Development of an affordable Automated Guided Cart for material handling tasks

T.P. FERREIRA, I.A. GORLACH
Department of Mechatronics
Nelson Mandela Metropolitan University
Gardham Avenue, North Campus, Summerstrand, Port Elizabeth
SOUTH AFRICA
s208008347@live.nmmu.ac.za, igor.gorlach@nmmu.ac.za, http://www.nmmu.ac.za

Abstract: - The use of autonomous vehicles for material handling tasks in industry continues to grow because of higher productivity, improved ergonomics and safety aspects. Despite these advantages, the major drawback of implementing autonomous vehicles is their high cost, which makes it difficult to justify economically the automation of processes. Hence, there is a need to develop an affordable design of autonomous vehicle or Automated Guided Vehicle (AGV). AGVs designs and capabilities vary depending on the complexity of the task, the environment and the level of autonomy. As the AGV market is highly competitive, the designer and the manufacturer need to provide a low-cost solution without compromising the AGV functionality. An Autonomous Guided Cart (AGC) is one of variations of AGVs that provides automation of transporting tasks with a minimum level of control and complexity, and at an affordable cost. In this research, a low-cost AGC was developed specifically for a local automotive manufacturer. The AGC employs a line-following mechanism for navigation making use of a guide sensor in conjunction with a magnetic strip. An industrial PLC controls the motors of the AGC using the principle of the differential drive. A wireless communication module is used for interfacing with the host computer and other devices of the material handling system. SCADA software provides a versatile platform for the overall AGC control. The developed AGC was tested in the real industrial application and demonstrated the required level of performance for the material handling tasks. Due to its low cost, simplicity and flexibility the AGC can be economically viable for small and medium enterprises in a variety of industrial sectors.

Key-Words: - automation, AGV, material handling

1 Introduction

The main challenge in designing AGVs is the choice of a reliable and cost effective navigation system. There are many navigation methods used for AGVs, of which following a physical track on the floor is the most common method used in industry. AGVs are generally comprised of a power source, wheels, electrical motors, safety devices and sensors. The AGV control system senses the line and repositions the robot to stay on course. A line follower can, therefore, be classified as a simple closed loop system. The track can either be created by coloured tape, as is the case with vision-based line followers, or by magnetic tape when special sensors are used for guiding. Magnetic tapes are widely used for industrial AGVs, since the magnetic tape can be placed on the floor with protection tape, or under the floor a where it cannot be damaged. The line following method for navigation is one of the most widely used in industry, [1], [2], [3] and [4].

Control of mobile robots is an important topic, as reported in [5], [6], [7], [8], [9] and [10]. In terms of the drive mechanism of AGVs, the most common is a differential drive system [2]. A two-wheel differential drive refers to a system where each wheel's drive motor is controlled individually, but in a coordinated manner in order to follow a path. Other designs of AGVs include: single wheel drive, syncro-drive and Ackermann steering [1]. Single wheel drive autonomous vehicles are constructed using three wheels, namely: two castor wheels at the rear and a single wheel at the front, which is used for both driving and steering. The direction of motion of the autonomous vehicle can be altered by repositioning the drive wheel. According to [1] a differential drive of autonomous vehicles has two independently controlled motors located on the left and right side of the robot. A differential drive can either have three contact points, i.e. two driving wheels and a single castor wheel when the driving wheels are placed at the rear of the robot, or four contact points when the driving wheels are positioned in the centre of the autonomous vehicle. If both the motors operate at the same speed, the autonomous vehicle will move forward. If the motors rotate at the same speed, but in opposite directions, the autonomous vehicle will rotate about a midpoint located between the two driven wheels [1]. If both motors rotate in the same direction, but with different velocities, the autonomous vehicle would move along a curve. The syncro-drive of autonomous vehicles consists of three wheels which are all used for driving and steering. The advantage is that the autonomous vehicle is omni-directional, meaning that it can move in any direction on the plane. However, autonomous vehicles with a syncro-drive cannot change direction while driving, thus it is required that the autonomous vehicle be stationary while the wheels are repositioned. Ackerman steering is used by standard automobiles and it consists of two driving wheels and two steering wheels. The rear wheels are used for driving, while the front wheels are used for steering, [1].

Line following using sensors is a preferred method for autonomous vehicles navigation in many applications. Line following performance is reported in [3] which concludes that line following can be achieved successfully. However, this method is less reliable at high velocities.

