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PROJECT-BASED LEARNING IN MECHATRONICS ENGINEERING: MODELLING AND DEVELOPMENT OF AN AUTONOMOUS WHEELED MOBILE ROBOT FOR FIREFIGHTING

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ABSTRACT: The mechatronics engineering education has advanced rapidly since the introduction of mechatronics as a new discipline in engineering education. The project-based learning becomes also one of the most effective approaches in teaching mechatronics subjects such as robotics and mechatronics system design. The main objective of this paper is to present the role of project-based learning in the mechatronics engineering education. An autonomous wheeled mobile robot that scans a rectangular area looking for a heat source (simulated by a burning candle) extinguishes it and returns back to its home position is designed. The project was developed successfully and the students got the second position in a robotic competition organized by the university. The design details as well as the performance analysis of the mobile robot will be presented here. Also, the milestones of the project will be discussed and analyzed.

Key words: Mobile robot, firefighting, competition, project-based, mechatronics education

INTRODUCTION

By about 1990, new assessments of college students had shown that the knowledge they acquired in high school remained at a superficial level. Even the best scoring students, those at the top colleges, often had not acquired a deeper conceptual understanding of material – whether in science, literature, or math [Gardner 1991]. Educators still face these critical problems today.

Project-based learning provides opportunities for students, teachers, and members of society to collaborate with one another to investigate questions and ideas. Collaboration helps students build shared understandings of scientific ideas and of the nature of the discipline as they engage in discourse with their classmates and adults outside the lecure hall [Krajcık &Blumenfeld]. A possible solution is the project-based learning where students can integrate their knowledge and appreciate what they have studied when they are able to see what they can achieve from the theoretical background courses as well as the hands-on courses. Project-based learning also builds the students' self-confidence and allows them to think, develop and design new ideas and approaches through their teamwork.

Recently there are many robotics competitions to enhance the student's understanding and present a learning environment for students. Pack et al. [3] presented the experiences of engineering students in fire-fighting mobile robot design at the U. S. Air Force Academy, Trinity College, and Penn. State Abington during a robotics competition. A survey results that support the values of the fire-fighting design and development was included as well. Khoon et al. [4] described the development of an Autonomous Fire Fighting Mobile Platform (AFFMP) that is equipped with the basic fighting equipment that can patrol through the hazardous site via a guiding track with the aim of early detection for fire. The tasks for the AFFMP once it navigates out of the patrolling route include the obstacle avoidance, locating for more precise location of fire source using front flame sensor and extinguish the fire flame. Kiranmai and Kumar [5] presented fire detection and controlling method using robot is proposed. Fire is detected using the fire sensor and immediately SMS is sent to the user by using the GSM module. Then the user can control the robot by using GSM Module from remote location. The robot also detects the obstacles while moving by the obstacle sensor. Setiawan et al. [6] presented an approach in designing a fire fighting robot contested in a robotic student competition. The approach makes use of computer simulation and animation in a virtual reality environment. The efficiency of the algorithms and parameters values employed can

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be easily evaluated. Tavera et al. [7] investigated on sensor fusion and navigation of a robot with intelligent vision, receiving signals from sensors and specialized control chaotic to reduce human, material and environmental injuries. A real robot moves in spaces with boundaries like walls or surfaces of obstacles. To solve this problem, we consider the motion of the robot in an imaginary space. This imaginary space is obtained by smoothly connecting boundaries of two spaces that have the same shape as the real space.

The main objective of this paper is to share the experiment of designing and development of a wheeled mobile robot for firefighting. This project was a course project for the third year mechatronics engineering student for the mechatronics system design course at Mevlana University, Konya, in Turkey in second semester of the academic year 2013-2014. The main idea behind this project is to allow the students integrate their knowledge in a complete project before going to their senior graduation project. Another reason came to our mind since the university was about to organize a robotic completion and I offered the students to participate in the competition with the course project and if they succeeded to get any of the first three position they will get final mark in the project since project has almost 20% of the marks of the course in addition to 10% for laboratory assignment.

The students were divided in three groups and each group has to present a weekly report on their activities. Although each group will concentrate in their role, but all of them will exchange ideas and proposals for other groups during the laboratory section of the course. The three groups are organized as follows:
1. The Mechanical Design Group: Mushahid Hassan, Shehzan Ali and Vehbi Mesin
2. The Trajectory Planning and Control Strategy Group: Sokhna Diarra, Ahmed Erkoc and Salman Farouk
3. The Trajectory Planning and Programming Group: Jabir Mohammed and Mohamed Ali

There is overlapping between the last two groups since the trajectory planning affects the control strategy and the microcontroller programming at the same time. Dealing with two groups for this topic ensures the better results.

