AN INDUSTRIAL AUTONOMOUS GUIDED ROBOT

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Abstract: There has been much interest on achieving educational and research goals by the use of mobile robot platforms. However these platforms are not usually composed by industrial of the shelf solutions. This paper presents the kind of industrial sensors that can be used in an autonomous mobile robot. The vehicle is supposed to follow a track, make choices on its way respecting visual indications of traffic lights, navigate inside a tunnel and park inside a given area. The original part about this AGV is the implementation by use of available industrial equipment rather than the common PC and/or PICs combination.

Keywords: Sensors, Autonomous Mobile Robots, Guidance Systems, Digital Images, Industry Automation, Encoders.

1. INTRODUCTION

There has been much interest in achieving educational and research objectives through the use mobile robots (Greenwald and Kopena, 2003). Low-cost robot platforms are widely used and they are usually controlled by some kind of microcontrollers or PC with interface cards. These projects are very important for dissemination of technology especially when competitions take place. In this paper, our goal was to design a industrial mobile robot based on industrial off-the-shelf equipment.

This paper presents an Automatic Guided Vehicle entirely based on industrial sensors and focus mainly on the industrial sensors that were employed for performing the tasks of a mobile robots competition.

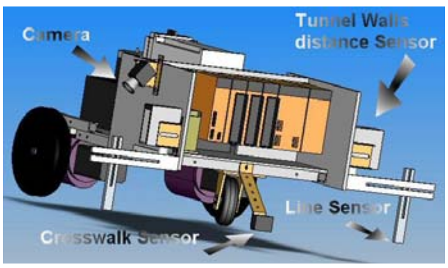

Figure 1: AGV artistic impression

Robotic competitions are increasing in popularity (Almeida et. al. 2000a,b), (Osuka 2000), and building a personal robot is becoming also popular (Jones, 1999). Several university teams have developed robots such as (Almeida 2000b) and (Camara 2000), (Osuka 2000), that participate in robotic competitions. Indeed, autonomous robots are being more and more used on teaching science and engineering (Beer et al. 1999).

AGV2004 (Figure 1) (Freitas and Vilela 2004) (Moreira and Abrantes 2003), when compared to most competitors (Brusey et. al. 1999), (Lima 2001), is original in the sense that all the sensors and control equipment comes from off the shelf industrial components. Hence the control is made by a PLC, the motors are controlled by industrial servodrives and even the image processing part is made with an industrial image acquisition system.

In this paper we present in section 1 a brief description of the AGV and its position in the actual state of art; section 2 presents the tasks that the robot must fulfil; section 3 presents the industrial sensors that allow the robot fulfil the previously defined tasks; experimental results are shown section 4 and conclusions are drawn in section 5.

2. TASKS TO PERFORM

The "Festival Nacional de Robótica 2004" – Autonomous Guidance Class consists in 3 different rounds. The major goal in the first round is to go as fast as possible in a 2 lap race (see Figure 3). There are different penalties if the robot steps over the side lines or for not stopping at the end of the race right where it started from. The second round is similar to the first one, but now the robot has to follow the traffic lights indications. There are five different signals to interpret (see Figure 2). Traffic lights indications are: stop (a red cross), turn left (yellow left arrow), go straight (green straight arrow), end (chess-like flag), turn right (yellow right arrow, meaning that the robot must go to the park). For the third round the track as a tunnel in which the robot has to guide itself without the floor lines (see location of the tunnel in Figure 3).

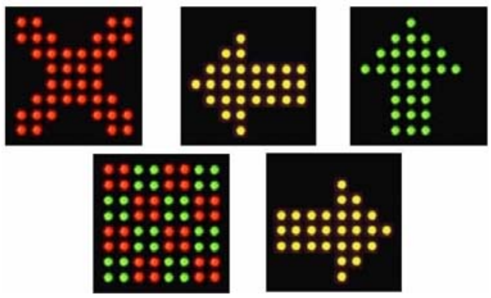

Figure 2 : Traffic lights indications: stop, turn left, go straight, end, park.

3. INDUSTRIAL SENSORS CHOICE

To fulfil the requirements presented in last section, four different types of industrial sensors are used. All this sensors are from Omron due to collaboration between Omron and the IDMEC/IST. To follow the track presented in Figure 3 it was necessary to have sensors for the following tasks: guide the robot throughout the track; prevent the robot from exiting the track if the guiding sensor fails; guide the robot in the tunnel (no lines are visible); recognise the visual signals from the traffic lights; stop the robot before the "Crosswalk".

