Technological Roadmap to Boost the Introduction of AGVs in Industrial Applications

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***Abstract*—This paper describes systems of multiple Automated Guided Vehicles (AGVs) used in factory logistics for the transportation of goods. We describe currently applied solutions, highlighting the main issues that, so far, have prevented a pervasive diffusion of these systems. A roadmap of technological solutions is then drafted, to improve the performance of AGV systems and boost their wide application in factory logistics.**

I. Introduction

This paper deals with systems of multiple Automated Guided Vehicles (AGVs) used for automated factory logistics, that is for the transportation of raw materials or final products.

Logistics is the management of the flow of resources between the point of origin and the point of destination in order to meet some requirements, for example, of customers or corporations (Fig. 1). The resources managed in logistics can include physical items, such as food, materials, equipment, liquids, and staff, as well as abstract items, such as time, information, particles, and energy. The logistics of physical items usually involves the integration of information flow, material handling, production, packaging, inventory, transportation, warehousing, and often security. Therefore, factory logistics plays an important role affecting production efficiency and energy consumption. It takes care of moving raw materials and final products from and to factory warehouse and the production shop floor: any bottleneck and inefficiency in factory logistics decreases the productivity level of the whole factory.

Nowadays, automation is only marginally applied to factory logistics. In fact, transportation of raw materials and final products from/to storage and shipment points usually requires the use of manually operated forklifts. The use of AGVs in factory logistics is not yet widespread in manufacturing plants. For this reason, factory logistics is still not well integrated into the modern manufacturing processes. The use of manual forklifts results in low efficiency and high energy consumption. Furthermore, the operation of forklifts is not safe for workers: in fact, forklift operations are listed among the most frequent causes of severe accidents in factories. According to EUROSTAT statistics [1], from 1998 to 2007, in the European Union, more than 3 million work accidents related to transports, warehouse activities and communications took place. This is mainly due to the fact that forklift drivers are prone to errors and not always sufficiently trained. In addition to that, manufacturing environments are often rather cluttered with numerous blind spots.

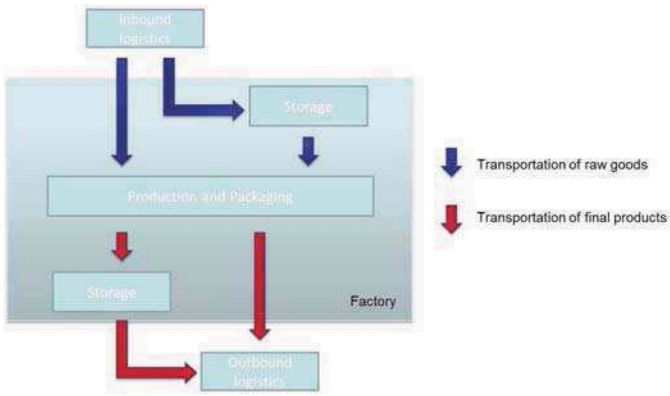

Fig. 1. Scheme of a logistic system

AGVs increase efficiency and reduce costs by helping to automate a manufacturing facility or warehouse. The AGVs can tow objects behind them in trailers to which they can autonomously attach. The trailers can be used to move raw materials or finished product. The AGVs can also store objects on a bed. The objects can be placed on a set of motorized rollers (conveyor) and then pushed off by reversing them. However, the most common application is loading objects on AGV **forks** (Fig. 2). AGVs are exploited in nearly every sector: from manufacturing industries, to hospital for medicinal handling.

The paper is organized as follows. Section II describes the scenario under consideration, that is the behavior of an AGV system used for factory logistics. Related works are then described in Section III. The main weaknesses of currently applied AGV systems are subsequently analyzed in Section IV. Then, Section V introduces guidelines for the development of technologies to overcome these weaknesses. Concluding remarks are then summarized in Section VI.

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Fig. 2. AGV with forks for object transportation

II. SCENARIO

An AGV usually picks up a pallet of goods from an automated production line, that ends with a wrapper (Fig. 3) or a palletizer (Fig. 4). The pallet has to be brought to the shipment area, usually composed by empty trucks. Sometimes the pallets cannot be shipped directly, but need to be stored in a warehouse. The warehouse may be composed of a set of racks and shelves (Fig. 5), or may be a set of block storage areas (Fig. 6).

The AGV system is generally handled by a centralized controlled, usually referred to as Warehouse Management System (WMS), that is in charge of assigning the tasks to the AGVs, and manage the traffic.

The main characteristics of an AGV system will now be analyzed in details

A. Plant installation

The installation phase for an AGV system is a complex set of operations, that need to be carried out for the system to be able to work in an autonomous manner.

Roughly speaking, given the geometric layout of the plant, and given the expected flows of material during the plant operation, the infrastructure for the localization system has to be set up, and the route map has to be defined.

