being used in such diverse fields as medical environment [3], education [4], agriculture [5], chemistry [6] and personal support such as elderly [7] and autism support [8]. The research on systems composed by multiple autonomous mobile robots in a cooperative scenario has been increasing, also focusing on group architecture, resource conflict, and origin of cooperation, learning, and geometric

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problems [9]. Also relevant research studies have been conducted on both a methodology for the implementation of autonomous mobile robots in flexible (cloud-based) manufacturing environments [10] and the development of production logistics systems [11, 12], as well as the planning and coordination of multiple mobile vehicles, what becomes crucial regarding safety and efficiency [13].

In a manufacturing environment, mobile robots are often used to automate simple tasks such as the internal transport of goods collaborating with workers adapting to production needs. They can be classified in two groups according to its features: *structural* (based on the physical aspect of the machine, the traction system, direction and wheels) and *sensorial* (based on the capabilities provided by the integrated sensors, such as the perception of the environment to avoid obstacles or the creation of alternative routes). In a semiautomatic deployment case, workers can manage robots to transport goods between production lines and to sanitize the specific areas through a vision system [14].

The *Automated Guided Vehicles* (AGV) and the *Autonomous Mobile Robots* (AMR) are actually the most implemented robots for internal logistics. This automation allows workers to focus on higher value-added tasks, optimising the productivity and fulfilling the delivery schedule. AGVs follow basic instructions moving through wires, magnetic strips or sensors. Its deployment often requires disruptive changes at a high cost. They are the best choice for fixed routes, so they can detect obstacles but cannot surround them. AMRs, however, move through maps created by software providing GPS-similar capabilities, calculating optimum paths consuming data from cameras, embedded sensors or scanners to detect elements around. The software can be used to manage not only an individual but a robot fleet, prioritising commands based on position and availability [15].

3. Methodology

The methodology covers a workflow designed to achieve a successful adoption of a mobile robotics solution at shop floor as well as providing mechanisms to conduct an overall assessment of the deployment. Main actors are detected and considered for the gathering of requirements supported by an ad-hoc survey targeted to manufacturers. The feedback is analysed based on company profiles and KPIs selected as mechanism to measure the level of fulfilment of any solution of this kind.

3.1. Actors' involvement

The deployment of industrial solutions on mobile robotics requires the participation of the following main actors:

- Manufacturers of logistics robots: companies producing robotic solutions for logistics, such as mobile and manipulators. Their interaction with other technical partners provides added value.
- Software developers: companies focused on the development and maintenance of software platforms for robotics: ROS modules, fleet management systems, planning tools. Together with the robots' manufacturers they can expand the scope of its implementations.
- Technology advisors: companies specialized in the advisory of deployment of technological solutions in the end user' premises.
- Outsourced logistics providers: companies providing logistics services to companies that prefer focusing to the most critical process in the organization, relying logistics to external parties.
- End users: mainly SMEs from any industrial cluster that may be potential beneficiaries of mobile robotics solutions to automate its internal logistics.

3.2. Elicitation survey

Manufacturers producing items in batches, distributors and companies with centralized warehouses are potential beneficiaries of mobile robotics. A survey targeted to these beneficiaries was launched to detect the key features to be covered by the system. This was not oriented to any particular use case, focusing on collecting the level of interest of the companies on adopting these solutions considering the blocking issues that industrial SMEs actually face in this regard. It should be noted that the survey has been defined also considering that most of these companies do not manage mobile robotics and they often lack enough knowledge on how these solutions could provide opportunities for productivity improvements. This was released through an online form and fulfilled by operations and production managers from 30 enterprises, 10 of them large companies with more than 350 employees.

