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Autonomous navigation of an automated guided vehicle in industrial environments

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ABSTRACT

The research presented in this paper approaches the issue of navigation using an automated guided vehicle (AGV) in industrial environments. The work describes the navigation system of a flexible AGV intended for operation in partially structured warehouses and with frequent changes in the floor plant layout. This is achieved by incorporating a high degree of on-board autonomy and by decreasing the amount of manual work required by the operator when establishing the *a priori* knowledge of the environment. The AGV's autonomy consists of the set of automatic tasks, such as planner, perception, path planning and path tracking, that the industrial vehicle must perform to accomplish the task required by the operator. The integration of these techniques has been tested in a real AGV working on an industrial warehouse environment.

1. Introduction

The main guidance system in early industrial automated guided vehicles (AGV) was a wire buried in the floor. A frequency was induced through the wire so that the AGV could detect and follow it, and so be directed through its route. The intelligence was in the floor controller that produced the signals along the wire. In this case, the AGV acts as a kind of dumb-device.

The next generation of AGV systems, driven by the advances and costs reduction in microelectronics and microcomputers, made the AGVs more intelligent, and thus they could store instructions about the routes, make decisions and take part in traffic control of the global system. Besides, new wireless guidance systems, using lasers or inertial systems, allowed AGVs to operate without physical guidepaths [1], namely free-ranging AGVs [2], which made the installation of such systems easier and facilitated guidepath modifications when new stations or flows were added.

Today, AGV systems are widely chosen by manufacturers to implement truly flexible material handling systems (MHS), which are often necessary for the highly automated manufacture model used today. Flexible MHS permit alternative routes that can be used to compensate machine failures or product changes, which makes them especially suitable for seasonal and cyclic variations. MHS composed of AGVs have been used for tasks like movement of products in warehouses, distributions and storage functions or transport of subparts between different assembly stations in a production line.

Developing an AGV system requires, at least, catering for some of the following topics: *navigation and guidance*, *routing*, *traffic management*, *load transfer* and *system management*. *Navigation and guidance* allows the vehicle to follow a route. *Routing* [3] is the vehicle's ability to make decisions along the guidance path in order to select optimum routes to specific destinations. *Traffic management* [4] is a system or vehicle ability to avoid collisions with other vehicles. *Load transfer* is the pickup and delivery method for an AGV system, which may be simple or integrated with other subsystems. *Management system* [5] is the method of system control used to dictate system operation.

Current point-to-point AGV navigation techniques can be roughly separated into two groups, *fixed path* and *open path* navigation [6]. In both cases the basic idea is that the AGV has to follow a fixed guidepath. *Fixed path navigation* uses the original idea of embedded wires in the floor, although other techniques like magnetic or reflective tape on the surface of the floor can be used as well. In this case, the paths are fixed and thus a modification of the layout implies stopping the whole system and changing the paths physically. On the other hand, the navigation task is easy, requiring only a sensor to detect the guide on the floor. In *open path navigation* the AGV can, at least theoretically, take any guidepath to navigate between points. Thus, in order to navigate in this environment, the AGV needs a map and a method to know its own location.

In current commercial systems, the routes for load transport are predefined during the design of flowpath layout [1,2].

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Typically, all the possible routes are stored in the AGV memory in conjunction with the map of the environment. When an order is received, the navigation system decides which of the memorised routes to take to move from one point to another. Normally, this is done in terms of the shortest path and it can be combined with the traffic coordination process to synchronise the use of paths between several AGVs. But this model implies that if the layout is modified, the routes have to be modified as well. In the case of *open path navigation*, free-ranging AGVs, modifying routes implies computing and programming the paths in all the AGVs. If there are many, the process requires the system to be stopped although in this case the non-productive period is shorter than with, *fixed path navigation*, wire guided systems.

Normally the guidepath programming is done by repeating the routes under manual control. When there are many AGVs the process becomes larger. In other cases, the programming process is done in a centralised computer and then the routes are broadcasted to the AGVs. In any case, if the floor plant is large and the number of load/unload points is high, the process is extremely time consuming.

