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SMALL AND LOW-COST AGV FOR DISTRIBUTED PRODUCTION LINES AND WAREHOUSES

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Abstract: Consumer's standards are getting higher, and the global market is more competitive than ever, demanding much more from the industry and services. Thus, material resources management is crucial to every company. The transport of materials between a warehouse and a production line is one classic example of a process possible to be optimized. The aim of this paper is to present the development of a prototype for an Automated Guided Vehicle, AGV. The purpose of the work was to build a small, low-cost, and electric vehicle able to transport small packages. All control devices, supervision applications, and user-interface software, was entirely developed for this project. Furthermore, the behavior of the robot will also be analyzed and discussed in this article.

Keywords: Automated guided vehicles (AGV), Warehouse automation, Production systems

1. INTRODUCTION

In modern flexible production systems (M.P. Groover, 2000), the materials handling and storage can be done by Autonomous Guided Vehicles, AGVs. The efficiency and effectiveness of production systems is influenced by the level of optimization of the materials' movement within the plant. Therefore, the performance of an automatic transportation system is crucial to achieve a good overall performance in the production system.

The purpose of this article is to develop a prototype for an autonomous vehicle, which should be able to travel autonomously, making it suitable to transport small packages within a factory, hospital, repairing service enterprise, etc. This Autonomous Guided Vehicle – AGV – must be flexible enough to operate in considerable different environments, without the need for auxiliary markers like buried wires or traffic lines. In a way to try and avoid working accidents, protecting the crew members that stand by the vehicle from eventual hazards, it must have small dimensions and low traveling speed.

There are already some AGVs in the market. However, almost all of them have a superior load capacity (hundreds of kg) and bigger dimensions, making them only suitable to operate in restricted environments, where the human presence is limited or forbidden.

The main navigation systems available are:

- Magnet-Gyro guidance

The Magnet-Gyro guiding and navigation system, developed by AGV Electronics, has a custom made magnet position sensor used to find small magnets installed in the floor, and Gyroscope technology to keep the AGV heading direction continuously under control

- Inductive guidance

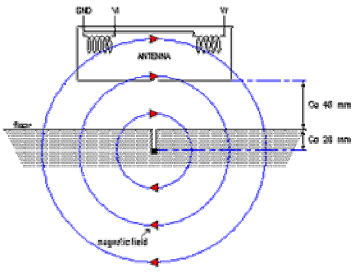

Fig. 1. Inductive guidance working principle.

The above picture shows this principle with a receiving antenna with two coils, which detects the electro-magnetic field around the wire in the floor.

Inductive guidance (also known as wire guidance) in an AGV is based on the fact that an electrical conductor through which an AC current is flowing will create an electromagnetic field around itself. This field is stronger close to the conductor, and is reduced with increased distance from the conductor.

An electromagnetic field, which passes through a coil, will induce an electric voltage across the coil ends. This voltage can be detected across the termination of the coil. The voltage is proportional to the strength of the field.

A guiding antenna contains two coils positioned on each side of the wire, which is embedded in the floor. The difference in electric voltage between the two coils will create the steering signal to the steering motor of the AGV.

When the antenna is centered over the guide wire, the voltage in the coils will be the same and the steering signal is equal to zero. If the antenna is positioned to either side of the guide wire, the voltage will be increased in one coil and reduced in the opposite coil. This voltage difference will generate a steering signal, which will control the rotation direction of the steering motor.

The floor loops will have different frequencies that the control board in the AGV can detect separately.

- Laser guidance

A laser scanner which gives out X and Y coordinates and heading is used.

A laser scanner is mounted in a high position on the AGV. The targets must maintain a good visibility from the point of view of the laser scanner. The targets are made of high reflective tape on a plastic cylinder or plate. A minimum of three targets must be detected at each time during travel. Normally there should always be five visible targets. The targets can be located up to 30 meters from the AGV.

