

IMPLEMENTATION OF CONTROLLER DESIGN AND NAVIGATION ALGORITHM FOR SENSOR-BASED PATH PLANNING AND TRACKING CONTROL SCHEME FOR NON-HOLONOMIC WHEELED MOBILE ROBOT

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Abstract

A variety of controller design and navigation algorithms have been proposed in literature for nonholonomic wheeled mobile robots in environments without obstacles. These controllers and navigation algorithms are very important for the robot to successfully achieve its goals, whether it is requested to accomplish a mission or simply to survive in the environment. It addresses the problem of active sensing, i.e. the selection of a robot motion, which makes the robot arrive at its desired goal configuration with maximum accuracy, given the available sensor information. In this paper, the implementation of the controller design scheme and navigation algorithm for sensor based path planning and tracking control on the laboratory prototype wheeled mobile robot is described in detail.

Keywords: Controller, sensor, path planning, control scheme, nonholonomic wheeled mobile robot

1 INTRODUCTION

Wheeled mobile robots are increasingly present in industrial and service robotics, particularly when flexible motion capabilities are required on reasonably smooth ground and surfaces (Scraft & Schmierer, 1998). Kinematics study of several configurations of wheeled mobile robots can be found in (Alexander & Maddocks, 1989). Beside the relevance in industrial applications, the problem of autonomous motion planning and control of wheeled mobile robots has also attracted the interest of researchers in view of its theoretical challenges (Arcot, David, & Wan, 2002).

There are considerable research efforts towards solving the mobile robot navigation problem in different applications in in-door or outdoor environments where new methods of control system for an autonomous robot using artificial intelligence can be found in (Nishi, Ando, & Konishi, 2005). The main goal of research on reactive navigation strategies is to allow autonomous units, equipped with relatively low-cost sensors and actuators, to perform complex tasks in uncertain or unknown environments. These technologies have a wide range of potential application fields, which include the exploration of inaccessible or hazardous environments, industrial automation, and

also biomedicine. In this research area, the development of the decision and control strategies necessary for autonomous operation plays a central role. In most mobile robot applications two basic position-estimation methods are employed together: absolute and relative positioning. Relative positioning is usually based on dead-reckoning (i.e. monitoring the wheel revolutions to compute the offset from a known starting position). Dead-reckoning is simple, inexpensive, and easy to accomplish in real-time. The disadvantage of dead-reckoning is its unbounded accumulation of errors (Anis, Amur, Lazhar, & Nouri, 2006). Omni-directional mechanism was employed as a driving and a steering wheel mechanism to drive and steer independently, the position and direction of the mobile robots with a high degree of accuracy. Self localization for navigation of autonomous mobile robots have provided high accuracy of dynamic guidance (Yukawa, Matsumoto, Okano, & Hosoya, 2006).

This paper presents the implementation of navigation algorithms for non-holonomic wheeled mobile robots (WMR) using controller together with passive photoelectric sensors designed for 'Robocon' competition. The navigation of the mobile robot is done with the help of a white grid terrain on a green background. The proposed controller permits the robot

not to diverge from its prescribed path and that guide the robots to the target with sub-optimal time.

This paper is organized as the following. The system description of the WMR is provided in Section 2, and this is followed by a presentation of the relevant features of the navigation algorithm in Section 3. The controller implementation and results are then discussed in Section 4, and finally concluding remarks are given in Section 5.

2 SYSTEM DESCRIPTION

Several microcontroller-based autonomous robots were developed and used to achieve a particular task. A few examples of the autonomous robots are shown in Figure 1.

2.1 Differential drive kinematics

Dead reckoning is the process of calculating your position relying on a previously determined position. The mathematical relations used for dead reckoning differ from a robot to another due to the steering mechanism differences (<http://www.ikalogic.com/wfr2.php>, 2013). The derivation of a differential drive kinematics model is shown in Figure 2. For detail derivation, see Rashid, Razif, Elamvazuthi, I., & Begam (2010).

