Progresses on the Design of Small Flexible Automated Guided Vehicles

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Abstract

This paper describes the sensing and control systems of an Automated Guided Vehicle (AGV) designed to follow an optical track in the absence of heavy obstacles. The system uses infrared (IR) sensors to follow a floor-painted track and to detect and recover from a track interruption by searching and moving towards a passive beacon. The onboard system includes guidance and speed feedback controllers running on a 80C552 microcontroller, infrared sensors, optical encoders and PWM motor actuators.

Keywords: AGV, optical guidance, microcontroller, beacons, infrared sensors.

1. Introduction

Modern factories require means of transportation controllable by a main scheduler/supervisor. This motivates an increasing use of Automated Guided Vehicles (AGVs) in automated plants and other reasonably well-structured environments. AGVs are also currently used in the service sector, carrying and distributing light loads with efficiency [2].

Moreover, there is a growing scientific interest on the development of small, cheap and modular systems endowed with distributed control systems based on low consumption and easy-to-modify electronics [1] [3].

Figure 1- The AGV prototype.

This paper describes the design and development of a low cost AGV prototype intended for research in development of intelligent vehicles and for use in the service sector (e.g., as a mail/document distributor in a large company or hospital). The vehicle is based on a four-wheel configuration, with four-wheel drive and four-wheel steering (see Fig. 1).

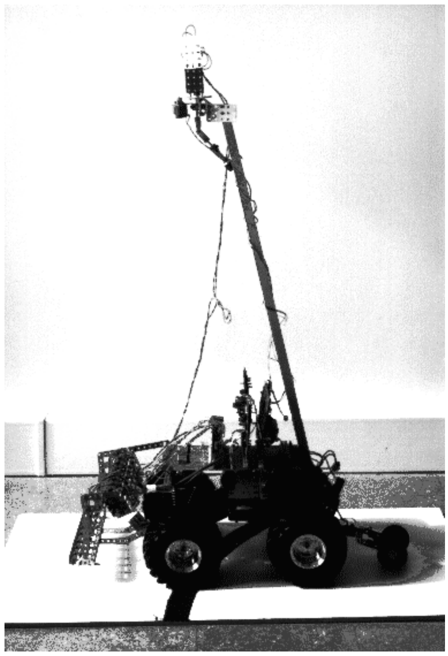

Figure 2 - The AGV prototype.

2. System specifications

The AGV must follow a 5cm wide track painted on a flat floor. There is no specific colour for the track, as the colour and reflection parameters of the track detector are adjustable. The only requirement is a good contrast between track and background floor. The AGV must also detect a track interruption and detect where the track resumes after the interruption, by using a passive-beacon searching sensor (*track finder*) mounted on the top of the AGV, as illustrated in Fig. 2 The track is composed of segments of two types: lines and arcs. The minimum radius of the arcs should be of approximately 1m.

3. Description of the basic blocks and principles of operation

There are three basic operating blocks in the AGV, notably as shown in Fig. 3,

1. *The Actuators*, that include the power drivers, the motors and the wheels;
2. *The Sensors*, that include the infrared (IR) track following sensors (including their triggering circuit), the track finder and the optical encoder that is used to measure speed;
3. *The Closed Loop Controllers*.

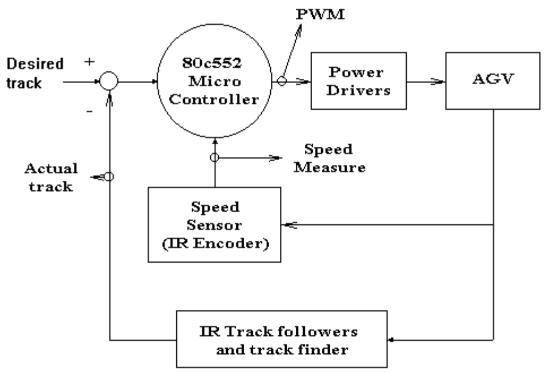

Figure 3 - Basic operative blocks and their connections.

From these three basic blocks we see that there will be two main feedback control loops in the AGV: the track following (for guidance) loop and the speed control loop.