According to [11] for the line following method, the error or offset of the AGV relative to the line can be determined with an array of sensors, using quadratic interpolation of their signals. The principle is depicted in Figure 1 where seven sensors are used to follow the line. If a value of -3 is assigned to the far left sensor, and the distance between two consecutive sensors is chosen to be 1, then the nominal position (under the chosen values) will be x and the far right sensor will be x +4. Using analogue sensors, the output will vary according to the proximity of the sensors to the line [11] and one will always be able to find three consecutive sensors with higher readings than the remaining sensors.

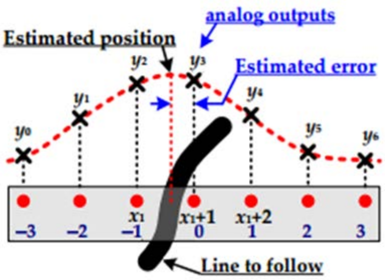

Fig.1 Line detection via quadratic interpolation [11]

It is proposed in [11] that the following equation for relating the coordinates of the sensors to their output values, be employed:

$$y_1 = ax_1^2 + bx_1 + c \quad (1)$$

$$y_2 = a(x_1+1)^2 + b(x_1+1) + c \quad (2)$$

$$y_3 = a(x_1+2)^2 + b(x_1+2) + c \quad (3)$$

From Figure 1 it can be observed that the curve follows a Gaussian distribution, with the maximum value on the graph representing the actual position of the line. The following equation approximates the error based on the three obtained sensor values and their coordinates, [11]:

$$Error = -\frac{y_2 - y_1 - 2ax_1 - a}{y_1 + y_3 - 2y_2} \quad (4)$$

The above algorithm was chosen for the line following control of the designed AGC.

2 Design of the AGC

2.1 Overall Design

The developed AGC uses a differential drive with two rear driving wheels and a magnetic guide sensor to follow the path represented by a magnetic tape strip. The AGC was designed for the specific purpose of towing trolleys while the AGC is positioned under the trolley. Hence, the AGC shape and overall dimensions were constrained by the trolley dimensions. Figure 2 shows the AGC model, where the frame houses: a control system with panel, a battery pack, a differential drive, an automatic tow-pin and safety sensors.

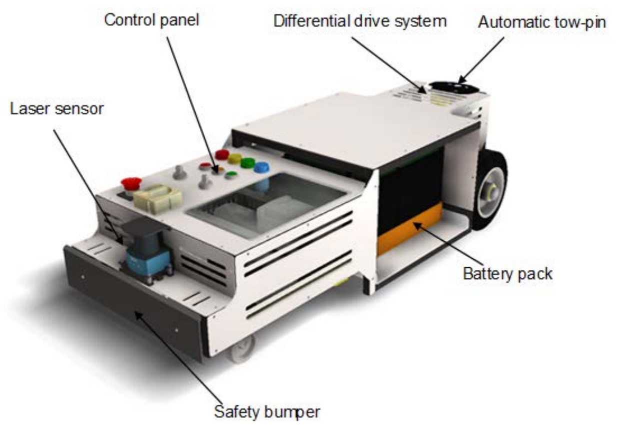

Fig. 2 CAD model of the AGC

The main purpose of the control system of the AGC is to compare the desired path to the actual path and transmit appropriate commands to the output devices (such as the motors) to insure optimal performance using a closed loop system with PID control. The AGC employs a MGS1600C Roboteq magnetic guide sensor, which is installed underneath the frame, in front of the AGC. The distance between the magnetic guide sensor and the driving wheels is important as this allows the control system to process the error signal and control the wheel motors timeously. The magnetic guide sensor measures the position of the centre of the scanner relative to the 50mm wide magnetic tape and supplies information to the controller. The AGC is steered and driven by two DOGA motors (24V), which are controlled by a Sabertooth 2x25A motor controller.

The tow-pin is a linear actuator consisting of a 24 Volt DC motor, timing belt and lead screw. By application of a 24V DC supply, the shaft of the actuator extends or retracts based on the polarity. The tow-pin is raised up automatically as the AGC is approaching the trolley underneath. The tow-pin is then comes into contact with the bracket on the trolley and guides it into place. This allows for the trolley to be placed with less accuracy and still achieve a successful coupling.