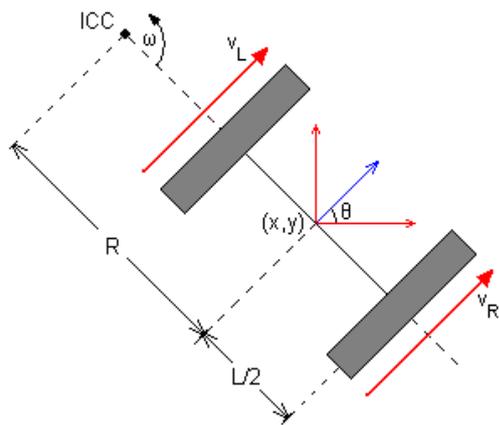


Figure 2. Kinematic model of wheeled mobile robot

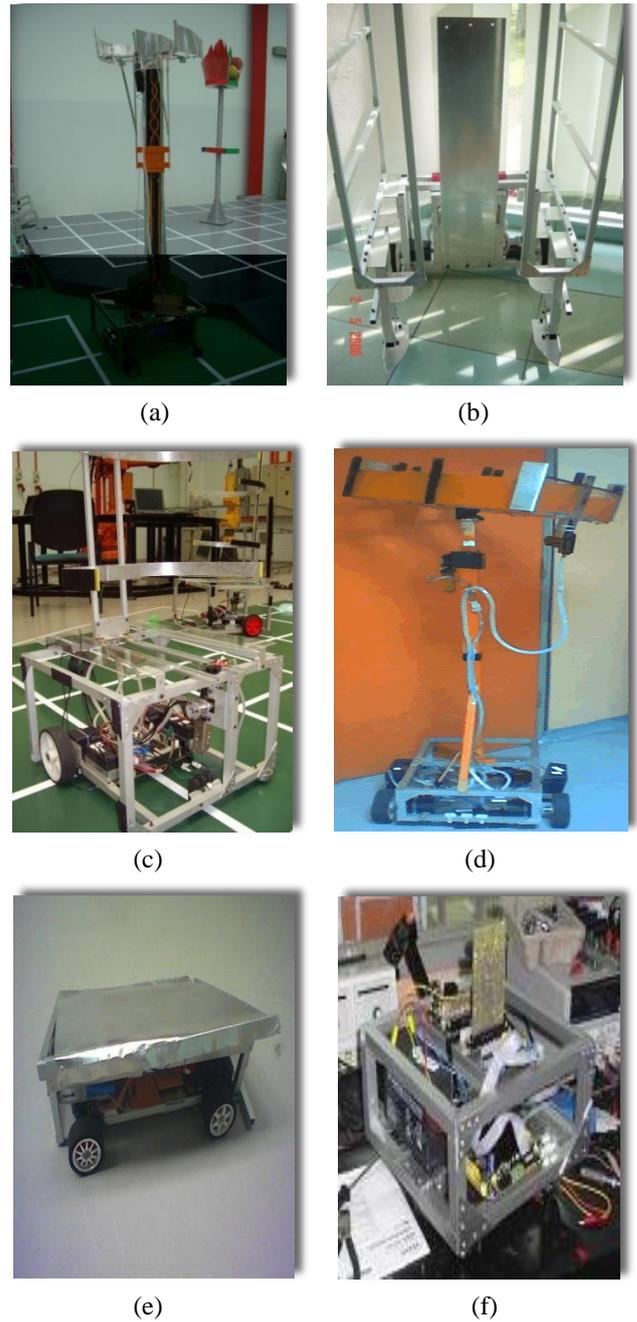


Figure 1. Autonomous robots (WMRs)

- r = nominal radius of each wheel
 L = distance between the two wheels
 R = instantaneous curvature radius of the robot trajectory, relative to the mid-point of the wheel axis
 ICC = instantaneous centre of curvature
 $R - (L/2)$ = curvature radius of trajectory described by left wheel
 $R + (L/2)$ = curvature radius of trajectory described by right wheel
 $v_r(t)$ = linear velocity of right wheel (1)
 $v_l(t)$ = linear velocity of left wheel (2)
 $w_r(t)$ = angular velocity of right wheel (3)
 $w_l(t)$ = angular velocity of left wheel (4)