To ensure the autonomy of the vehicle, a NiCd battery (7.2 V - 1.8 A/h) was used to drive two DC motors and a steering servo, while lead-acid bateries were used for the electronics :

- a 12 V - 1.2 A/h battery to provide the +12 V;
- a 12 V - 0.7 A/h battery to provide the -12 V;
- a 6 V - 1.3 A/h battery for the electronics of the power drivers.

There are two distinct power supplies for the power driver modules and for the rest of the electronics. Besides, optocouplers were used to physically decouple these modules. The latter solution was implemented to reduce the noise induced by the two driving motors.

3.1. The Actuators

The actuators block is composed of two driving motors and one steering servo, with the corresponding power drivers, and four driving/steering wheels. The AGV has four-wheel steering to improve its steering rate and to increase sensitivity to steering commands.

Speed closed loop control was required by fluctuations on the battery power. Motor speed control is obtained by means of a Pulse Width Modulation (PWM) control signal generated directly by the microcontroller. The direct current (DC) motor extracts the PWM signal mean value. The end result is a motor control system with a lower consumption than the equivalent DC-controlled system.

Two DC motors have been used to drive the four wheels system configuration. This guarantees system performance when the vehicle is used to displace small loads. The steering servo command was also obtained by PWM control of the steering motor.

3.2. The Sensors

3.2.1. Track Follower - Inductive following, where two analogue sensors control the vehicle direction, is the most usual AGV guidance technique. The signal received by those sensors has a linear variation with the distance from the sensors to the track, implemented through a wire imbedded in the ground. When guidance is based on an optical white-over-black track by using IR emitter/receiver pairs as sensors, the received signal is proportional to the portion of track within the sensor scope (see Fig. 4 below). As the beam width of an IR light emitting diode has typical values of 30º, that means that the IR emitter/receiver pairs cannot be used as analogue sensors, since the track is much wider than the sensor scope. Hence we decided to use the sensors as on-off switches, using very narrow beam width sensors so that their scope would be very small, reducing cross-talk. The sensor set designed for track following is therefore composed of eight IR emitter/receiver pairs. These pairs are mounted on a frontal structure, giving the system information about the distance **d** (see Fig. 5) between the longitudinal axis of the AGV and the optical track . The output is a 8-bit digital word that can be read and processed by the on-board microcontroller.

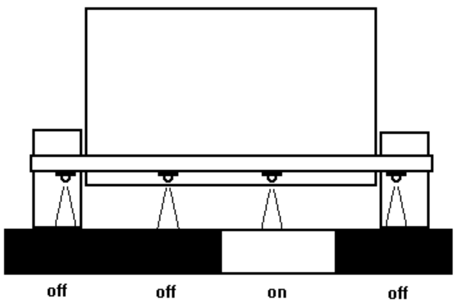

Figure 4 - Frontal location of IR track following sensors and their scope.

This technique has the advantage of increasing the area covered by the sensor set, enabling the detection of track crossings and docking bays, and making the AGV more robust to temporary track losses. Another advantage is that the signal is originally digital and therefore does not require a conversion to be read by the microcontroller.

However, there are a few disadvantages: a number of sensors greater than in the analogue case , and the burden put on the on-board microcontroller to compute the steering signal. For a given speed of the AGV, if there is a large delay between sensing and steering locations the system may become unstable.

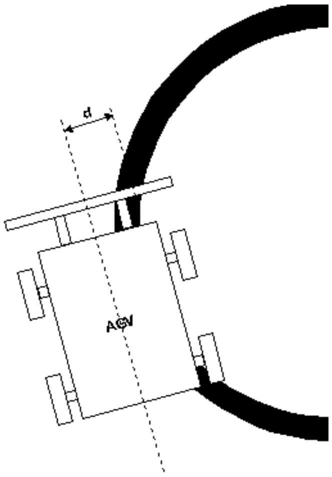

Figure 5 - Front placement of the IR emitter/receiver pairs (grey).

The emitters are mainly composed of a pulsed IR light emitting diode and the IR receivers are tuneable, so that the operation is robust to changes in environment light conditions and floor / track reflective properties.

The emitting/receiving operation is hardware-triggered by a timing circuit in order to further prevent the cross-talk between adjacent pairs, sequentially switching each pair in turn.

3.2.2. Track Finder - In many applications, painting and maintaining an optical track on the floor is sometimes difficult. Examples are painted zones and existence of floor-scraping vehicles. To avoid this problem, a track-recovery system was implemented , to be used when a track interruption occurs. A passive beacon is located 1 meter above the point where the track resumes. This might also be used as a prevention method: by locating beacons regularly along the track, track recovery is ensured in the event of partial erasure.

