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SIMPLE AND EFFICIENT BI-COLOR PATH FOLLOWING ROBOT CONTROL ALGORITHM TEACHING IN ELECTRICAL ENGINEERING EDUCATION

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ABSTRACT: In this study, bi-color path following robot control algorithm teaching is presented. Mostly, autonomous robots follow a path on black colored surfaces having white line or vice versa. Courses having different line colors are rarely used because of its difficulty in its implementation. Several algorithms or hardware designs are developed for the autonomous solution of path following robot problem. Two electrical engineering students are taught about robot control algorithm development through inquiry teaching approach. A novel algorithm is developed after this process. This paper investigates the efficient and simple path following robot control algorithm development over two colored lines on same course simultaneously.

Key words: teaching methods, robot design, robot control, line following robot

INTRODUCTION

Nowadays, student-centered teaching approach is seem to be most popular teaching approach in higher education. Active learning, project based learning, problem based learning and inquiry based learning are some of the well known and mostly advised learning approaches in higher education (Aceska 2016; Demirel and Turan 2010; Demirel 2009; Felder and Brent 2009; Gormally et al. 2009; Healey 2005; Sönmez 2011) which are significant methods for student-centered learning.

Science, Thecnology, Engineering and Mathematics (STEM) education became more popular to educate well trained students (Miura 2016). Specially, the positive impact of inquiry based, problem based and project based teaching approaches in engineering education cannot be ignored (Erdem 2002; Furtak 2006; Gençoğlu and Cebeci 1999; Lotter et al. 2007; Mao and Chang 1998). Besides these approaches, the previous knowledge level of learners are also important to use teaching approaches like inquiry based teaching (Kirschner et al. 2006).

Inquiry based teaching approach forces learners to understand the required knowledge in detail. Tearcher guidence helps students to develope skills in learning and critical thinking. Engineering education involves critical thinking in its nature. Path following robot control algorithm development requires critical thinking and

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therefore inquiry based teaching approach should be aimed to be applied. In this study, inquiry based teaching together with project based teaching approach is implemented with two electrical engineering students.

This paper investigates, efficient and simple line following robot control algorithm development teaching with inquiry teaching approach. The brief introduction of inquiry based teaching approach and the line follower robot problem are given in methods section. The students' performance about line follower robot design and control algorithm development are given in results and findings section. Observations about inquiry teaching approach for line follower robot design and control algorithm developments are discussed in conclusion section.

INQUIRY TEACHING METHOD

Inquiry based teaching is one of the widely used student centered teaching approach in engineering education. This teaching approach aims to increase the motivation and attention of learners in learning process (Erdem 2002; Furtak 2006; Gençoğlu and Cebeci 1999; Lotter et al. 2007; Mao and Chang 1998). The applied inquiry based teaching approach with project based and problem based teaching can be illustrated as shown in Figure 1. Basically, problem based teaching approach involves development of a solution to a given problem. If a novel product or design is developed during the problem solution process, then this teaching approach is called as project based teaching. Both project and problem based teaching approaches are kind of inquiry teaching approach. Learners search and investigate the required solution or knowledge having a guide from an instructor.

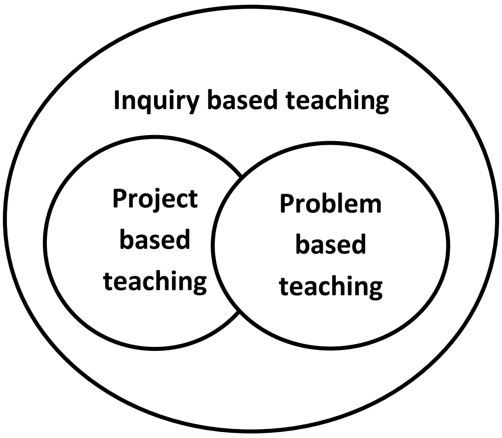

Figure 1. Inquiry teaching approach

Traditional instructional teaching approach cannot be removed from higher education. For an effective learning, students' interest can be increased by using active teaching strategies (Kirschner et al. 2006). Inquiry based teaching might be useful when the learners have enough background about a problem.

An important issue about inquiry teaching approach might be the required time to accomplish a project. This study is accomplished in two semesters. Learners spent around one semester to finalize robot manufacturing and one semester to develop a novel control algorithm. Another important issue is that, students have enough knowledge about used components and programming. The previous knowledge of learners is very important to start investigation.