With respect to ICC the angular velocity of the robot is given as follows:

$$w(t) = v_r(t)/(R + (L/2)) \quad (5)$$

$$w(t) = v_l(t)/(R - (L/2)) \quad (6)$$

$$w(t) = (v_r(t) - v_l(t))/L \quad (7)$$

The instantaneous curvature radius of the robot trajectory relative to the mid-point of the wheel axis is given as

$$R = (L(v_l(t) + v_r(t)))/(2(v_l(t) - v_r(t))) \quad (8)$$

Therefore the linear velocity of the robot is given as

$$v(t) = w(t)R = (v_r(t) + v_l(t))/2 \quad (9)$$

The kinematics equations in the world frame can be represented as follows:

$$\begin{aligned}
 \dot{x}(t) &= v(t) \cos \theta(t) \\
 \dot{y}(t) &= v(t) \sin \theta(t) \\
 \dot{\theta}(t) &= w(t)
 \end{aligned} \quad (10)$$

The Equation (10) can also be represented in the following form:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos \theta & 0 \\ \sin \theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ w \end{bmatrix} \quad (11)$$

The controlled variables of the model are the position and orientation of the mobile robot, while the control variables are the angular velocities of the left wheel and the right wheel.

3 NAVIGATION ALGORITHM

Navigation algorithms are very important for autonomous robot to successfully achieve its goals, whether it is requested to accomplish a mission or simply to survive in the environment. In order to navigate effectively, the autonomous robot must be able to carry out the tasks shown in Table 1.

Table 1. Navigation tasks

No.	Tasks
1	Know where it wants to go
2	Know where it is and what direction it is facing
3	Determine the heading (direction to) its destination
4	Steer to and maintain the heading to its destination
5	Stop when it has reached its destination

Figure 4 shows the top view position of motor 1, motor 2 and sensors for ‘line following’ for the status ‘straight’, ‘left’ and ‘right’.

From Figure 4, it can be seen that by assuming that only one sensor is focused on white line while the rest are outside, meaning both SEN 1 and SEN 3 are LOW while SEN 2 is HIGH; this will make both motor 1 and motor 2 to be energized together and the robot will move forward in a STRAIGHT line. If the robot move a little bit to the right, both SEN1 and SEN2 are activated (detect white line), LEFT is executed and motor 1 will give little bit speed to the mobile unit to move a bit to the left. Right If SEN 2 and SEN 3 are HIGH while SEN 1 is LOW, meaning robot move little bit to the to the left, RIGHT is executed and motor 2 is energized and this makes the robot to move a bit to the right side.

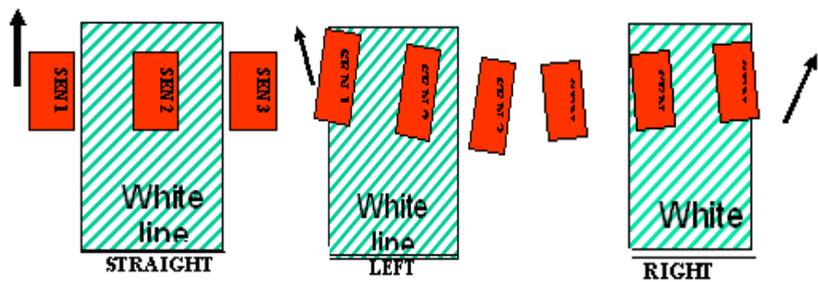


Figure 4. Position of sensors and motors for ‘line following’

Table 2 provides the logic for the ‘line following’ algorithm using three sensors.

Table 2. Sensor logic instruction

	SEN1	SEN2	SEN3	STATUS
1	0	0	0	OPTION
2	0	1	0	STRAIGHT
3	1	1	0	LEFT
4	1	0	0	LEFT_2
5	0	1	1	RIGHT
6	0	0	1	RIGHT_2

From Table 2, it can be seen that there are status for robot maneuverability such as Option, Straight, Left, left_2, Right and Right-2. These six statuses will determine the position of robot and how much offset level is needed during robot’s forward mobility. All ones indicate that the sensors are ‘active’ or detecting white line while all zeros indicate the sensors are ‘not active’ or ‘does not detect line’. Figure 3 shows the top view position of motor 1, motor 2 and sensors for ‘line following’.