Specifically, in this paper we consider laser guided vehicles. Namely, each AGV is able to localize itself measuring its relative distance from some previously mapped artificial landmarks. These landmarks are made of reflective material, and distances are measured by means of a laser scanner, placed on the top of each AGV.

The *route map* is the set of paths (i.e. the *routes*) along which the AGVs can travel to fulfill their tasks. The route map has to be defined such that a path exists that connect each pair of operation positions. Moreover, each path is defined in order to avoid collisions with the infrastructure, and among the AGVs. For each segment of the route map, the maximum allowed speed is defined, in such a way that the safety devices (typically laser scanners) are able to effectively detect unforeseen obstacles, and appropriately stop the AGV. An example of route map defined in a portion of a plant is represented in Fig. 7.

(a)

(b)

Fig. 3. Example of wrapper machine

Fig. 4. Example of palletizer machine

B. AGV missions

A *mission* is defined as a task to be fulfilled by an AGV. Missions can be divided into the following classes:

1) AGV journey:

From an AGV viewpoint, a task to be completed is defined

Fig. 5. Racks or shelves, for pallet storage

Fig. 6. Block storage area

as a sequence of segments of the route map to be followed.

Hence, once the centralized controller has assigned a task to an AGV, the AGV is required to follow a predefined path, in order to reach the final destination. While moving inside the route map, the AGV is required to keep trace of its position, with respect to the global reference frame.

2) Pallet handling:

Each journey is performed by an AGV with the purpose of moving a pallet of goods from one location to another one. Therefore, loading and unloading operations have to be completed at the beginning and at the end of each journey.

Moreover, when traveling along a path while carrying a pallet, AGVs are required to move in such a way that the pallet is never dropped off, and external objects are never touched.

3) Battery recharging:

Specific areas are defined in the plant for battery recharging. In these areas, AGVs can autonomously replace the onboard (discharged) battery with a new one (fully charged).

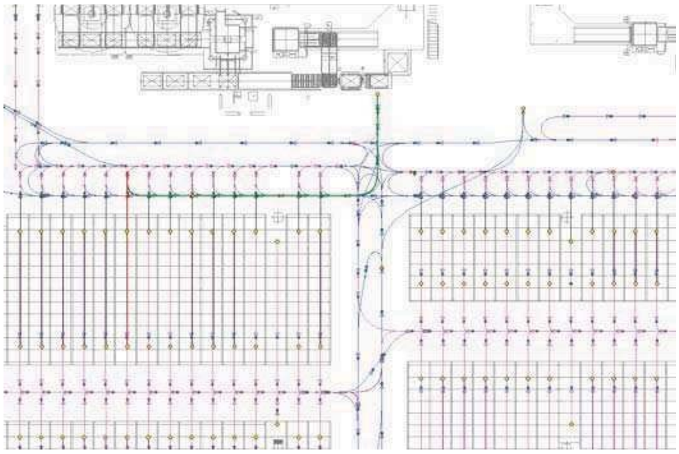

Fig. 7. Portion of the route map of a plant

Therefore, when the battery level is below a given threshold, AGVs are required to travel to the battery charge area to change the battery.

C. Safety

AGVs share the environment with human operators. As a matter of fact, in the presence of human operators, safety is a major concern. Therefore, during its motion, AGVs are required to suddenly stop if any objects (or person) is detected on its trajectory, and could cause a collision.

Safety is ensured by means of laser scanners, placed in the front of each AGV. These safety laser scanners are able to detect the presence of an obstacle within a given area. The maximum speed for the AGVs is set in order to guarantee the effectiveness of emergency stops, due to suddenly detected obstacles.

III. Related Works

In this section, without claiming completeness, we analyze some of the main works that can be found in the literature, that describe solutions for the application of AGV systems for industrial purposes.

AGVs turn out to be a very attractive technology, for transportation of goods in industrial applications. For instance, the work in [2] describes the use of multiple AGVs for cooperative transportation of huge and heavy loads. Generally speaking, AGVs are adopted in industrial applications for material handling [3], [4].

A comprehensive survey is presented [5]: in this paper, authors describe the main technologies adopted for localization and guidance of AGVs in industrial environments. Laser–based localization systems [6] are presented as an effective manner of obtaining high accuracy with a good level of flexibility. However, the presence of artificial landmarks (i.e. reflectors) is compulsory to adopt this technology. Optimal landmark placement is studied in [7] to improve localization accuracy.

Avoiding the necessity of introducing artificial landmarks, used only for localization purposes, would be a great advantage. In fact, it would reduce installation time and costs, and increase the flexibility of the system. The use of natural landmarks (i.e. features of the environment) for localization purposes would be possible exploiting different sensors, such as vision sensors. Preliminary results were presented in [8] on the use of three–dimensional vision sensors for localization purposes.