Line Follower Robot Problem

A mobile robot follows a pre-defined path. Traditional line follower courses include one line on the path. The path may contain screws and the color of line may be black or white as illustrated in Figure 2.

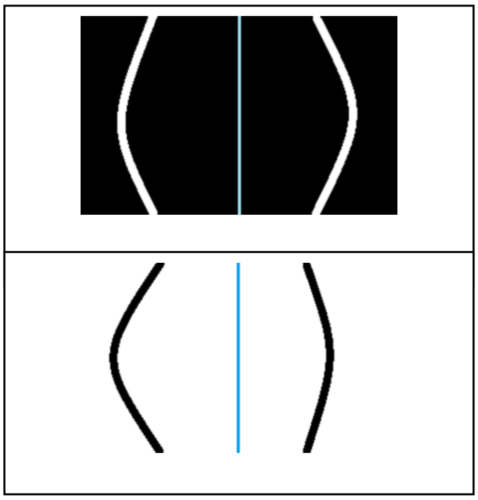

Figure 2. Example of courses having different colors

The control algorithm of a line follower robot in such courses may include contradictions. Sensor perceptions are the reverse cases of each other when the color of line changes. A truth table of sensor array with three sensors summarizes the sensor perception sequence. Assume that logical one represents black color and logical zero represents white color. All possible sensor perceptions are given in Table 1.

Table 1. Table Captions Should Be First letters capitalized

Sensor			**Required Action**	**Description**
Left Sensor L	***Center Sensor C***	***Right Sensor R***		
0	0	0	No action	All white color
0	0	1	Turn right	Black line turns right
0	1	0	Forward	Black line on the center
0	1	1	Turn left	White line turns left
1	0	0	Turn left	Black line turns left
1	0	1	Forward	White line on the center
1	1	0	Turn right	White line turns right
1	1	1	No action	All black color

A line follower robot performs only three actions; go forward, turn left and turn right. Based upon the table above, there are eight cases at most having a sensor array with three sensors. Regardless of the line color, same logical expressions are aimed to be used for the robot's control algorithm. Logical expressions of the control algorithm are developed by using data in Table 1. Simplified expressions are given in Table 2 are used only in algorithms 2 and 4. This simplification shows that only three cases are enough to control a line follower robot on bi- color line courses. This algorithm is easy to update when you increase the number of sensors. The only modification is to add a new XOR statements to the corresponding action case with logical AND operation.

Table 2. Logical Expression List

Logical Expression	**Action**
(L XOR C)AND(C XOR R)	Forward
(L XOR C)AND(R XOR L)	Turn Left
(R XOR C)AND(R XOR L)	Turn Right

These three cases are enough to work on both black and white color lines. Algorithms that are given below are tested with CIURunner. Obstacle sensing routine given below is commonly used in all algorithms. It causes to stop both motors when an obstacle is sensed by the Sharp IR range finder. Algorithm 2 and algorithm 4 is developed in this study.

Obstacle sensing:

- *do*

- *Read IR range finder 3 times and calculate the average distance*
- *If distance <= desired distance*
  - *Stop all motors*
- *While (distance > desired distance)*

Pseudo Code of Algorithm 1:

- *Program initializations*
- *While (true)*
- *Call obstacle sensing algorithm*
- *Read sensor values (L, C, R)*
- *If (C & !L & !R) Then*
- *Go forward with a fixed speed*
- *If (L & !C & !R) Then*
- *Turn Left with a fixed speed*
- *If (R & !C & !R) Then*
- *Turn Right with a fixed speed*
- *End while*

Pseudo Code of Algorithm 2:

- *Program initializations*
- *While (true)*
- *Call obstacle sensing algorithm*
- *Read sensor values (L, C, R)*
- *If (L XOR C)AND(C XOR R) Then*
- *Go forward with a fixed speed*
- *If (L XOR C)AND(R XOR L) Then*
- *Turn Left with a fixed speed*
- *If (R XOR C)AND(R XOR L) Then*
- *Turn Right with a fixed speed*
- *End while*

Pseudo Code of Algorithm 3:

- *Program initializations*
- *While (true)*
- *Call obstacle sensing algorithm*
- *Read sensor values (LM, L, C, R, RM)*
- *If (C & !L & !R & !LM & !RM) Then*
- *Go forward with a fixed speed*
- *If (L & !R & !LM) Then*
- *Turn Left with a fixed speed*
- *If (R & !L & !RM) Then*
- *Turn Right with a fixed speed*
- *If (LM & !C & !L) Then*
- *Strong Turn Left with a fixed speed*
- *If (RM & !C & !R) Then*
- *Strong Turn Right with a fixed speed*
- *End while*
- *End while*

Pseudo Code of Algorithm 2:

- *Program initializations*
- *While (true)*
- *Call obstacle sensing algorithm*
- *Read sensor values (L, C, R)*
- *If (L XOR C)AND(C XOR R) Then*
- *Go forward with a fixed speed*
- *If (L XOR C)AND(R XOR L) Then*
- *Turn Left with a fixed speed*
- *If (R XOR C)AND(R XOR L) Then*
- *Turn Right with a fixed speed*
- *End while*

Pseudo Code of Algorithm 3:

- *Program initializations*
- *While (true)*
- *Call obstacle sensing algorithm*
- *Read sensor values (LM, L, C, R, RM)*
- *If (C & !L & !R & !LM & !RM) Then*

- *Go forward with a fixed speed*
- *If (L & !R & !LM) Then*
- *Turn Left with a fixed speed*
- *If (R & !L & !RM) Then*
- *Turn Right with a fixed speed*
- *If (LM & !C & !L) Then*
- *Strong Turn Left with a fixed speed*
- *If (RM & !C & !R) Then*
- *Strong Turn Right with a fixed speed*
- *End while*

Pseudo Code of Algorithm 4:

- *Program initializations*
- *While (true)*
- *Call obstacle sensing algorithm*
- *Read sensor values (LM, L, C, R, RM)*
- *If (L XOR C) AND (C XOR R) AND (C XOR RM) AND (C XOR LM) Then*
- *Go forward with a fixed speed*
- *If (L XOR R) AND (L XOR LM) Then*
- *Turn Left with a fixed speed*
- *If (R XOR L) AND (R XOR RM) Then*
- *Turn Right with a fixed speed*
- *If (LM XOR L) AND (LM XOR C) Then*
- *Strong Turn Left with a fixed speed*
- *If (RM XOR C) AND (RM XOR R) Then*
- *Strong Turn Right with a fixed speed*
- *End while*

Algorithm 1 and *Algorithm 3* are modified with additional instructions for a black line but CIURunner couldn't follow the line. However, when algorithm 2 and algorithm 4 are tested with CIURunner, it has been observed that they work properly on both courses. Same motor speeds are used in all algorithms. However, motor control speeds differed for each action.

CIURunner is tested in two courses having different line colors. Instead of long straight lines a path with strong screws are preferred to test the algorithm performances as shown in Figure 3.

a) Course 2: Path with black and white line

b) Course 1: Path with white line

Figure 3. Used Line follower courses

The performance of the proposed algorithms (*Algorithm* 2 and *Algorithm 4*) is tested in course 1 and course 2 which have 4.16 meters length. The performance of the proposed algorithm and traditional control algorithm are summarized in Table 3. The proposed algorithm might look similar to the control logic which is given in studies (Hasan and Al Mamun 2012; Hasan et al. 2013). The advantage of the proposed algorithm is, having the ability to follow a path with bi-color. A similar logic circuitry that is presented in (Hasan and Al Mamun 2012) can be constructed for the proposed algorithm as well.

Table 3. CIURunner Control Performance

Courses	Performances of Algorithms			
	Algorithm1	***Algorithm2***	***Algorithm3***	***Algorithm4***
Course 1	15,5 sec	15,3 sec	15,4sec	15,3 sec
Course 2	Lost the line	15,3 sec	Lost the line	15,4 sec

The speed of the CIURunner is recorded with different number of sensors and logical expressions. CIURunner speed was 0.4 m/s in ITURO2013. However, then the motor control parameters are increased. Thus, the performance of CIURunner is reached to 0.55 m/s. Dynamic PID control algorithm provides high quality of line following behavior with the speed of 0.2 m/s (Engin and Engin 2012). However, CIURunner does not astray from the line when the speed is 0.4 m/s with the algorithms 2 and 4.