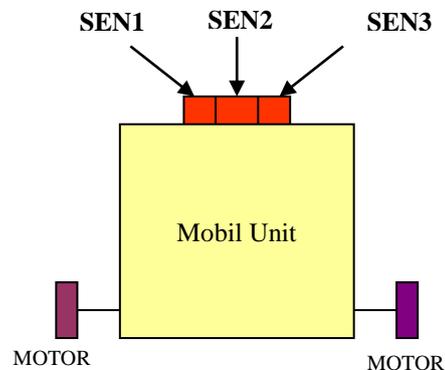


Figure 3. Top View of WMR

In this work, tracking was done using three digital fiber sensors, NAVI FX-300 series from SUNX. NAVI is an abbreviation for New Advanced Sensor With visible Indicator. Figure 5 shows the position of three line following sensors, SEN1, SEN2 and SEN3 on autonomous robots.

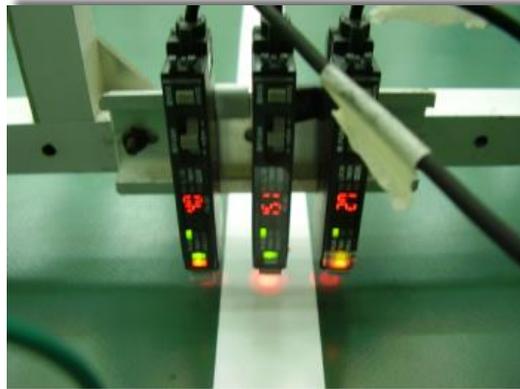


Figure 5. Position of sensors on robot

Counting is a method that was applied to the robot especially when precision mobility is required. The idea of counting technique is focused on how to stop the robot at certain point when it starts moving from one point to another point. Figure 6 shows the exact position of sensor 4, SEN4 on the robot for counting purposes.



Figure 6. Position of SEN4

Counting is a method that was applied to the robot especially when precision mobility is required. The idea of counting technique is focused on how to stop the robot at certain point when it starts moving from one point to another point. Figure 7 shows the flow chart of counting technique that has been applied in this work.

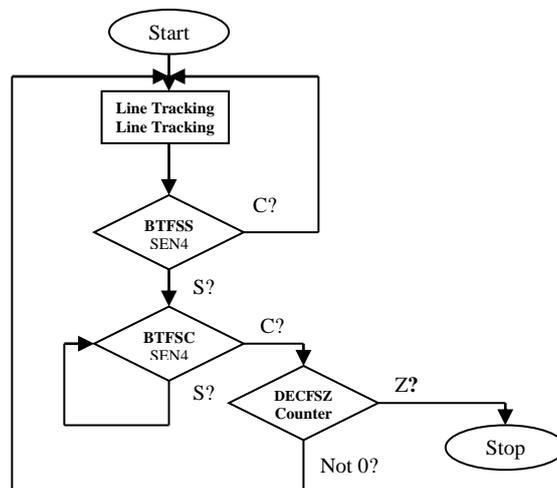


Figure 7. Position of SEN4

4 CONTROLLER OF AUTONOMOUS ROBOTS

The autonomous robots shown in Figure 1 used three different controllers, i.e. PIC16F877 microcontroller, 16F84 microcontroller and Programmable Logic Device (PLD). They are shown in Figure 8.