When dealing with a single AGV, several strategies can be exploited for single–robot path planning (see e.g. [9]). Conversely, when dealing with multiple AGVs, coordination strategies need to be adopted in order to optimize the traffic, from a global point of view [10]–[14]. Partially decentralized solutions have been also recently proposed [15], to reduce the complexity of the optimization process.

As mentioned in Section II, safety is a major issues for AGV systems in industrial applications. In fact, typically AGVs are required to move in cluttered environments, where unforeseen (possibly moving) obstacles can suddenly appear. AGVs need then to be equipped with an appropriate sensing system, to allow them to identify obstacles. Sensor uncertainties are considered in [16], for collision avoidance tasks.

Interaction with human operators has to be considered as well. In fact, in a warehouse, AGVs typically share the environment with human operators. Moreover, human operators are often required to interact with AGVs, to assign them tasks, or to cooperate with them. User friendly interfaces [17], [18] need then to be developed, to facilitate the coexistence of AGVs and human operators.

IV. Weaknesses of currently utilized AGV systems

Considering the Scenario described in Section II, in this Section we highlight the main weaknesses of currently utilized AGV systems.

While several AGV systems have already been implemented in several industrial applications, their use is still limited, due to several reasons. Generally speaking, main reasons are related to: cost, efficiency, flexibility and safety.

We will hereafter detail some of the main issues that have been highlighted analyzing several currently installed AGV systems.

A. Cost for the installation of the system

Referring to typically utilized laser guided AGV systems, the installation process is a demanding and expensive task.

One of the main reasons is in the fact that, in order to obtain a properly working system, it is necessary to implement a precise localization system. For this purpose, several reflectors are manually placed in precise positions of the environment. While moving in the environment, each AGV can localize itself by measuring its distance with respect to a few of these mapped reflectors [6]. In a typical industrial environment, hundreds of reflectors are needed to always guarantee the required localization accuracy. This is due to the fact that typical industrial environments are often very cluttered, and it is necessary to guarantee that the AGVs, in every position of the environment, can acquire the position of at least three reflectors. Therefore, this operation requires high costs, in terms of money (i.e. cost of each reflector) and time (i.e. time for precisely mapping hundreds of reflectors).

Moreover, during the installation phase, the entire route map has to be defined, in order to have the possibility for each AGV to reach any desired location. Defining the route map and the traffic rules is another time consuming operation, that increases installation costs.

B. Efficiency of the system

As stated in the introduction, efficiency is one of the main reasons for adopting an AGV system for industrial logistics. In fact, with respect to manual forklifts, AGVs offer the possibility to optimize the overall behavior of the system. Specifically, it is possible to optimally assign the tasks, and to compute the most efficient paths to be traveled.

In currently utilized AGV systems, several causes of loss of efficiency may be identified. Typically, efficiency is lost in terms of *non–productive time*, that is the amount of time that is spent for operations not directly related to the transportation of goods. This can happen, for instance, in the presence of traffic jams, where queues of stuck AGVs are created.

Efficiency is also reduced when AGVs do not travel at their maximum speed. Speed limits are often imposed for safety constraints: at critical points (e.g. intersections) speed needs to be reduced to ensure the ability of safety sensors to acquire the presence of unforeseen obstacles. In fact, the limited sensing capabilities of currently utilized AGV systems do not allow them to understand the context, and to effectively react to different situations, and different kinds of obstacles.

C. Flexibility of the system

With respect to rigid automation systems, the use of AGVs introduces flexibility in the logistics system.

To enhance this aspect, it is crucial to reduce the need for installing dedicated infrastructure elements, making then the system ready to cope with changes is the plant layout, or in the production process. However, accuracy in the localization, as well as in the relative positioning with respect to target objects, need to be guaranteed, in order to ensure effectiveness of the system.

D. Safety of the system

When sharing the operational environment with human operators, safety is the main issue that always needs to be fully addressed. In fact, as the behavior of human operators is completely unpredictable, AGVs need to be intrinsically safe, in order to never cause injuries to humans. For this purpose, safety sensors (typically bumpers or laser scanners) are used, to stop the AGVs in the presence of obstacles.

The maximum allowed speed for the AGVs is computed in order to always ensure that, as soon as an obstacle is perceived, the AGV is able to stop before touching it, under the hypothesis that the obstacle is static (i.e. it does not move). While this assumption is valid when the perceived obstacle is an object, it does not hold in the presence of human operators. However, the sensing equipment on currently utilized AGV systems do not provide semantic classification capabilities, that might make the AGVs able to react to different kind of obstacles in a more appropriate manner.