The laser scanner measures distance and angle to each target and gives out X and Y coordinates on a serial port.

The AGVs from AGV Electronics (AGV Electronics, 2007) and Egemin Automation (Egemin Automation, 2008) are an example of robots made to work with high loads and within confined places since their navigation systems are based on the technologies previously referred.

In Portugal, a company named EFACEC has been developing some autonomous vehicles for the transport of batches. However, they are again projected to work with high loads and, they use lines painted on the floor or laser vision for guidance purposes. This brings them two major drawbacks, either their paths are confined to these lines, or to the targets placed down for use with the laser vision.

The loads that are going to be transported by the developed AGV are smaller and lighter, which allow the robot to be smaller and make it able to work in smaller and more crowded spaces. Its smaller dimensions also bring a lower cost both in robot components and engines. The way in which this AGV pinpoint its position and move around is also completely different from the ones previously presented. In fact, it uses more than one location method, gathering together data collected from different sensors (cameras, encoders, laser range meter and sonars), and fusing that information according to the location algorithms. Altogether, the information collected from the different sensors, allows the AGV to operate in a wide range of industrial and service environments, where the human presence is acceptable.

In this way, this project intends to be a new approach for the practical and logistical problem of transporting small loads in a more flexible and versatile way, without the need for placing localization targets.

2. ROBOT DESCRIPTION

A prototype of an electric traction vehicle for the transport of small packages – an AGV powered by a 24 Volt DC engine – as well as all the control, supervision and user-interface applications were all built from scratch.

The vehicle must have the following characteristics:

- Movement control with differential traction;
- Autonomous movement;
- Localization based on visual markers, ultrasonic sensors, and the world map of the surrounding environment;
- Lift system with the capacity to transport small packages (boxes or pallets), and place/collect them from shelves;
- Automatic charging system for its batteries, whenever the robot is not in use;
- Creation of a data base that includes all relevant information;
- Wireless communication with an application responsible by the maintenance of the database;
- Packages' identification through a bar code reading system.

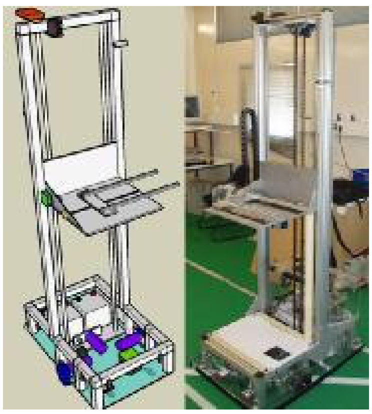

Fig. 2. General view of the AGV.

All the technology used in this prototype was developed in the university (FEUP), using as model some technologies implemented by the robotic football team.

3. DEVELOPED APPLICATIONS

The next image shows a scheme with the overall architecture of the applications developed and the different interfaces.

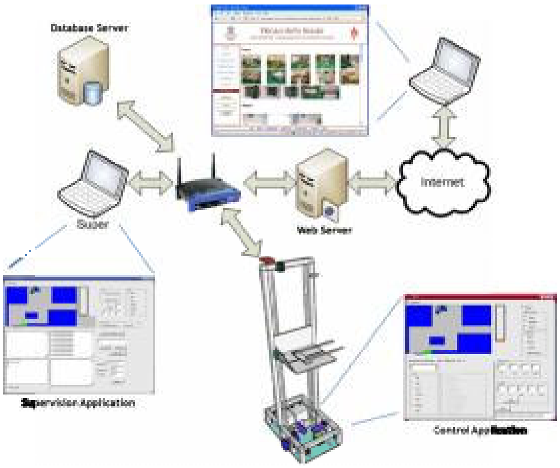

Fig. 3. AGV' overall architecture.

The architecture of software implemented, includes the following applications:

3.1. Web Application

Fig. 4. Web Application’s view.