3.3. User requirements

The user feedback collected from the survey enabled the definition of a list of user requirements that need to be covered the robotics mobile solution. They are:

1. Efficiency and accuracy: the system should enable the improvement of logistics in both internal and production scope. Given that production plants in most SMEs do not have obstacle-free spaces, the navigation accuracy needs to be as much adjustable as possible.
2. Return of Investment (ROI): the ROI period should be short, so the deployment cost should depend on the achieved improvements. The cost of the internal logistics needs to be known beforehand, and the cost of the deployment of the solution should not be excessive.
3. Customization: the system should be easily customizable without increasing the deployment cost. The involvement of company staff in the deployment provides a self-sustaining management.
4. Flexibility: the system should be scalable and easily extendable, guaranteeing the security for people independently from the size of the fleet and the flow frequency.
5. Ease of use: the lack of repetitiveness in logistics tasks means a handicap to be addressed. This can be solved by providing the system with a flexible and easy programming system together with some smart component that may anticipate needs by taking real time data.
6. Connectivity: the solution should be easily connectable to other management systems already available in the company.

This list of requirements considers the survey's feedback at high level, and technical aspects brought by technicians who are familiar with the implementation of mobile robotics solutions.

3.4. Key performance indicators

A set of KPIs was elaborated from the survey's feedback and requirements introduced before, in order to evaluate the level of fulfilment of the target values once the solution is deployed. The target values indicated in the Table 1 below are references defined by a set of developers of mobile robotics solutions, based on their experience on previous deployments.

Table 1
Reference KPIs defined for the evaluation

KPI number	KPI description	Target value
KPI 1	Time dedicated to the implementation of the solution (considering 10 mobile robots)	30 days
KPI 2	Time required to connect the system to other management tools of the company	40 hours
KPI 3	Failure rate between missions	1 each 100 missions
KPI 4	Time required to reprogramming the tasks	30 minutes

KPIs were selected from experts in AIDIMME, considering those whose values can be related to the requirements and the improvements to be obtained from the adoption of the overall solution.

4. Experimentation environment

The experimentation aims at collecting data that could be later analysed to get an evaluation from the reference KPIs. The Robotics Laboratory environment of AIDIMME is selected from the need of the proposed solutions to interact with productive processes where the number of workers and fixed base robots are the same. Given that this is a laboratory environment, the gathered results would be affected by the scale and specific differences in relation to a real production environment. Therefore, the logistics here adopts both interaction types: human-mobile robot, and fixed-based robot-mobile robot. The most relevant equipment in this environment is formed by:

- The Robot ABB IRB 1600, which supports 10 Kg. as maximum load. It can be configured to operate as an industrial or a collaborative robot through the use of a software module. An artificial vision system by Cognex and an external torque sensor were also integrated.
- The Robot UR 16e, which supports up to 16 Kg. and operates within 900 mm. range. It is an easy to program robot and it is mounted over a mobile base to be manually moved.
- The Robot YASKAWA HC 10, a 6-axis collaborative robot that supports up to 10 Kg. and can operate within 1200 mm. It has a force sensor that stops the robot in case of contact with a human worker, enabling the collaborative operation at shop floor.
- Bin picking system PHOTONEO with a scanning surface area of 590 x 404 mm. This system identifies single pieces randomly placed in a container, so robots could pick and extract them.
- Mobile robot ROBOTNIK RB KAIROS with integrated arm UR 5e.
- Artificial vision system KEYENCE, used for general purposes.
- Enclosed conveyor belt, also used for general purposes.

This equipment is targeted to research activities related to the simplification of programming systems and the development of special applications for complex processes. The Figure 1: Layout of the robotics experimentation environment in AIDIMME below shows the distribution of the fixed elements in the test environment.

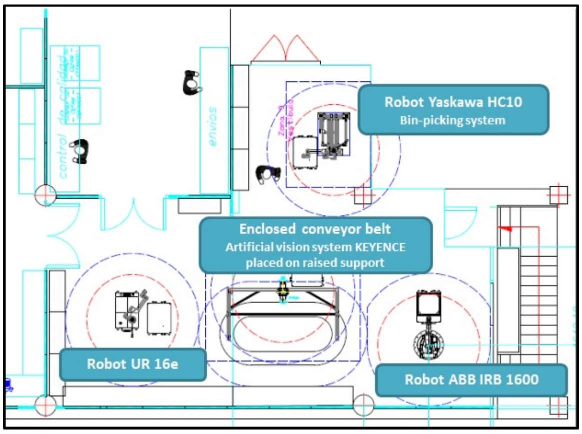

Figure 1: Layout of the robotics experimentation environment in AIDIMME

The mobile robot ROBOTNIK RB KAIROS requires significant space to operate and it is usually hosted in a nearby room. This setup enables the execution of experimentation scenarios such as:

- Coordinated transport between work places with human worker and/or automatic operation.
- Picking and delivery processes with automated origin and destination, coordinating two fixed based robots and one/two mobile robots.
- Picking process of items on the move, coordinated through artificial intelligence.
- Dropping process of items to container in random position

The design of the test is elaborated so KPI#2, KPI#3 and KPI#4 could be measured. The deployment time of a small fleet will be extrapolated to calculate KPI#1. This fleet is formed by one Robotnik RB1 (a mobile indoor robot that provides optional integration of a robotic arm or torso and laser range finders and sensors to detect obstacles [16]), one Robotnik RB KAIROS (on which a UR5 robotic arm can be mounted), and one fixed-base Universal Robot UR3 (a compact manipulator robot for the handling of small pieces [17]). This setup enables scenarios for communication and interaction between mobile and fixed devices, automating logistics operations such as stock transactions (labeling, stock check), manufacturing operations (procurement, waste management), maintenance support (planned machine shutdowns) and quality control support (management of defective pieces).

5. Use case statement

The ceramic tile cluster in the Castellón region of Spain is constituted by around 240 companies producing 580 million of sq. meters of tile per year, which are commercialised in more than 180 countries all over the world, with an average global turnover of 5.000 million € per year [18].

The ceramic tile manufacturing is a highly automated process with no human intervention in processes involving tile handling from the first stage (the pressing operation), until the last one (the sorting and packing of the finished product). However, in many stages the process quality control requires the intervention of skilled operators. Operators move tiles sampled from different process stages for flaws visual evaluations. Although this is a continuous process in which tiles are processed in batches, a stock of semi elaborated items separating the pressing/glassing stages from the firing stage and this one from the final sorting is managed. The period from the pressing and glassing of the ceramic green bodies to the firing stage varies from hours to days. During the batch production, operators need to anticipate the samples' firing to check if the pressing and glassing stages are providing tiles with appropriate properties (i.e.: size, mechanical strength, colour shade).

The operators interact with the system requiring a robot to pick-up control tiles from the pressing line to transport them to the kiln entrance. The robot advertises the kiln operator the necessity of processing the samples and, after being retired from the robot, this goes to the kiln exit to collect the fired samples and returns to the press zone, notifying the controller about the availability of the fired tiles. This allows assessing both the navigation system and the interaction between robots and workers asking for specific logistic missions. This experimentation enhances the proper adaptation of the system to a real working environment as a proof of concept for other industrial deployments. The Figure 2 below illustrates the handling of tiles by a control operator and a robot during quality control.

Figure 2: Tiles being handled by a control operator (left) and a robot in quality controls (right)

6. Conclusions and future work

The results of the survey conclude that less than round the 3rd part of companies use some mobile robotics solution, and about half of them have a medium knowledge on this topic. This is relevant so in most companies the dedication to internal logistics covers almost the half of the working time. Economic aspects, the lack of free space available at plant, and the irregularity of surfaces are the main barriers to automate logistics operations. In this regard, also the lack of repeatability in the movement of materials, and the lack of knowledge about the benefits of this technology become significantly relevant. The adoption of logistics solutions should consider the ROI, the cost of maintenance, the flexibility of the system, the security and accident prevention, the connection to internal systems, and the ease of programming to reduce external dependencies.

The most representative operations will be considered to design a general demonstrator. The objective is to propose a scenario that reduces as much as possible the time dedicated to deployment and connection to other systems and the rescheduling of tasks, as well as the failures in picking and dropping missions. Experimentation with mobile together with fixed-base robots becomes crucial to conduct research devices' orchestration at shop floor. Also a comprehensive scenario involving humans and mobile robots in strong collaboration can be designed in order to evaluate possible mechanisms to establish picking and delivery objectives with the minimum loss of coordination.

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