The paper has five sections: section (2) summarizes the problem in a mathematical form and model the mobile manipulator to calculate roughly the motor size while section (3) shows the mechanical design development of the mobile robot as well as the intial water pumping system. Section (4) discusses the control strategy while section (5) explores the performance analysis followed by conclusions and references. This paper contains some tecnical details so the reader will be familiazed with the subject as well.

Problem Formulation

A mobile manipulator consists of a single link which is attached to a cart as shown in Figure (1). The rod can rotate about its pivot and has a length of $2l$ and a mass of m_{rod}. This rod (Hollow tube) was initially designed to direct the water from a reservoir to the heat source using a water pump. The mobile platform has a mass M and two wheels each of mass m_w and radius r . The position and orientation of the mobile robot can be identified by the cart position $x(t)$ and the rod angle $\theta(t)$. A force input $F(t)$ is applied to the cart through two DC motors that drive the two wheels attached to the same axis. A castor was attached for stable movements of the mobile robot as shown in Figure (1).

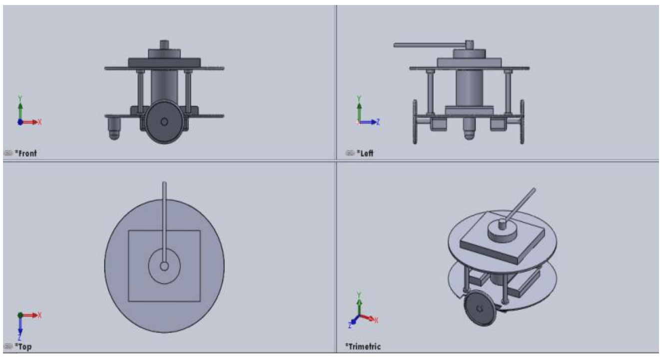


Figure (1) Configuration of the wheeled Mobile Robot

The main objective of this section is to derive a simplified model for the wheeled mobile robot without taking into consideration the non-holonomic constraint of the mobile platform. We need to have a rough estimate of the motor wheels to select the proper motor size.
The equations of motion of the mobile manipulator can be derived using Lagrange equation which states that:

$$\frac{\partial L}{\partial \dot{q}_j} - \frac{\partial L}{\partial q_j} = Q_j \qquad (1)$$

Where L is the Lagrangian of the system which is the difference between the kinetic and potential energies, q_j is the generalized coordinate and Q_j is the generalized force associated with the generalized coordinates.

The kinetic energy and the potential energy of the manipulator are given by:

$$K.E. = \frac{1}{2}\left(M + m_{rod} + \frac{3}{2}m_w + m_{tp}\right)\dot{x}^2 + (m_{rod})l\dot{x}\dot{\theta}\cos\theta + \frac{1}{2}(m_{rod})l^2\dot{\theta}^2 \quad (2)$$

$$P.E. = (m_{rod})gl\cos\theta \quad (3)$$

If we consider the equivalent mass as:

$$M_{EQ.} = \left(M + m_{rod} + \frac{3}{2}m_w\right) \quad (4)$$

Hence the Lagrangian of the system is given by:

$$L = \frac{1}{2}M_{EQ.}\dot{x}^2 + m_{rod}l\dot{x}\dot{\theta}\cos\theta + \frac{1}{2}m_{rod}\,l^2\dot{\theta}^2 - m_{rod}\,gl\cos\theta \quad (5)$$

Upon substituting the Lagrangian into Equation (1) and after some algebraic manipulations the equations of motion can be obtained as:

$$F = M_{EQ.}\ddot{x} + m_{rod}\,l\ddot{\theta}\cos\theta - m_{rod}l\dot{\theta}^2\sin\theta \quad (6)$$

$$\tau = M_1\ddot{x}\cos\theta + m_{rod}l^2\ddot{\theta} - m_{rod}\,lg\sin\theta \quad (7)$$

From Equations (8 and 9) the linear and angular accelerations are given by:

$$\ddot{x} = \frac{1}{M_{EQ.}}\left[F - m_{rod}\,l\,\ddot{\theta}\cos\theta + m_{rod}\,l\dot{\theta}^2\sin\theta\right] \quad (8)$$

$$\ddot{\theta} = \frac{1}{M_2 l^2}\left[\tau - m_{rod}\ddot{x}\cos\theta + m_{rod}\,l\,g\sin\theta\right] \quad (9)$$

Equations (6 and 7) can be used to estimate the motor torque needed to drive the wheel as well as required motor torque to rotate the water tube.