RESULTS AND FINDINGS

In this study, a simple and efficient line follower robot control algorithm is developed for bi-color line course where it detects obstacles in front of it. The robot named as CIURunner is developed for the line follower robot competition of ITURO2013 which is organized by the İstanbul Technical University in every year. CIURunner is designed as a line follower robot as shown in Figure 4. The robot has two DC motors which control two wheels, two free wheel at front and end of it, five light sensors and one IR range finder. Inquiry teaching approach is applied during the development of this robot.

Figure 4. The Line Follower Robot (CIURunner)

The block diagram of the line following robot architecture is illustrated in Figure 5. Since +5V is not sufficient to work with DC motors, a L298N motor driver is integrated to the PIC. In order to perceive accurate IR sensor voltage values, 74HC14 comparator is used in this architecture.

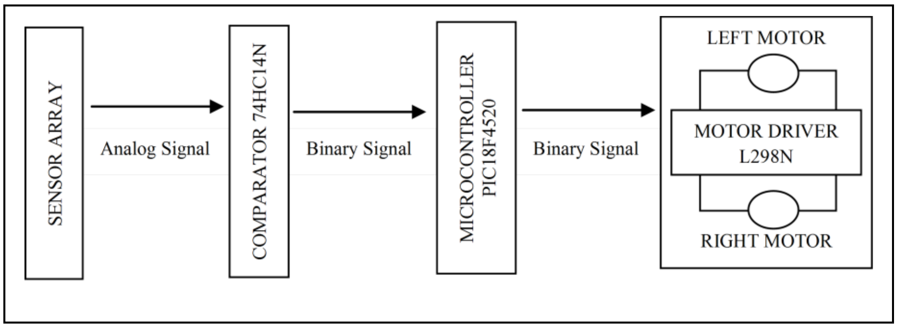

Figure 5. Block Diagram of Line Follower Robot

In order to make CIURunner to turn screws fast, five IR reflective sensors (QRD1114) having 2 cm distances between each is installed on sensor array. The organization of sensor array is shown in Figure 6. Path color information is perceived by IR sensors as an analog voltage between 0V and 5V. These values are converted to binary values as 0 or 1 by 74HC14 comparator. Path colors are represented as sequence of 0s and 1s. Binary sensor information is used by the microcontroller to control the line follower robot.

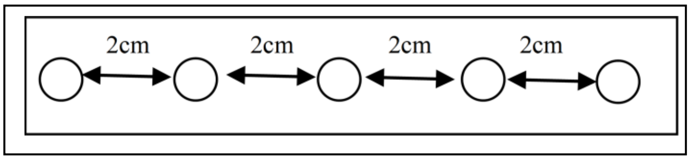

Figure 6. Top view of sensor position

Obstacle avoidance behavior can be implemented by using range finder sensors. Therefore, an IR range finder sensor (Sharp IR range finder) is integrated to the body of the robot as shown in Figure 7. This sensor works with analog signal with the range between 20 cm to 150 cm.

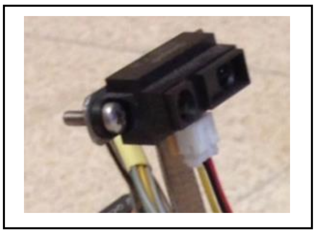

Figure 7. Sharp IR range

CONCLUSION

This study analyzes the effect of inquiry teaching method for mobile line following robot in Electrical and Electronics Engineering students as case study at Cyprus International University. Only 2 students are chosen as a group and the line follower robot problem is given to them. At the beginning, students searched the literature for line follower robot design and the related control algorithms and then they discussed their observations with the instructor.

A novel control algorithm is given to students at the beginning. However, after literature review, students couldn't find similar control algorithm and therefore they decided to implement known algorithms first. The experimental results showed that the known algorithms are not working for bi-colored paths. When the given algorithm is implemented, it is seen that it works perfectly without any modification. Since these students have enough experience about line follower robot the proposed algorithm implementation is done very quickly and easily.

Students have been attended to a well known robot competition organized by İstanbul Technical University. The speed of CIURunner was 0.4 m/s in ITURO2013. After that, the motor control parameters are increased. Thus, the performance of CIURunner is reached to 0.55 m/s. This was the first experience of the students in robot competitions. The students' performances show that the inquiry based teaching approach has significant effect on students' learning levels. This might be because of interactive learning and it followed with exact learning.

It can also be observed that the inquiry teaching method with project based learning be the most suitable teaching approach for courses such as Robotics. Furthermore, to see the effect of this approach in the education of Robotics course further research is required.

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