When the track is by any means interrupted, the AGV switches to beacon-searching mode. In this mode, it still looks for the path, but, at the same time, it enables the operation of an IR emitter/receiver pair mounted one meter above the vehicle on a rotating shaft (see Fig. 6). In the actual implementation, a 4 emitter / 2 receivers assembly was used, to increase the signal power.

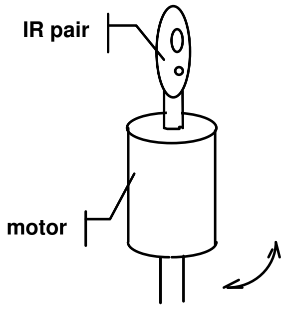

Figure 6 - Beacon finder.

This IR pair rotates to the left and right emitting an IR beam covering a discrete set of directions parallel to the floor plane(see Fig. 7). A reflected beam is received when the pair points towards the beacon. Based on the computed orientation of the beacon with respect to the vehicle the microcontroller generates the PWM signal that will command the steering servo.

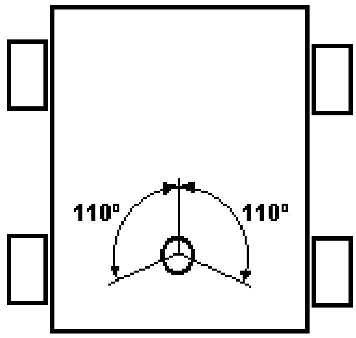

Figure 7 - Rotating angle of beam sensor.

3.2.3. Speed - For speed measures, the AGV has an optical encoder mounted on a trailer. The pulses generated by this encoder are compared with fixed-width pulses generated by the microcontroller, therefore generating a speed measurement signal.

The average speed of the vehicle while following a track is approximately 55 cm/s.

3.3. The Closed loop controllers

A 80C552 microcontroller is used to implement the track following, passive beacon following and driving speed feedback control loops (see Figs. 10,12 and 13).

3.3.1. The track following control algorithm - The system uses 8 IR sensors for track following, providing a binary word that measures the distance **d** from the longitudinal axis of the AGV to the track (see Fig. 8). One approach to the track following algorithm consists of assigning weights p_i to each of these sensors, from the leftmost to the rightmost with the values -8,-4,-2,-1,1,2,4 and 8. When a given sensor is active (over the path) its corresponding weight p_i is multiplied by an adjustable gain (K_p). This value is then added to the PWM value that corresponds to null steering (PWM_0) :

$$PWM_d = PWM_0 + K_p \cdot p_i \qquad (1)$$

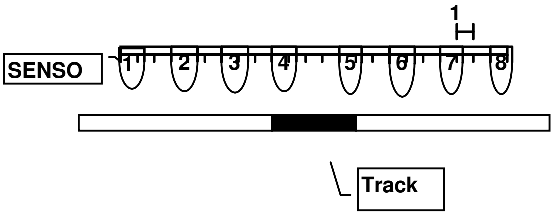

Figure 8

The PWM_s value is then verified in order to prevent an overflow in the admissible variation interval for the steering PWM and after that is finally fed into the steering servo driver.

binary word	d - Distance to the centre of the path (cm)
10000000	11 - 13 (to the right)
11000000	9 - 10 (")
01000000	8 (")
01100000	6 - 7 (")
00100000	5 (")
00110000	3 - 4 (")
00010000	1 - 2 (")
00011000	0 (in the centre)
00001000	1 - 2 (to the left)
00001100	3 - 4 (")
00000100	5 (")
00000110	6 - 7 (")
00000010	8 (")
00000011	9 - 10 (")
00000001	11 - 13 (")

Table 1

However, this algorithm is not robust to spurious sensor noise, i.e., to sudden changes in the binary value read by the IR pair, due to shadows, dirty floor or other sources. Therefore, a matching algorithm was developed. It compares the binary word read by the microcontroller to the binary words on Table 1. If one of the words on the table matches the word read by the sensors, the corresponding gain K_p is used. Otherwise, the input word is discarded. As noise is often spurious, track following is not affected. Fig 10 shows the implemented function, based on empirical adjustments of K_p.