There is another way to roughly estimate the motor size by calculating the total weight of the robot and assuming the coefficient of friction between the wheels and the ground and calculate the torque as:

$$\tau = \mu_k Nr \quad (10)$$

Where r is the wheel radius which can be calculated from the assumed linear velocity of the robot as well as the angular velocity of the motor as:

$$V = \omega r \quad (11)$$

The initial mass of the robot is assumed to be 3 kg and the rod and wheels masses as 0.3 kg and 0.5 kg respectively. A fifth order polynomial trajectory is assigned for the linear motion of the platform as well as the rotation of the rod and these trajectories are shown in Figures 2 and 3 repectively. For simulation purposes, The platform is assumed to move forward 8 m and return back as it achieves the boundary of the field .The rod is assumed to move upward an angle of 90 degrees during the same period.

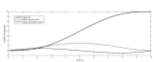


Figure (2) Platform Trajectory

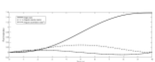


Figure (3) Rotating Rod Trajectory

Upon substituting theses trajectories into equations 6 and 7, the traction force as well as the torque for the rotating rod can be simulated as shown in Figure (4)

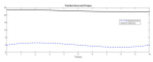


Figure (4) Traction Force and Torque for the Rod

Mechanical Design

The mechanical design was the first and important task since it affects the motion and the trajectory design for the mobile robot. The differential derive with two wheels driven by DC motors and castor for balancing was selected for the locomotion system and the platform was designed as a two-level circular shape with two grooves for wheel fixation. The circular body shape minimizes the possibility of collision with objects inside the course of motion and allows ultrasonic sensors to work accurately without signal interference. The two similar motors were attached at the bottom of the first level and the space between the two levels is reserved for the controller, the battery and the circuit boards as shown in Figure (1).

In the initial design, a water pump and a reservoir were proposed to splash water at the heat source (simulated by a burning candle). But due to time constraint and unavailability of light weight water pump, a fan-based system was used instead. A single fan was used and then after performance analysis another fan was added to produce strong flow of air. A 12 V light weight rechargeable battery to reduce the weight of the robot and hence the motor rates and weights.

CONTROL STRATEGY and TRAJECTORY PLANNING

Since the main objective of this robot is to locate the heat source and extinguish it, two main problems arise in this regard:

1. The first challenge is the proper selection of the heat or flame sensor that is able to sense the heat source from a suitable distance and send a signal to the microcontroller to start the extinguishing process timely and accurately.
2. The second challenge is to design the robot trajectory properly to cover the inspected area and accurately moves the robot towards the heat source as soon as it detects the flame. This trajectory is the main issue here since the heat sensor can detect the flame at a reasonable distance not a big one and if the sensor fails to detect the heat source the whole process collapse.

To solve the first problem, the students searched the internet and explored the previous literature review until they came up with a good sensor that can accurately detect the flame from a distance of 20 cm and gives a 5 V signal to the microcontroller to take action. The picture of the flame sensor is shown in Figure (5).

Figure (5) Flame Sensor

The second problem was a little bit difficult and needed a lot of trials to design the effective trajectory. First the flame sensor was mounted on a rotating base that can scan 180 degrees. The mobile robot moves in a straight line starting from the home position and moves forward until it reaches the boundary of the selected area. Ultrasound sensors fixed at the front side of the mobile robot will detect the presence of a boundary or any obstacle and the robot will make U-Turn andreturn back to cover the whole area. During that time, the flame sensor with its rotating base is searching for the heat source. As soon as the flame sensor detects the heat source, the base stops rotating and the mobile platform moves towards the source. When the robot is about 15 cm from the heat source it stops and the two fans start working to extinguish the flame. After finishing the task, the robot returns back to its home position again to start another search. Figure (6) shows the assembly of the mobile robot.

The Arduino microcontroller was used to control the mobile robot since the programming team is familiar with its programming language. The team started programming the motion of the robot as well as the flame sensor and the fans after the mobile robot was assembled. The team spent a lot of time adjusting the robot and refining the code until the robot works properly. The flowchart of the project procedure is shown in Figure (7) while the controller details are illustrated in Figure (8) .