Under the scope of this article, we will only focus on the access to the database. The web page allows the following operations with the database:

- Read data from tables;
- Run both direct and cross queries;
- Put and Cancel tasks to the AGVs;
- Add and remove active AGVs;
- Insert/remove packages from the Warehouse

The users of the website have different permissions, and not all of them have access to these features. They are only available to users with a certain access level, and the access is granted or denied though a login web page. This authentication mechanism allows the selection of contents and features provided by the website in accordance with the user. These features have a connection to the database and this connection is implemented with the PHP programming language. The web pages with the rest of the features were built resorting to HTML.

3.2. SUPER

This is the high level control software. It is responsible for assigning the tasks to be performed to each one of the available AGV,

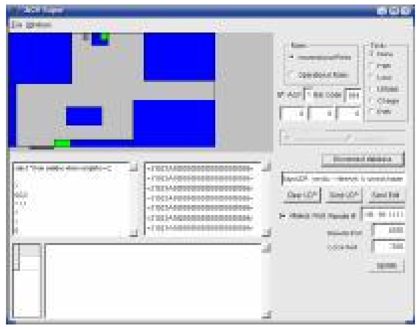

Fig. 5. SUPER Application’s screenshot.

The application named Super is always active. Continuously, it performs a query to the database checking for pendant requests. If there is any, the Super books one AGV, and gives it the order related to that request. The AGV, after having been assigned to a request, moves toward the starting point in order to pick up the desired package. Then, after having collected the package, it moves to the destination point and place the load carried on the desired site. At this time, the vehicle checks its batteries and if their level is below a predefined value, it automatically moves to the charger point. Otherwise, if the level of the batteries is above that level, it moves to the garage and stays idle waiting for a new request. This is the point where the cycle is restarted, and the loop repeated again.

The application Super change data with the application AGV Decision, implemented in the AGV, through UDP frames.

The following state chart diagram, describes the state machine associated with the application Super.

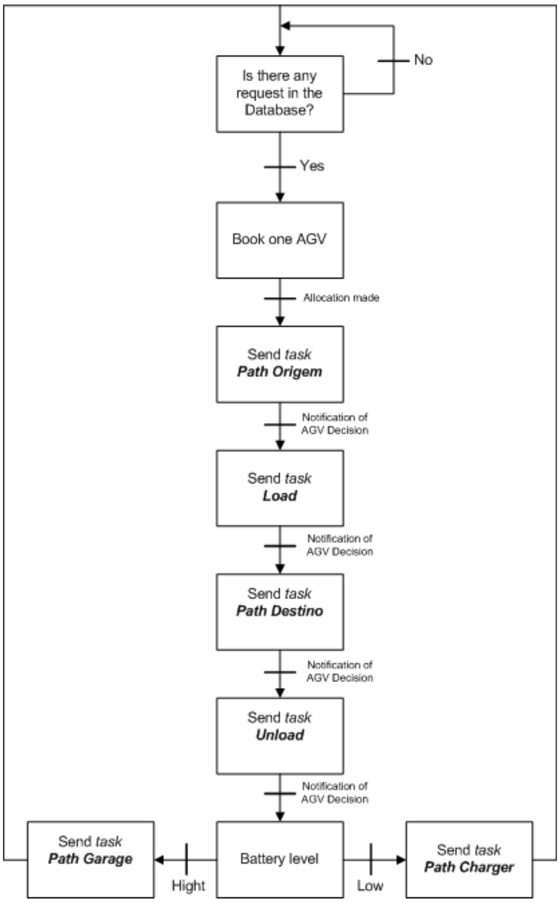

Fig. 6. States' machine of the application Super.

3.3. AGV Decision

Tis is the software implemented in each one of the AGVs. It receives commands from the Super application, and carries out each of the functions that were assigned to it though the actions (Actions). These actions are themselves, the functions to be done.