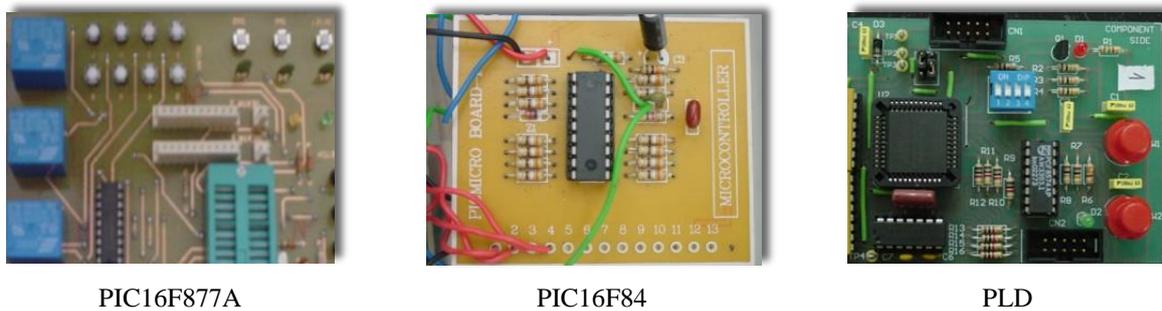


Figure 8. Autonomous robots with controllers

4.1 PIC16F877

The control subsystem of the autonomous mobile robot comprised of a PIC Microcontroller Board, VEXTA DC Brushless motor, DC brush motor, IR sensors, solenoids, and limit switches as shown in Figure 9.

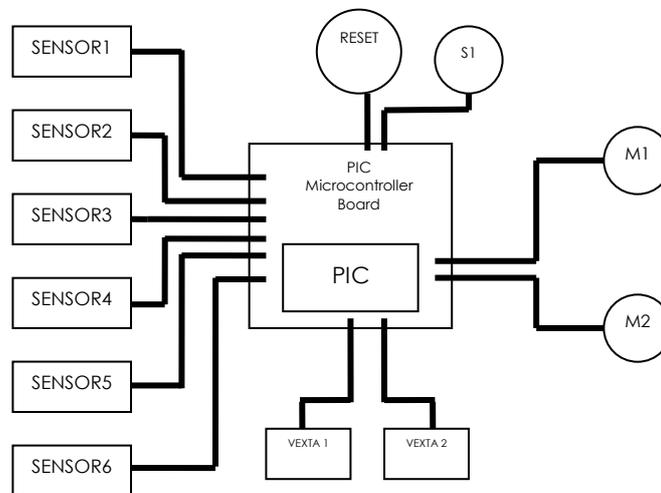


Figure 9. Control subsystem

In order to control the movement of the DC brush motor to turn clockwise and anticlockwise the board uses 2 relays per motor and the configuration can be seen in the Figure 10.

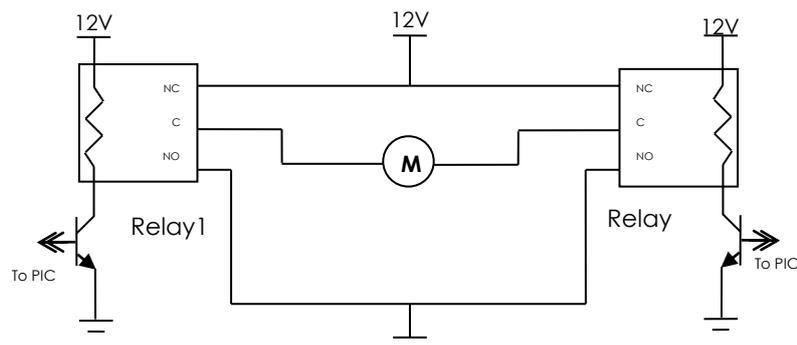


Figure 10. DC brush motor control circuit

4.2 PIC16F84

Another autonomous mobile robot uses PIC 16F84A which is an 18 pin Enhanced Flash/Eeprom 8-bit Microcontroller as the main controller. The circuit is able to drive two DC motors and control 4 relays using L6203 DMOS dual full bridge driver.

4.3 Programmable Logic Device

The other autonomous mobile robot was based on a Programmable Logic Device. Software called MAXPLUS II is used as a programmer and compiler for the Programmable Logic Device. VHDL language with graphical design entities was used as the language of programming.

4.3.1 System objectives and state diagram

A list of expectation (LOE) to be performed by the autonomous mobile robot is given in Table 3 and shown in Figure 11.

Table 3. List of expectation of autonomous mobile robot

No.	Actions
1	Follows the guide line (white) correctly
2	Counts the number of junctions that it crosses
3	Turns 90° to the right or the left
4	Launches a blocking mechanism represented by two bars horizontally placed

The understanding of the list of expectation leads to the second phase of the design that is the state diagram of the system. The state diagram is designed based on a prescribed path that is planned. The state diagram is shown in Figure 12.