Figure 3: Contest track

3.1 Track guiding sensor

For guiding the robot in the track, the industrial image acquisition system consists on a F150-3 system (see Figure 4). This system is common in some visual inspection applications in Portuguese industry.

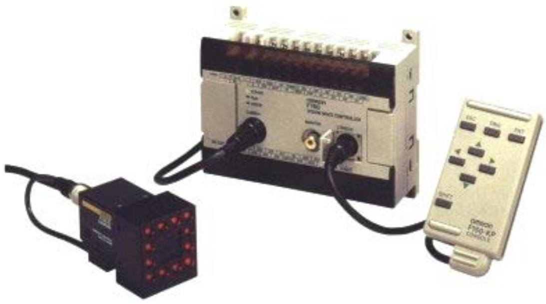

Figure 4: F150-3 image processing system

This image acquisition system may perform several tasks in real-time. For instance, function "grey edge position" (see Figure 5) detects the first edge on the image when scanning from left to right. The two points highlighted in the right part of Figure 6 present the result of the application of this function on 2 predefined regions. The image acquisition system computes the XY coordinates of the highlighted points.
The principle of operation of this task is the well known procedure for finding edges in images which is done by replacing each pixel by the gradient relative to its neighbours in the sought direction.

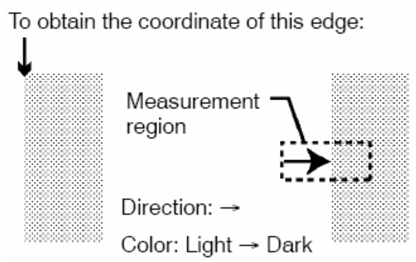

Figure 5: F-150 function "grey edge position"

Moreover, for knowing the robot orientation relatively to the track, the image controller computes the angle between the line defined by the two highlighted points and the track as shown in left part of Figure 6. For this, the "Direction for Position Displacement Compensation" function (see Figure 7) was employed for obtaining the theta angle from the 2 points.
To avoid perspective problems the camera is placed in a position almost normal to the floor.

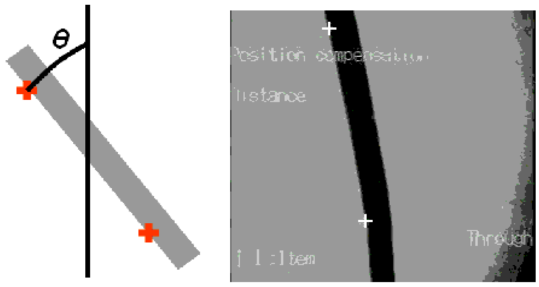

Figure 6: Processing image in the F-150 intelligent sensor

The obtained theta angle is then transferred to the PLC, using a specific protocol. The PLC uses this information to correct the robot trajectory. Combining more rules and confidence factors for each region increases the system robustness.

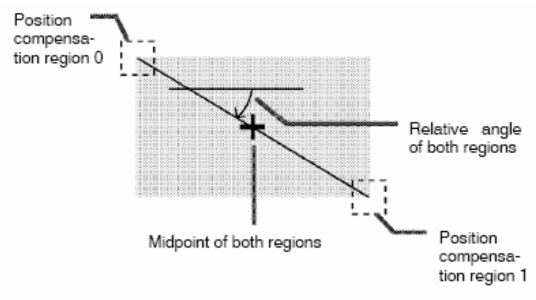

Figure 7: F150-3 “Direction for Position Displa-cement Compensation” function.

3.2 Line sensor

Two E3X-DA51-N (see Figure 8) were selected to perform the detection of the roadway boundaries.

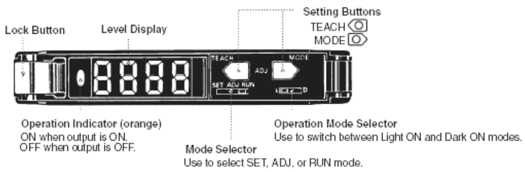

Figure 8: E3X-DA51-N sensor display panel

These sensors are based on reflective photoelectrical principles. An emitter beams, light reflects on the target and a receptor measures the intensity of light. As there is a huge contrast between the track and the floor, this sensors provides us information if the robot is approaching the border line. Actually, this sensor is used to prevent robot from exiting the track in case of a failure on the image acquisition system. If one of these sensors is activated, the PLC controller performs a pre-programmed correction which intends to make the robot return to the track and resume following the track through the image processing system. If not, the robot will follow the track in a zigzag manner. It is not very elegant but it is effective.