Although most of the key issues to obtain autonomous navigation systems have been broadly addressed in different scenarios by the autonomous systems community, developing systems that are able to plan and react to dynamic and uncertain environments, there are not many successful examples of fully working service robots in industrial applications, like AVGs. Outdoor transportation of containers by autonomous AGVs for harbour logistics, navigating along fixed guidepaths, is addressed in [7]. The coordination problem of AGVs, also considering fixed guidepaths, has been addressed using different techniques [8,9]. To facilitate the guidepath design, automatic calculation of shortest paths considering the *a priori* knowledge of the environment is addressed in [10]. Besides, in order to remove the dependence on guidance infrastructure, which is not suitable or not possible in some applications, some AGV's prototypes have incorporated vision systems for operating in infrastructure-free environments [11].

In order to cope with the configuration problems mentioned above, which are especially problematic when production is affected by product demand changes and seasonal variations, and increase the flexibility and autonomy of traditional AGV systems, this work presents the successful development of a flexible AGV system that:

- is *easily configured* and adapted to floor layout changes to reduce non-productive periods and decrease the amount of manual work when establishing the *a priori* knowledge of the workplace.
- is *easily commanded*, which facilitates integration with any management system.
- is able to navigate autonomously through the workplace by incorporating a *high degree of on-board autonomy*, which increases flexibility.
- is able to operate in partially structured environments with *industrial grade accuracy*, *repeatability and reliability* that permit it to perform precise manoeuvres, such as pickup and delivery.

The paper is organised as follows. Section 2 introduces the flexible material handling problem and describes the proposed solution by developing a flexible AGV system. Section 3 focuses on the high-level representation used to configure, command, and planning the tasks of the AGV easily. Section 4 presents the navigation techniques that the AGV has incorporated for increasing flexibility while performing precise manoeuvres. Section 5 describes the different behaviours for performing different tasks, such as obstacle avoidance and highly precise path tracking. The evaluation of stand-alone critical functionalities and the AGV system operating as a whole in an industrial warehouse environment are presented in Section 6. Finally, Section 7 gives some conclusions.

2. Problem and proposed solution

Material handling problem consists of how to transport raw materials, partially manufactured products and goods between different locations of manufacturing systems, warehouses, etc. When the transport is automated, the solution is provided by Material Handling Systems (MHS), which can operate continuously or under demand. Depending on the kind of products to handle and the transport to perform, there are different solutions on the market. For instance, we can mention belt, roller and vertical conveyors, elevators, material handling robots and AGVs. Belt conveyor is an economical way of conveying most types of product, while roller conveyor is popular for transporting general packing or solid products, both in horizontal and inclined operations. Depending on the type and weight of the material, vertical operations are performed by vertical conveyors, elevators and manipulators. AGVs are especially suitable for applications where space is at a premium and flexibility is critical.

The different MHS differ in the way they operate, the configuration of the system, and how they are ordered. Fig. 1 shows the MHS solution of both approaches for the same specific problem in order to show the differences between MHS based on traditional AGVs and the proposed approach. The problem consists of connecting six workcells, which are fed with pallets, which are then dispatched.

The solution based on the use of a traditional AGV, Fig. 1(a), shows how the guidepaths are designed to reach all the workcells, given the floor layout and considering the capabilities of the vehicle, i.e., the way of navigating and performing accurate manoeuvres. In order to simplify the guidepath, some connections are usually obviated, at the cost of performance, and non-optimal paths are usually used by the system. We can observe that to pickup a pallet at *docking-point* 6 and dispatch it at *docking-point* 4, the AGV should go through both central points to reach the goal because the path between *docking-point* 4 and *docking-point* 6 is obviated for simplicity. In addition, the guidepath should be redesigned when the floor layout is modified, e.g., new workstations, obstacles, etc.

The proposed approach is based on the development of a flexible AGV, able to navigate freely between different places of the workplace while adapting to possible modifications of the environment, including non-expected objects and layout changes. The solution based on the use of a flexible AGV, Fig. 1(b), shows that there is one AGV with a rough description of the environment, including location of workcells and way-points to facilitate the manoeuvres. By developing an AGV that it is automatically configured by this world description and which is able to navigate freely through this workplace, the MHS solution is simple and efficient. Following the previous example, the flexible AGV can navigate directly from *docking-point* 4 to *docking-point* 6 because optimal paths considering the current situation of the environment are calculated on-board. In addition, in order to adapt the system to a different layout, we only have to provide a different world description of the workplace.

In order to develop the flexible AGV system that satisfies the requirements mentioned in the previous section, we have implemented a set of techniques which are integrated following the scheme shown in Fig. 2. The different methods are grouped into modules according to a functional decomposition of the problem that they address [12]. Organisation by modules provides