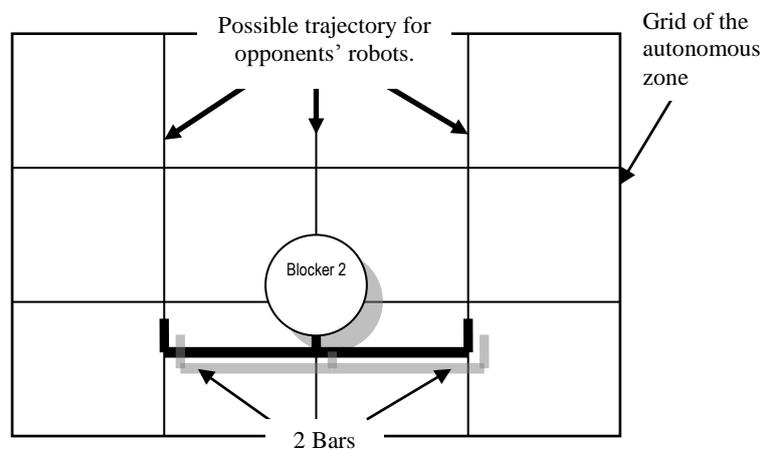


Figure 11. List of expectation diagram for autonomous mobile robot

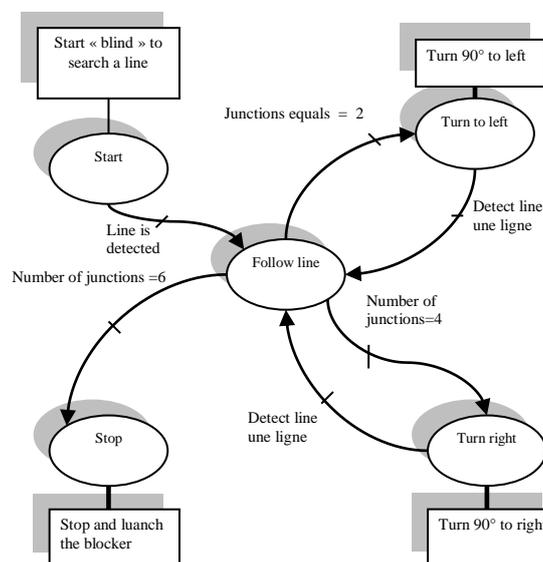


Figure 12. State diagram of autonomous mobile robot

4.4 Implementation and analysis

Development and implementation of the controller design scheme and navigation algorithm for sensor based path planning and tracking control on the laboratory wheeled mobile robot is critical. To materialize this, a test field is created and the path is developed based on which direction one wants to navigate the robot. Navigation control can be done by a controller using programming techniques. Testing and analysis were carried out to determine the robustness of the algorithms.

4.4.1 Programming the PIC

Programming the PIC is necessary to perform the desired application of the WMR. These codes enable the robot to do its explicit function, designed by the programmer depending on the tasks that are needed to be completed. The functional diagram of velocity control is shown in Figure 13 and the sample code is given in Appendix.

4.4.2 Programming the PLD

Based on the setting of the state diagram as shown in Figure 12, the functional modules for the Programmable Logic Device program was initialised using MAX plus II software. Figure 14 represents the functional modules of the system. Table 4 shows the flag conditions.