These sensors come together with an optical fibre extension allowing the sensitive part of the sensor location to be far away from the processing part. This particular sensor model has analogical and digital outputs. In analogical mode the output is proportional to the grey level measured by the optical fibre. The PLC processes this input and defines a threshold level to decide the presence of the limiting line, as shown if Fig 9.

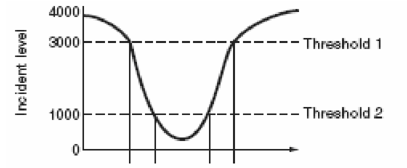

Figure 9: Line sensor theoretical values

3.3 Tunnel navigation Sensor

For the guidance inside the tunnel, we used 2 Omron E3NT-L47 (see Figure 10).

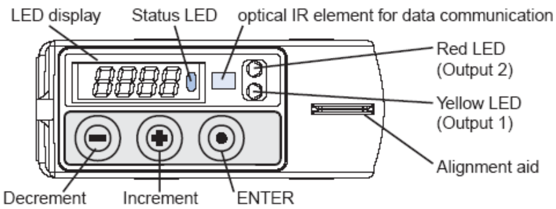

Figure 10: E3NT-L47 sensor

These distance-setting photoelectric sensors are based on the principle of triangulation. A beam is sent by an emitter with a given angle, so that the reflected beam will arrive back to the sensor and be guided by a lens to a receptor. Measuring the distance between the emitter and the point where the beam arrived, by triangulation, the sensor compute the distance to the target. These sensors have a double triangulation method to increase robustness.

Output of these sensors is both analogical and digital. Being positioned at both sides of the AGV these sensors can measure the distance to each wall. Having a rated sensing distance of 2 meters it can take values right from 0.1 meters.

These sensors connect to the analogical input of the PLC allowing the analogical measure of the distance.

3.4 “Traffic Lights” sensor

For recognising the traffic lights shown in figure 2 we used the same industrial processing system we used for following the track, using a dedicated camera for pattern recognition. The principle of operation is proprietary but it seems that it uses Pattern matching using correlation, which is obtained shifting the pattern template over all possible locations on the image, higher values on the sum of the cross product of the pixels providing a set candidate pixels of a good match.

Making the system learn previously the images we were able to distinguish the different traffic lights with some robustness. Of course the system only works if the alignment of the robot is correct. The size of the target compared with the size of the image is more or less 1/6th so the robot alignment must not be very tight (see Figure 11).

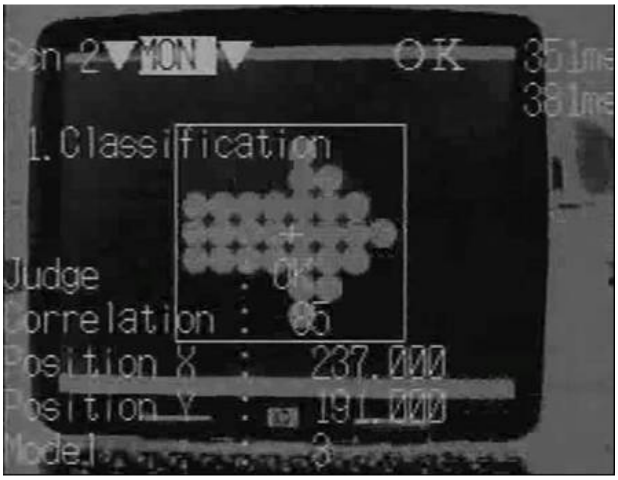

Figure 11: pattern recognition (image is 85% correlated to model 3)

3.4 “Crosswalk” sensor

To detect the crosswalk we used Omron’s E3M-VG 11 sensor (see Figure 12).

The operational principle of this sensor is the same as the Omron’s E3M-VG 11, but its implementation is much simpler. This sensor has only a digital output and is able to detect colour variations. It is located at the front of the AGV to detect the crosswalk which appears perpendicularly to the border lines (see Figure 3). In fact this sensor does not detect the crosswalk itself but the first perpendicular line.

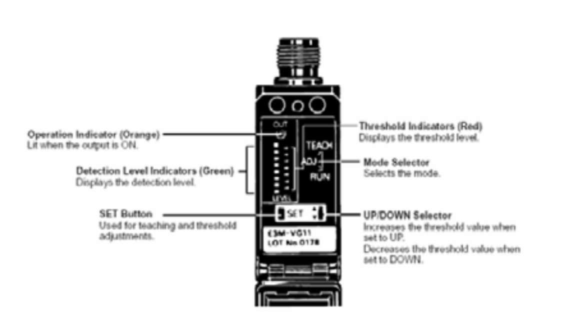

Figure 12: E3M-VG 11 sensor

It could have been used the same kind of sensors used for detecting the border lines but we decided to use a simpler OMRON sensor. The drawback is that sensing distance is too narrow (10±3 mm) and forced us to fix the sensor in a position very closed to the floor. Despite this condition the sensor showed nice performance over a larger distance.