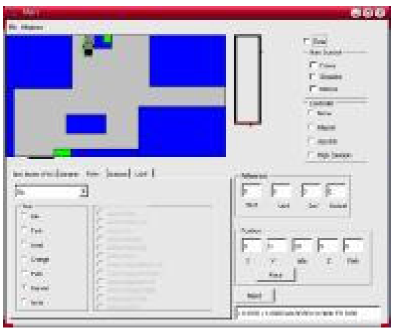

Fig. 7. *AGV Decision* application's screenshot.

The main routine of this application is called each 40ms, whenever an interruption is generated by the camera. It is inside of this routine that the control of the entire application, and the synchronization of all information, is implemented.

To find out the references that will make possible to achieve the desired results for the AGV, is necessary to know its position and orientation, since the entire decision-making is based on that. This is one of the main problems of robotics. The AGV developed has several types of sensors. Therefore, to pinpoint its most likely position, it merges all the information gathered from these sensors. After the position and orientation of the AGV have been determined, the next step is to evaluate the values for the velocity references to apply in the motors drives.

4. HIGH-DECISION MODE

The software architecture is structured as follows:

- The functions performed by the AGV are called roles. They are given to the AGV when it is requested to do something.
- After have been assigned a role, the AGV performs the *tasks*, which are the jobs related with the given function;
- The *tasks* are divided into *actions.* They are the lowest level of the control chain.

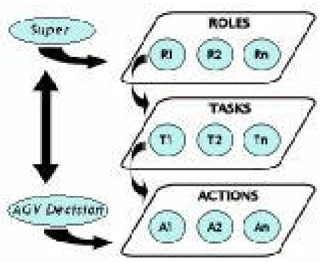

Fig. 8. Cooperation Architecture.

5. WORLD LOCALIZATION

5.1 Sensors

5.1.1 Odometry

The odometry is one of the most widely used methods to estimate the position of a robot. It is known that the odometry provides a good accuracy in the short term, it is cheaper to implement, and enables very high sampling rates. The fundamental idea of odometry is the integration of the incremental movement data over time (information provided by encoders), which involves an inevitable accumulation of errors. The accumulation of direction errors causes errors in the estimated position, which will increase with the distance travelled by the robot.

5.1.2 Sonars

Due to the environment in which the AGV is expected to work, it becomes necessary to detect obstacles along its routes. In order to detect and avoid collisions with obstacles, the AGV bumpers were fitted with some sonars. The sonars are also used to update the position of the AGV in certain maneuvers (such as when it is parking), since they provide information about the position of the vehicle. The AGV has 7 sonars scattered along its perimeter in order to detect obstacles in all directions.

5.1.3 Hilti PD30 Laser range meter

This small laser range meter makes it possible to measure distances with an accuracy of less than 1.5 mm within a range of 200 meters. It has also a measurement time below 0.5 seconds, and allows Bluetooth connections to other devices like computers and PDAs.

If the Hilti laser range meter was settled in a high enough position to prevent it from picking obstacles ahead, it would be simple to evaluate both the position and orientation of the robot inside the room. As a fact, it would be enough to do a scan around the robot, and this sensor would be used only sporadically. As a method to collect information, it would be enough to use a stepper motor making a 360º scan. For every step, the distance to the wall should be recorded and inserted in a diagram, becoming relatively easy to obtaining both the position and orientation of the AGV by simple interpretation of the referred diagram.

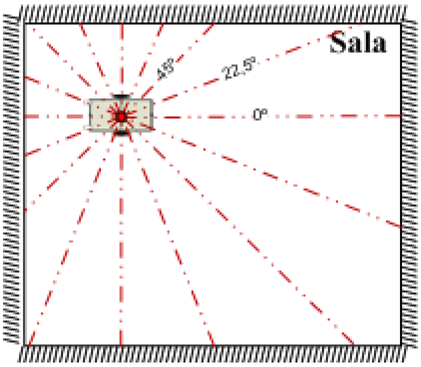

Fig. 9. Scan of the HILTI meter.