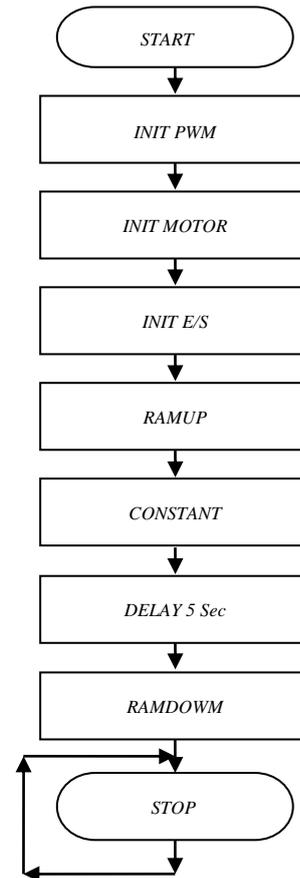


Figure 13. Functional diagram of velocity control

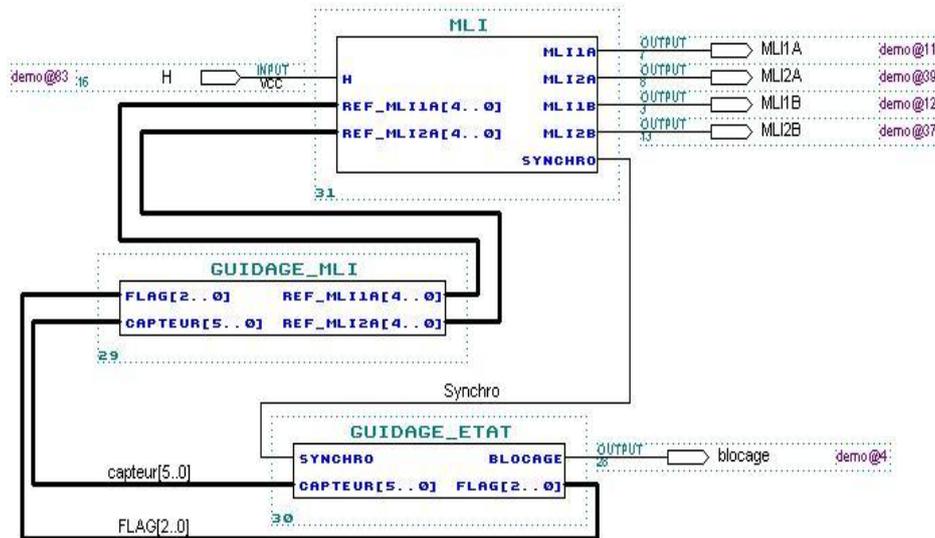


Figure 14. Functional modules

Table 4. FLAG conditions

State	FLAG
Start	111
Follow	100
Turn left	010
Turn right	001
Stop	000

4.4.3 Analysis

The final stage in the project is testing and analysis. During testing, all the robots had been tested on similar game field used in the competition. As an example, one of the autonomous robots that were tested is shown in Figure 15 and the game field is illustrated in Figure 16 respectively.