V. Technological roadmap to improve industrial application of AGV systems

In this Section we propose a few technological solutions, that would lead to overcoming the weaknesses highlighted in Section IV, therefore improving the spread of AGV systems for factory logistics.

A. Automatic route map definition and traffic management

Defining the route map in an automatic manner would highly decrease the installation time and cost, since manual definition of the route map is a time demanding operation.

An algorithm for the automatic definition of the route map would require the following input data:

- The geometric layout of the plant, that is the position of racks and other obstacle.
- The position of each operation point, that is the positions where pallets need to be placed and/or picked.

Based on these input data, an algorithm may be defined to build a route map, that is a set of segments such that a path exists between each pair of operation points. The paths need to be defined in order to optimize the overall behavior of the plant, in terms of number of AGVs needed, and in terms of time and energy consumption.

In order to increase the flexibility of the plant, it would be useful to include the possibility of updating the route map, in case of modifications in the plant layout.

B. Improved sensing system

Currently utilized sensing system is mainly focused on safety: in fact, AGVs only acquire information about the presence of obstacles, that is used to slow down and stop to avoid accidents.

The introduction of advanced sensing devices and improved sensor data elaboration would lead to increased safety, efficiency and flexibility, as will be detailed hereafter. Examples of advances sensing technologies include (but are not limited to) 3D laser scanners, 2D cameras, steroscopic cameras, and RGB–D sensors.

1) Localization based on natural landmarks:

The term *natural landmarks* is usually exploited to denote features of the environment that can be effectively and reliably recognized by the sensing system. For instance, features like walls, doors or corners might be exploited.

The development of a localization system based on natural landmarks would lead to avoiding the need for the installation of laser reflectors, thus greatly reducing installation time and cost. The localization system is however required to be robust and precise enough, to guaranteed the required accuracy in the computation of the position of each AGV with respect to the layout of the plant.

2) Autonomous layout measurements:

Sensor systems might be exploited for measuring the features of the plant, whose actual positions might be different with respect to the blueprints. More specifically, advanced sensor systems might be used to measure the position of infrastructure elements, as well as the precise loading and unloading locations.

These data can then be exploited for automatic route map definition, and for localization based on natural landmarks. Therefore, it is necessary to guarantee a high precision in the measurements.

3) Enhanced safety management:

Advanced sensors and improved elaboration of sensor data can be exploited to enhance the management of safety operations. Currently utilized safety devices, in fact, provide very poor information, that is presence or absence of obstacles. Therefore, when the presence of an obstacle is acquired, an AGV stops, and waits for the obstacle to be removed.

To improve the efficiency of the system, it would be necessary to react in a different manner to different kinds of obstacles. For example, a static object may be easily avoided with a small deviation in the foreseen path. Therefore, the enhanced sensing system should provide a reliable measurement and classification of the obstacles, that would lead to more efficient avoidance strategies.

4) Object recognition, measurement and categorization:

A sensing system able to effectively measure and categorize recognized object would greatly improve flexibility and efficiency of the AGV system.

Categorization of recognized objects can be useful from several points of view. In fact, infrastructure elements can be used as natural landmarks for navigation, and can be included for automatic definition of the route map. Moreover, moving objects can be recognized, in order to set up efficient avoidance strategies.

A fundamental category of objects to be recognized is represented by pallets and pallet locations. In fact, pallets represent the main typology of objects to be handled by AGVs. Currently, to let an AGV be able to pick up a pallet, it has to be precisely located in a predefined position. In order to increase flexibility, it might be useful to allow pallet positions to be modified. To allow this flexibility, the sensor system has to reliably recognize a pallet and precisely measure its relative position.

On the same lines, recognition of loading and unloading positions would allow the layout of the plant to be modified, without interfering with the ability of the AGVs to correctly accomplish their missions.

C. Enhanced navigation system

Improvements in the navigation systems and in the traffic management have a great impact on the overall efficiency of the AGV system. In fact, mission assignment, path planning, and conflict resolution (e.g. right of way in an intersection) are critical aspects in defining the productive and non–productive time of each AGV. In fact, for example, an inefficient traffic management may lead to the creation of queues of AGVs, that obviously cause losses of time.

Navigation strategies need also to be developed to improve the performances of the pallet loading and unloading operations. Generally speaking, it is necessary to develop strategies to drive an AGV to a target position. Target position is the location of a pallet (in the case of loading operation) or the location of an unloading position (in the case of unloading operation). Navigation strategies need to ensure sufficient accuracy in the relative positioning, and avoidance of collisions.

VI. Conclusions

A wide diffusion of AGV systems in factory logistics would greatly improve the efficiency and the safety of manufacturing systems.

In this paper we described some technological solutions, that would lead to overcoming the main weaknesses of AGV systems currently adopted for factory logistics.

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