2.2 Controller Architecture

The AGC controller architecture is shown in Figure 3. The core of the controller is a PLC, which is supplied with 24V DC power from a battery. The Allen Bradley Micrologix 1100 PLC was selected as the AGC controller due to its low cost, availability and flexibility. The PLC, with an extension card, utilises 14 digital inputs, 2 analogue inputs and 6 replay outputs. The PLC was programmed in ladder using RSLogix Micro software. The PLC main functions include: path guidance, speed control, tow-pin control, safety monitoring and battery management system (voltage measurement).

For navigation tasks, the magnetic guide sensor sends the data to the PLC, which converts it into a signal that is able to direct the motor controller. This signal must pass through the PID controller to achieve a stable motion along a path. Two magnetic marker readers are used for the AGC path branching and other control commands.

2.3 Navigation System

The AGC navigation system includes the magnetic tape representing the path and the magnetic guide sensor. The magnetic guide sensor was configured using MagSensor Control Utility software as shown in Figure 4. The sensor was connected to a PC with a “USB A” to “USB B” cable. The sensor interacts with the controller through digital signals, therefore the command priority was set to “Digital In”.

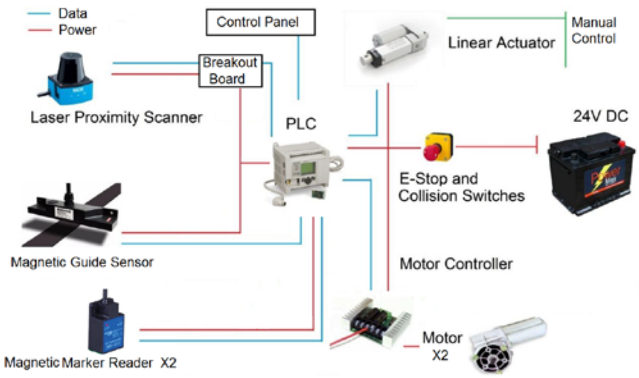

Fig. 3 AGC controller architecture

The second part of configuring of the sensor was to calibrate the output values of the sensor in relation to the centre of the magnetic tape. The offset and horizontal polarity parameters are related to the analogue signal that will be passed to the AGC controller. Changing the offset will influence the mid-point of the scanner range, while the polarity parameter specifies whether the analogue value should increase, or decrease, when moving the scanner over the magnetic tape in a certain direction. This magnetic guide sensor is designed to operate with a unipolar magnetic tape. A 50mm wide magnetic tape with a South polarity was selected for the path.

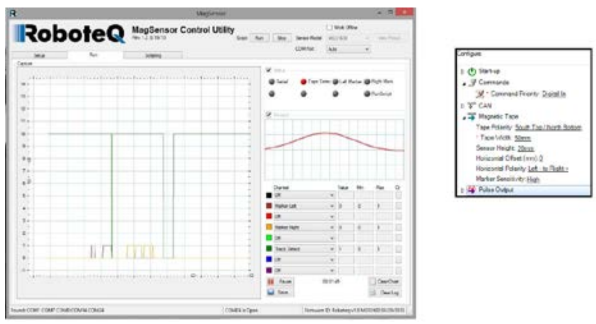

Fig 4. MagSensor control utility GUI for the magnetic guide sensor configuration

The magnetic guide sensor reads the positional offset from the magnetic tape and transmits the information to the PLC as an analogue signal that ranges from 0V to 5V. The PLC reads the information as an integer value, which is then subtracted from the experimentally determined value for the instance when the magnetic tape is in the centre of the AGC. The obtained value represents the error signal. Mathematically this can be described as follows:

$$Error = \partial_{Actual\_position} - \partial_{Target\_position} \quad (5)$$

A scaling function is then used to convert the error signal to a smaller range that is used by the PID function. The PID function returns a decimal value that represents the differential speed of each motor. This speed differential is added to one motor while subtracted from the other, depending on the position of the AGC. The PID tuning parameters were experimentally determined and optimised with the assistance of a SCADA program created in Movicon. The speed commands for each motor are converted from decimal to hexadecimal by the PLC programme and are then sent to the motor controller.

The AGC must be able to follow a certain path on the track taking a left or right split, change the speed of travel, as well as to start/stop. This is achieved by placing magnetic markers at certain locations on both sides of the magnetic tape. Markers are pieces of magnetic tape placed North-pole or South-pole side up and/or in a certain sequence on both sides of the tape. Two SMR-100C readers are fitted underneath the AGC to read the markers. The PLC programme determines the course of action depending on the information obtained from the marker readers. For example, for a typical trolley towing task from point A to point B, the system would require 18 sets of markers. This would include branching, speed control, switching ON/OFF safety zones and tow-pin control.