For the calibration of this sensor the procedure is very much like the used in the E3X-DA51-N for the one-point calibration. The calibration parameters stay in memory even after shutdown.

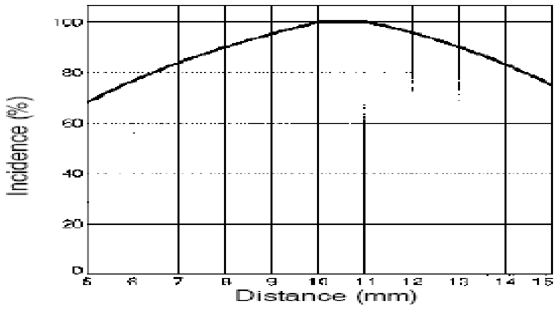

Figure 13: E3M-VG 11 sensor features

4. RESULTS

<u>4.1 Track guiding sensor</u>

As previously stated, the image acquisition and processing unit is able to perform several high level functions, as an intelligent sensor. The output to the PLC was the angle (see Figure 6) and not the image. However, in practice, the usual lightning problems arose. Because of a reflector floor and an extremely concentrated light focus in certain points of the track the outside lines simply disappear (see Figure 14). A later angle filter was implemented in the PLC to detect these non-sense values. If the value if non-sense it is better to let the robot take the previously computed result rather than take into account an erroneous value.

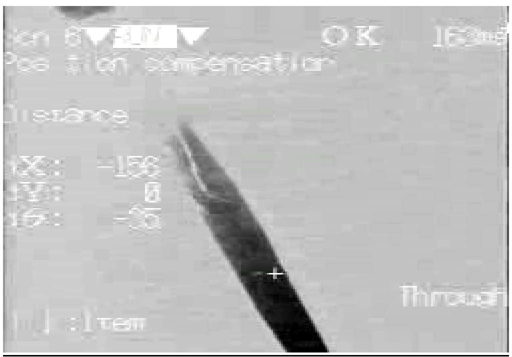

Figure 14: the usual lightning problems

<u>4.2 Line sensor</u>

These line sensors can be parameterized by a PC. Tests were made to know how differently they would act one from another. In the graph below (Figure 15) it can be seen the little difference among both, so no additional parameterizations were made. The similarity with the theoretical results can be seen (Figure 9).

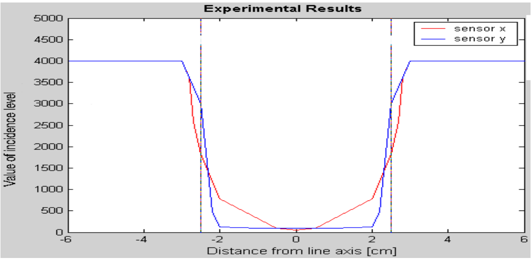

Figure 15: Line Sensor experimental results

As seen above the response of the sensors is very abrupt. These analogical outputs were hence treated as digital ones making a simple signal conditioning at the PLC. Figure 16 shows the transformation, in the PLC, from analogue to digital signal for each sensor.

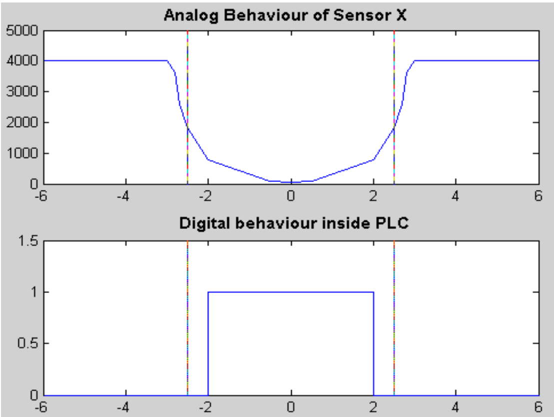

Figure 16: Line sensor treatment

4.3 Tunnel Walls distance Sensor

As said before these sensors are able to measure the real distance from the robot to the wall. However, as a first attempt, only a digital implementation of these sensors was made. The robot presents a zigzag trajectory when it enters the tunnel, allowing however the task to be completed successfully.
This behaviour is similar to the one obtained using just the line sensors (disabling the image acquisition system) and is due to the binary nature of the signal.
These movements are expected to become smoother and more efficient when using the analogue information which, by now, is carried away.