5.1.4 Camera

The camera uses visual targets (bar code type), placed all over the compartment, to measure the distance and angle of the AGV regarding these visual targets. It's necessary in situation where the Laser Range Meter is not usable.

When a target is identified, the camera sends to the control application (AGV Decision), the identification of the target, the distance to the target, the angle with the target, and a measure of confidence in the measures. The communication is done through UDP frames, and after some processing, it is possible to update the location of the AGV.

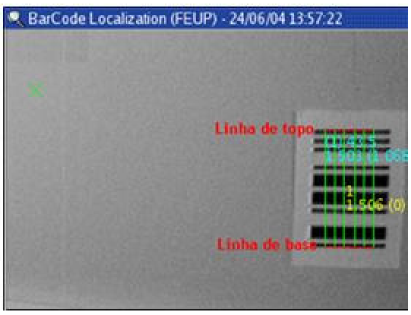

Fig. 10. Example of an image displayed by the camera.

After identifying a visual target, the global position of the AGV becomes somehow known. But that, only works when the AGV passes relatively close to the target and, due to some restrictions, it is not possible to place targets in many places. This creates a need to complement this location technique with other sensors information.

The distance to the bars code target can be easily determined. Indeed, it is enough to use the height of the bars code in the image captured by the camera. To get the angle that the camera makes with the bar code, we must use the top line and the baseline. Since these are horizontal lines in the world, knowing their direction on the image, we get the angle that the camera does with the bars code. The confidence in the measures is given by the number of vertical lines identified on each bar code.

5.2 Fusing Information

The greater the accuracy of the information about the location of the robot, the more correct the decision-making process is.
To fuse all the information from the different sensors, it has been used a simplified Gaussian filter, where each of the measures is considered a random variable with Gaussian distribution (Sebastian Trun, *et al.*, 2005). The variance of this random variable is inversely proportional to the confidence level we have in the measures from sensor. With a prior study, it is possible to estimate the variance associated with each sensor, and then fuse all the measures from the different sensors according to these variances.

6. PRATICAL RESULTS

To test in a practical way, all the knowledge achieved through the work and research done, and in order to validate the applications developed it can be presented some data collected during the test of the robot.

The AGV performed with success, a small route which it was ordered to follow. In fact, the AGV moved by itself and without any human intervention, from the place where it charge its batteries to another place considerable far away from the initial one.

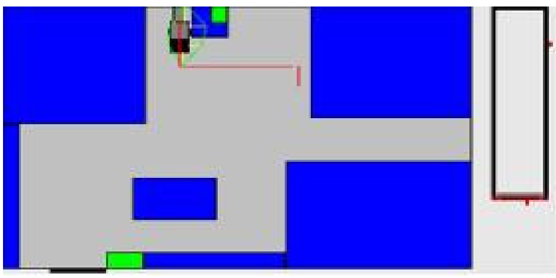

Fig. 11. Shows the position of the robot as well as the path intended to be done, as shown in the application *AGV Decision.*

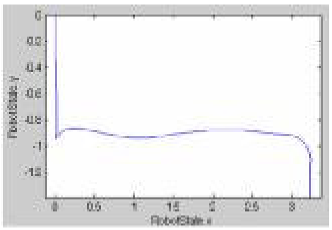

Fig. 12. Shows a graph with the (x,y) coordinates of the points detached from the path done. These data was obtained from the log of the *AGV Decision* application.

The robot performs the task above illustrated, through the commands “role op” and “task path”.
As can be seen, the differences between the path followed by the robot, and the one that it should have really followed are considerable small.

After this, the whole system was put to work, and exhaustively tested. To do this, it was inserted through the web page a role in the system, which was automatically assigned by the supervision applications to the only AGV available. The completion of this task can be seen in the movies available on the “Galeria Fotos” of the web page AGV FEUP (AGV FEUP, 2007).

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