2.4 Motor Controller

The Sabertooth 2x25A motor controller is used for simultaneous control of two motors. The PLC sends hexadecimal values to the motor controller. Values in the range of 1-127 are assigned to motor 1 and values between 128 and 255 are assigned to motor 2. A value of 0 will stop both motors at the same time. Due to the mechanical mounting of the motors, the left motor rotational direction is opposite to the right motor rotational direction. The hexadecimal commands that are used to control each motor of the AGC are shown in Table 1.

A simplified serial communication was chosen for data transfer between the PLC and the motor controller. A MAX232 chip was used to convert the serial signal from the PLC to TTL level serial, which is required by the motor controller. The simplified serial protocol uses a single byte to control the motors, whereas a packet-based communication protocol is used for transmitting information. The simplified serial protocol input was selected to control the motors, since it is less susceptible to noise and also provides higher accuracy as opposed to analogue input signals. To ensure optimal responsiveness of the motors, a rate of 38400 baud was selected.

Mode	Right motor	Left motor
Full Speed Reverse, 1m/s	$(1)_{10} = (1)_{16}$	$(128)_{10} = (80)_{16}$
Stop	$(64)_{10} = (40)_{16}$	$(192)_{10} = (C0)_{16}$
Full Speed Forward, 1m/s	$(127)_{10} = (7F)_{16}$	$(255)_{10} = (FF)_{16}$

Table 1. The hexadecimal commands for motor control

2.5 Battery Management System

Due to the nature of the differential drive system the power consumption of the AGC will vary, since both motors move at different speeds and hence require different amounts of power. The amount of power consumed by the motors was determined experimentally to be within the range of 40W to 85W. The range of current was experimentally determined to be 1.7A to 3.5A.

A Voltage Sensor Relay (VSR) was set up by monitoring the AGC and noting when changes occur in its performance. The voltage level of the supply was measured and noted each time a decrease in performance was observed. From observation it was found that the AGC starts behaving irregularly when the supply voltage drops below 23 Volts. From the preliminary results it was found that it takes about 150 minutes for the voltage level to drop by 0.5V. The threshold of the VSR was, therefore, set to notify the PLC when the voltage reaches 23.5V so that the AGC stops before any performance degradation occurs.

3 Experimental Results

The performance of the AGC in following the path and responding to the marker commands was evaluated experimentally. The oscillations of the AGC during movement were recorded by means of a PLC programme. Figure 5 shows the decimal value of the control command transmitted to each motor as well as the decimal analogue value for the positional error, which was determined by the magnetic guide sensor. Samples were recorded every 1ms and transmitted to a PC using an Ethernet connection and the Modbus communication protocol. In order to convert the error signal to millimetres it was necessary to relate the actual measured position to the error signal observed in the PLC program, which was achieved by means of calibration. This experiment revealed that one unit in the error signal equates to one millimetre of AGC displacement. From Figure 5, it can be seen that a maximum overshoot of 69mm occurred over 500 samples. The time it took the system to correct its path is 0.5s, which is a product of number of samples and time interval. The average error was calculated to be 0.2mm. Overshoot was found to occur mainly around corners or in areas where the floor is uneven or not clear of small objects.

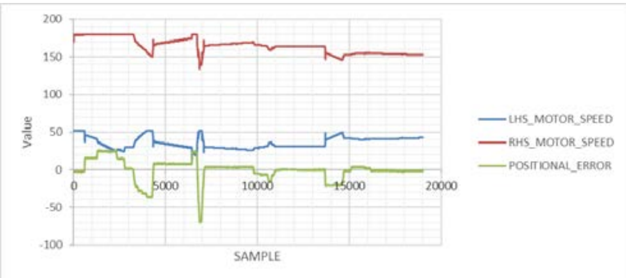

Fig. 5 Error signal and motor commands during operation

The AGC was specifically designed for material handling tasks of the car assembly line shown in Figure 6. Trolleys loaded with parts are placed by an operator at a certain location. The AGC collects the trolley and tows it to the assembly point, which is approximately 30m away. The trolley is released automatically and an assembly worker takes it to the moving conveyor, to which the trolley is then attached. In the meantime, the AGC returns to the collection point to restart the cycle. During the trials, the battery performance of the AGC was assessed and found to be satisfactory for the duration of two 8-hour shifts.