4.4 “Traffic Lights” sensor

Actually, the industrial image processing was very efficient for this task. An almost zero % error was achieved (even with misalignments, inasmuch as the target image remains inside the whole image). This is mainly due to the fact that this sensor is well suited for quality control and hence the adaptation for this task was straight forward. Figure 17 shows the system matching pattern 2 and Figure 11 shows the system matching pattern 3. In both cases the correlation factor is high and the system is robust concerning some misalignments. The processing rate is around 3 Hz for matching 5 different patterns.

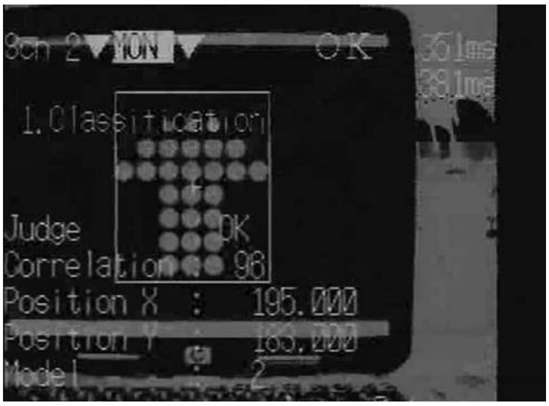

Figure 17: Pattern Recognition of a misaligned image (Image 96% correlated to model 2)

4.5 “Crosswalk” Sensor

As said before, this sensor was used to read bigger distances than specified. Because of this, it was very difficult to calibrate. Without filtering, any impurity in the track can cause the actuation of the sensor. However, during the competitions, the track and floor have much better quality and the sensor works fine without giving false indications.

4.6 Control

The control system was implemented in the PLC. The main controller was a simple proportional controller providing a differential speed variation in each wheal, proportional to the angle for the track. Stationary behaviour would be achieved when the robot drive parallel to the track. Without interrupts from other sensors this hybrid system would resume this task. This hybrid system changes its mode of operation when interrupted by a given sensor: a track limit or a wall sensor sensor actuated generates an event that forces the system to perform a timed state machine that is programmed to send the robot back to the middle of the roadway. The crosswalk sensor generates an event that switches to a state machine that does the traffic lights pattern recognition and drives the sensor towards the direction provided by the signal, resuming the robot with the continuous track follower behaviour.

4.7 Performance Analysis

The usual implementation of the robot controllers is on normal PCs or microcontrollers. Comparing our image acquisition system to a PC based image acquisition system, we notice higher sampling rates (15 Hz for edges and 3 Hz for pattern processing) than the performances we achieved for a normal PC doing a simple mass centre (centroid) computation (1 Hz). Moreover, all the image processing is embedded on the controller, letting the main controller free for other tasks.

5. CONCLUSIONS

In this paper, we presented an industrial implementation of a mobile robot using only existing of-the-shelf products from a known industrial automation manufacturer, Omron.

It is difficult to state that the choice presented is the best, by comparing to existing solutions widely used in competitions we may state the following regarding performance, development facility and price:

The robustness of these sensors is by far much higher than sensors made from scratch. Make sensors from scratch is by far more pedagogical but in complex systems it is not worth to develop sensors that already exist.

The industrial image processing system is indeed a smart sensor. It processes the image sending us back only relevant information about the track or the traffic lights. Moreover, all the image processing is embedded on the controller, letting the main controller free for other tasks.

However, some drawbacks also arise from this implementation:

There are some difficulties on dealing with ladder programming for all the tasks (including control). Even using an interface (i.e. cx-server) allowing us to control and supervise the robot in real time with a common programming language, showed to be not a good solution because of the lower refresh rate achieved. More user friendly programming tools are becoming available, to bypass this drawback.

The industrial image processing system is effective, robust and highly configurable, but its results are provided by 8 digital I/O lines or a RS232 port. To get the measurements the digital I/O lines weren't enough, and hence we had to use the RS232 connection to get the values computed by this smart sensor. Unfortunately, to cope with the specific protocol and the RS232 speeds, the refresh rate lowered down to 1 Hz. Actually this is a nice smart sensor for quality control, where the output is binary (accept or reject) but more difficult to use when analogue values must be extracted from the images and sent in a high rate to the controller.

Considering the costs of this equipment, normal universities might use these industrial solutions when cooperation with a specific manufacturer is considered to lower the cost to the university and provide a good visibility to the manufacturer products.

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