It is important to print out that the steering capabilities of the vehicle are limited to a minimum curvature radius of 90 cm.

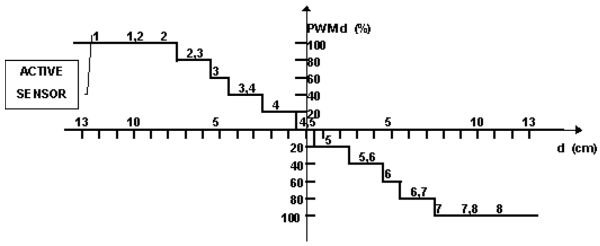

Figure 9 - Function for the control of the vehicle.

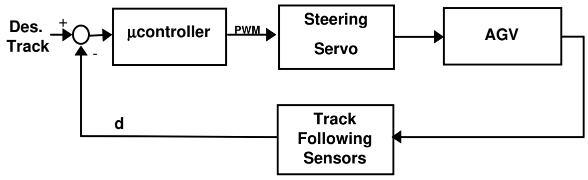

Figure 10 - The track following control loop.

3.3.2. The beacon following control algorithm - When the AGV is in beacon searching mode, the angle α of the maximum amplitude of the received beam signal is detected and stored. Hence, the orientation of the passive beacon with respect to the vehicle is computed.

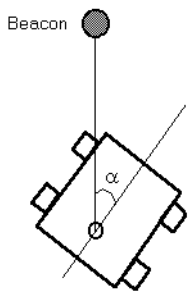

Figure 11 - Angle α between the AGV and the beacon

After α is determined, the PWM signal send to the steering servo is computed by multiplying α by a gain K_b and adding the result to the PWM signal corresponding to the zero direction[1](PWM):

$$PWM_d = PWM_0 + K_b \cdot a \qquad (2)$$

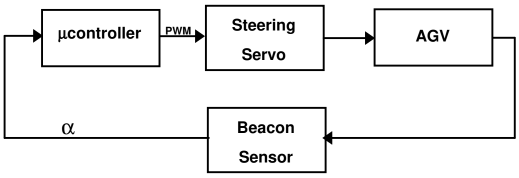

Figure 12 - The track finder control loop.

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[1]The zero is defined as the longitudinal axis of the AGV (e.g., the beacon is in front of the vehicle).

After checking the limit PWM values , the signal PWM is sent to the steering motor drives.

3.3.3. The speed control algorithm - This algorithm is implemented as follows: every 0.25 seconds a microcontroller's internal timer triggers an interrupt handler that reads the present value of a counter. The counter accumulates the number of pulses occurred at the encoder's optical switch output since the last interrupt. We call this value *I*. The reference value I_{ref} for pulses (therefore for speed) is stored in the microcontroller's board memory and is compared to the counter output, generating the error signal, subsequently multiplied by an internally stored gain (see Eq. 3),

$$PWM_s = K_s(I_{ref} - I) \qquad (3)$$

giving the PWM incremental value that will be added to the current PWM value.

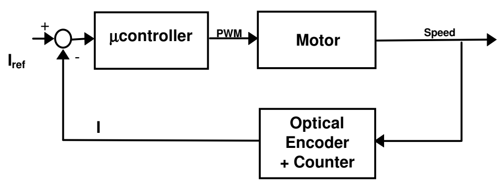

Figure 13 - The speed control loop.

4. Concluding Remarks

This paper described the design and development of a flexible optical AGV, robust to environment light changes and different reflective floor properties. The vehicle can also recover from track losses, assuming that there exists a passive beacon above the track resuming point. The only limitations to track following and speed were imposed by the mechanical characteristics of the vehicle.

Currently, the vehicle can follow a track with lines and arcs of different orientations, crossings and alternating background vs. track colours. It can also detect and stop on a docking bay, represented by a 5cm wide and 20cm long track perpendicular to the main track, distinguishing this from a crossing. The beacon following algorithm is also working but has not been integrated with the track follower yet.

On-going research seeks the extension of this work by using an additional optical RAM sensor to improve track following and beacon detection. A trend towards a distributed control scheme, with a 80386-based central controller and several PIC16C74-based controllers for the different sensing/control/actuation loops is also being considered. It is expected that this will lead to small, flexible, relatively cheap and reliable AGVs.

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