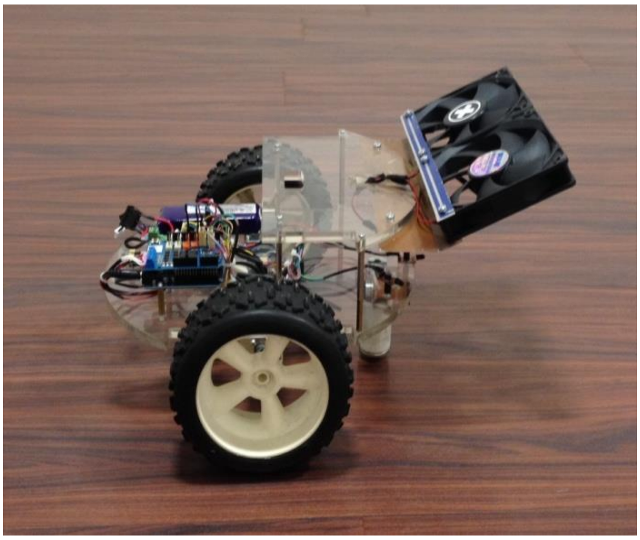
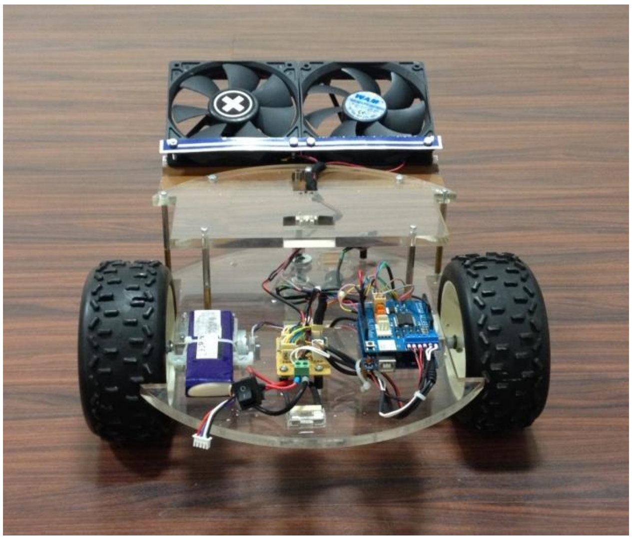


Figure (6-a) Side View of the Wheeled Mobile Robot

The floor of the laboratory has a moderate coefficient of friction and the students made many tests during the performance analysis stage to check the maneuverability of the wheels and the suitability to work in similar grounds. During the competition the floor was different and the students asked to move to another near place with better coefficient of friction similar to the laboratory floor because they are afraid of wheel slippage.