Figure 15. Autonomous robot on the testing field

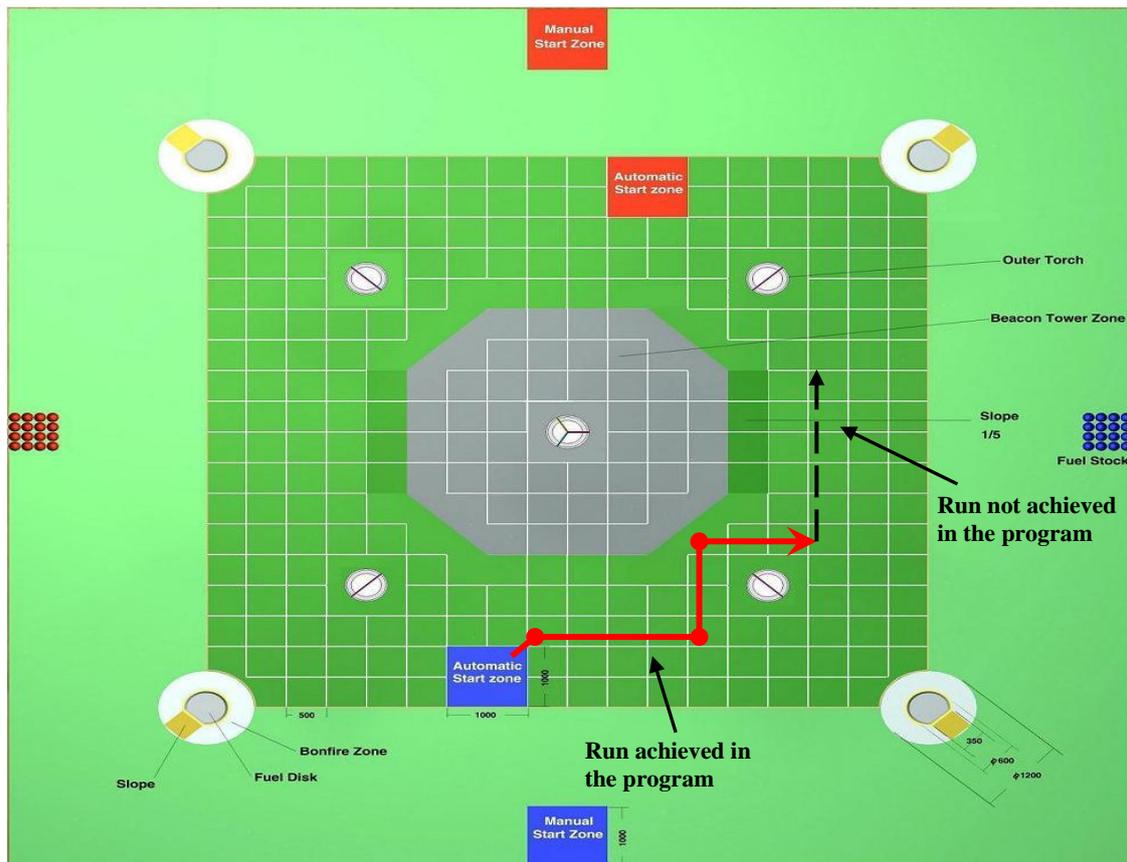


Figure 16. Path of autonomous robot on the testing field

A series of tests were carried out to determine the robustness of the algorithms. It was found that for line tracking, the position of the sensor and its arrangement on the WMR is very important due to its effect on the robot mobility. WMRs can have two drive techniques similar to today's car which can be either *front drive* or *back drive*. Advantages of the *front drive* technique are that the WMR is able to accelerate faster with maximum torque and less vibration during motion. The advantage of the back drive is that offset can be reduced to minimum level so that sensors are able to respond faster to any state from STATUS condition. With this kind of arrangement, the WMR can move forward smoothly with minimum offset. The repeatability reaches 91% with slow trajectory profile. The efficiency of the movement is limited with the bandwidth of the sensor. The repeatability of fast trajectory was reduced to 73% with the same program implemented.

The use of single or multiple processors offers great possibilities for design of control schemes. Many possible trades-offs between performance goals, computational time, and hardware/software cost and complexity are possible. The assessment criteria given in Table 5 can be used as a guide for selecting the type of processing system that is required.

Table 5. Selection criteria for the processing system

Selection Requirements	System Level Attributes
Performance	Modular construction
Cost	Interconnection
Flexibility	Task allocation
Expandability	-
Programmability	-
Reliability	-

The PLD that is implemented in this project is 7064SLC 44-10 with 64K Byte of memory whereas the PIC microcontrollers are PIC16F family. Comparing the two devices in sense of 'system requirements', the performance of the blocker under the both device exhibited stable and reliable operation with a slight advantage of the microcontroller type PIC in term of memory usage. The PLD 7064SLC 44-10 has a small amount of memory that cannot handle long programming codes with many variables.

For the system 'level attributes', students adhered to the utility of modular programming, in which it is an attribute of MAX Plus II programming method. The graphical design file display provided a clear and better understanding for the controller program.

5 CONCLUSION

This paper discusses the development of autonomous robots and different controllers with the implementation of navigation algorithms for non-holonomic autonomous mobile robots. The algorithm uses only three photoelectric sensors to retrieve the information regarding the position and orientation of the robot with

respect to the grid line of the ground. The algorithm worked efficiently to correct the position of the robot even in high speed experiment. It has also reported comparative analysis between the microcontrollers and programmable logic device that were used in autonomous mobile robots.

APPENDIX

Sample Program in 'C':

```
void main (void)
{
// Init all function
TRISC=0x81;
TRISE=0x01;
TRISA=0xFF;
init_pwm();
init_moteur();
// Start Program
acceleration(100); // RAMUP until PWM1 & 2 = 100 45% capacity max
cst(100,100); // Value wheel right and left
Delay10Ms(250); // Delay 2,5 seconde
Delay10Ms(250);
ralentissement(100); // RAMDOWN
while(1){} // End program
}
```

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