4 Conclusion

In this research, an affordable AGC was developed for material handling tasks in an automotive industry. The main components of the AGC include: the frame, the Allen Bradley Micrologix 1100 PLC, the MGS1600C Roboteq magnetic guide sensor, the SICK TiM310 laser sensors, the Sabertooth 2x25A motor controller, two DOGA 24V DC motors, and the tow-pin mechanism.

Fig. 6 AGC

The AGC is capable of towing trolleys between assembly stations using a line following algorithm. The AGC track is represented by a 50mm wide magnetic tape laid out in a loop along the process stations. The magnetic guide sensor detects the position of the AGC relative to the centre of the tape and transmits a signal to the controller. The AGC controller processes the signal and corrects the error using PID control, thus providing stable motion of the AGC at speeds up to 1m/s while towing a trolley weighing 200kg. There are a number of magnetic markers along the path, which are used for sequence and speed control. Two SMR-100C address marker readers on both sides of the AGC send signals to the AGC controller, which executes the preprogramed functions.

For safety, the AGC uses a laser proximity sensor with multiple safety zones allowing the AGC to operate safely in different working environments, regardless of space constraints. A sensitive bumper on the AGC provides additional operational safety in the case of an unforeseen collision or a failure of the laser proximity sensor.

For future work, the development of an intelligent controller is required. This would allow for more efficient operation in applications where a number of AGCs can be used simultaneously for material handling tasks between workstations; however, additional hardware is required before this can be implemented. In addition to magnetic markers, RFID tags and a RFID scanner need to be implemented. The RFID scanner will read a tag and transmit its value to the intelligent controller using a wireless communication system. The intelligent controller will use the tag command to control the AGC and override the internal sequence either manually or automatically with the aid of SCADA.

The developed design has the following advantages over other designs: low cost, compact, versatility, and the ease of operation, configuration and incorporation in various industrial and commercial environments.

5 Acknowledgments

The authors would like to acknowledge the support and financial assistance provided by both General Motors South Africa through the GMSA Chair of Mechatronics.

References:

[1] Bräunl, T. *Embedded Robotics - Mobile Robot Design and applications with Embedded Systems.* Perth: Springer, pp. 145-153. 2003.

[2] Agarwal, M., Agrawal, P., Gupta, K. N. & Meghani, H. *Line Follower Robot*, s.l.: s.n. 2008.

[3] Baharuddin, M.Z., Abidin, I.Z., Mohideen, S.S.K., Siah, Y.K. & Chuan, Y.T.T. Analysis of Line Sensor Configuration for the Advanced Line Follower Robot. [Online], 2005.

[4] Yakut Ali, M., Hossain, S. G., Jamil, H. & Haq, M. Z. Development of Automated Guided Vehicles for Industrial Logistics Applications in Developing Countries Using Appropriate Technology. *International Journal of Mechanical & Mechatronis Engineering,* 10(02), pp. 13-17. 2010.

[5] Hymavathi, V. & Vijay Kumar, G. Design and Implementation of double line follower robot. *International Journal of Engineering Science and Technology (IJEST),* 3(6), pp. 4946-4953. 2011.

[6] Pallottino, L., Scordio, V. G., Bicchi, A. & Frazzoli, E. Decentralized cooperative policy for conflict resolution in multi-vehicle systems. *IEEE Transactions on Robotics*, Volume: 23, Issue: 6, Dec. 2007.

[7] Alami, R. et al. Multi Robot Cooperation in the Martha Project. *Robotics Automation Magazine,* 5(1), pp. 36-47. 1998.

[8] Le-Ahn, T. & De Koster, M. *A Review Of Design And Control of Automated Guided Vehicle Systems,* The Netherlands: ERIM. 2004.

[9] Holland, J. M. *Designing Autonomous Mobile Robots - Inside the Mind of an Intelligent Machine.* Oxford: Elsevier. 2004.

[10] Floreano, D., Godjevac, J., Martinoli, A., Mondada, F. & Nicoud, J.-D. Advances in Intelligent Autonomous Systems. In: S. G. Tzafestas, ed. *Design, Control, and Applications of Autonomous Mobile Robots.* Dordrecht: Springer, pp. 159-186. 1999.

[11] Su, J.-H., Lee, C.-S., Huang, H.-H., Chuang, S.-H. & Lin, C.-Y. Workshop Proceedings of the 8th International Conference on Intelligent Environments. *An intelligent line-following robot project for introductory robot courses*, 8(4), pp. 455-461. 2010.