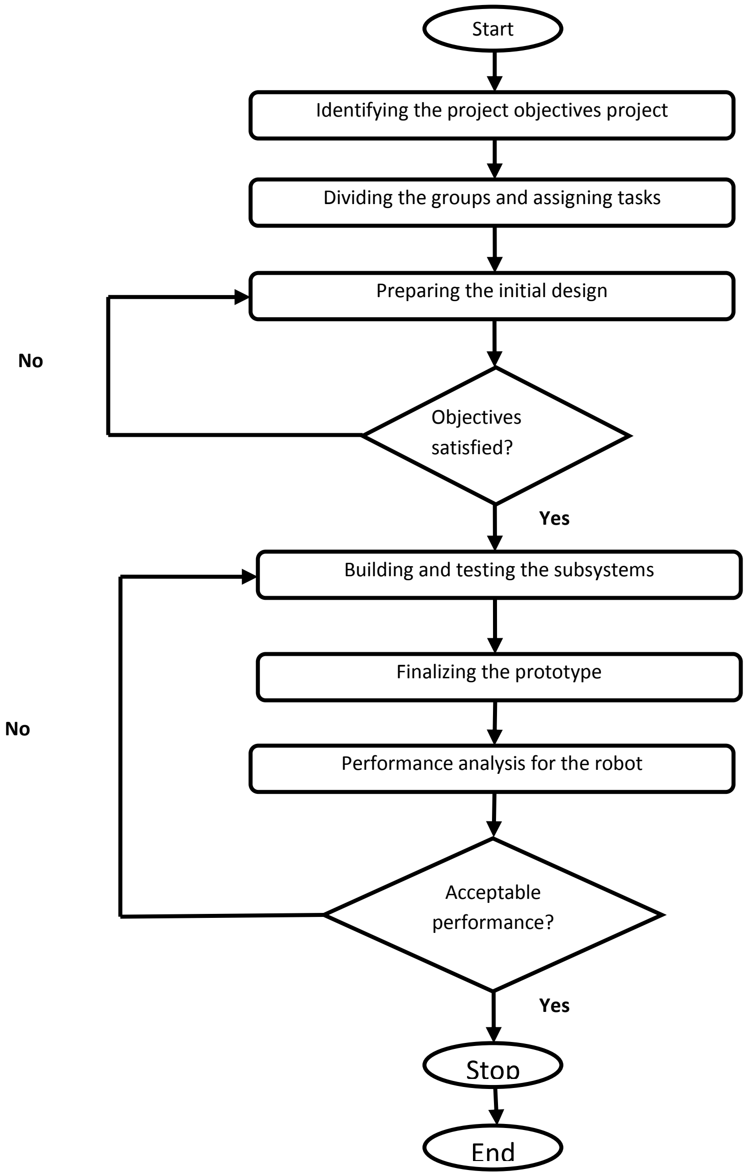


Figure (7) Flowchart of the Development Procedure

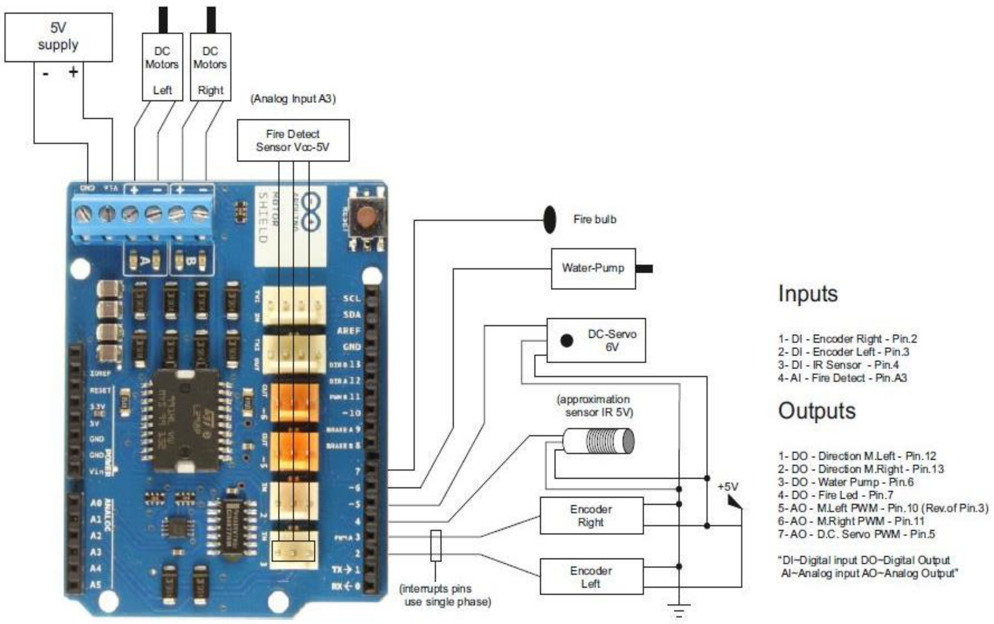


Figure (8) The Arduino Microcontroller and Circuit Analysis

DISCUSSION and CONCLUSIONS

Before the competition day the students spent a lot of time adjusting the code so the flame sensor can detect the heat source easily. They tried many trajectories and they ended with straight line trajectory starting from the home position in the middle of the area moving forward and the robot should make a U-Turn and the end of the course and repeat it until it covers the whole designated area. The students started by putting the heat source randomly at the right of the mobile robot and the robot started from its home position. The robot was able to reach the heat source and extinguish it. One referee changed the position of the heat source to the far left of the proposed inspected area and asked them to repeat the experiment. The mobile robot did not recognize the heat source in the first time but it was able to detect it and extinguish the flame when they repeat the experiment starting from the home position of the robot. They got the certificate for the second position since the prize was reserved only for the first position winner.

It is worth mentioning that the students learnt from this course and their performance was very good compared to other courses. I taught six mechatronics courses to this group except the Electrical student and I knew their level. I discovered that some of them are not good in theoretical aspects courses but they have very good hands on experience which I watched during the different phases of the project. They were very enthusiastic to finish the project on time specially when we approached the competition. As a whole, I believe the experience was successful and this kind of teaching approach is appropriate for mechatronics education because of its multidisciplinary nature.

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