Fuzzy Logic Simulation as a Teaching-Learning Media for Artificial Intelligence Class

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Abstract:
Polytechnic as a vocational education institution has to keep updating its curriculum with innovation and the latest technology application in industry and domestic. Teaching learning process in the classroom also has to be based on technology application. The teaching-learning process will be more effective and interesting by involving the students to be more pro- active and creative. To engage the students more, the teacher needs a teaching-learning media, and one of these media is simulation software. The visualization of the simulation attracts students' interest and enhances students' creativity. This paper proposes the application of an open source and low-cost software simulation as a teaching-learning media to create an interactive and exciting robotics class. This study will show the design and application of fuzzy logic controller in a mobile firefighter robot, and simulate the design in SCILAB, an open source software, and in MobotSim, a low-cost software. This alternative of open source software can be as good as the high- end ones. This paper shows that the application of fuzzy logic controller can be fun and variant for students to enjoy the class. The contribution of this research is to show and encourage teachers and students to learn robotics and artificial intelligence in an interactive classroom using free software and also encourage them to search more alternative open source software.

Keywords: *fuzzy logic controller, mobile robot, open-source software, teaching-learning media*

1. Introduction

The polytechnic curriculum has to reflect the update innovation in the modern technology industry and social activity. Vocational education, unlike conventional education, is required to develop a curriculum that based on applied science, indicated with more laboratory and workshop than classroom time. Teaching has to focus on forming the knowledge, abilities, and competencies enabling the graduates to be successfully integrated into the modern socio-technical systems. Therefore, Teaching learning process in a classroom has to more based on technology application [1], [2], [3] [4].

The teaching-learning process will be more effective and exciting by involving the students to be more pro-active and creative. The interactive class should be two ways discussion by engaging the students more, facilitated by a teaching-learning media such as simulation software. It can visualize the content of textbook/lecture notes more than teachers' explanation. This visualization of the simulation attracts students' interest, and students can apply what they have learned from a textbook [5], [6], [7], [8].

There is some reliable software for simulation purpose, well designed and user-friendly with a certain price [9], [10]. However, not all universities or polytechnics in a developing or third world country can provide high price simulation software such as MATLAB for teachers and students. Teachers have to be more pro-active to search for low price or even open source software that has the ability close to the high-end software, as presented in [11].

Robotics related subjects have to be included in the Electrical Engineering Department to provide students with basic and latest applications in industry. Robotics learning is also known as educational robotics [12], [13], [14], [15]. The design and implementation are possible with simulation for subjects taught in the classroom. Assaf et al. 2012 [16] and Ĺopez-Rodŕiguez et al. 2016 [17] presented the robot kits for educational robotics, however, with simulation the students can focus more in learning and designing without having to deal with the complexity of the real system [18]. One of the robotics-related subjects is artificial intelligence (AI), and the basis of this subject is best learned by simulation. The difficulty and complexity of the teaching materials can grow each week, and students' involvement is very crucial to ensure the successfulness of the teaching-learning process. One of the most studied subject in artificial intelligence is the Fuzzy Logic Controller (FLC) [19]. Due to the broad application of FLC, it has to be inserted in the AI lesson plan [20], [21]. FLC has been widely applied in planning and control of robot since it can approximate any nonlinear function within any level of accuracy. FLC is very useful for modeling a complex system that is not easy to be modeled with exact mathematical equations, such as a mobile robot that suffers the non-holonomic constraints [22]-[31].

This paper proposed the application of low cost and open source software simulation as a teaching- learning media to create an interactive and interesting educational robotics. This paper shows that the low cost and open source software can be the substitute for high-end software such as MATLAB. The effectiveness of the proposed method is demonstrated by designing FLC for a mobile robot and simulating it with two softwares [32], [33]. The rules and robot scenario are kept simple to give room for students to develop and be creative with the controller design. The contribution of this research is to show and encourage teachers and students to learn robotics and artificial intelligence in an interactive classroom using free/low-cost software, and also encourage them to search more alternative open source software.

2. Research Method

2.1. Mobile Robot Modeling

Kinematics modeling is to design robot motion in the robot coordinates frame relative to the work coordinate frame [30] [31]. Fig. 1 shows the most applied a two-wheel differential driven mobile robot with the pose (position and orientation) given as

$$q = \begin{bmatrix} x \\ y \\ \phi \end{bmatrix} \tag{1}$$

where x and y are robot's position in x and y-axis, ϕ is the orientation of the robot, and X_W and Y_W are the world coordinates frame.

The pose given in (1) gives the translational and rotational velocities as following

$$\dot{q} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\phi} \end{bmatrix} \tag{2}$$

where $\dot{x}\cdot$ and $\dot{y}$ are the translational velocities in x and y-axis respectively, $\omega = \dot{\phi}$ is the rotational velocity, L is the half width of the robot, r is the wheels' radius, and $\dot{\theta}_R$ and $\dot{\theta}_L$ are right and left tire's velocities.

In order to get the value of tires orientation and velocity, the inverse kinematics of the robot is derived as follow

$$\begin{bmatrix} \dot{\theta}_R \\ \dot{\theta}_L \end{bmatrix} = f\left(\dot{x}, \dot{y}, \dot{\phi}\right) \tag{3}$$

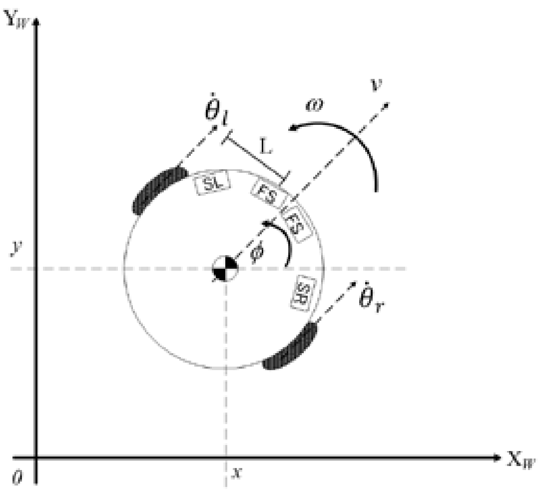


Fig. 1. Two-wheel differential driven mobile robot in its coordinate frame relative to world coordinate frame

$$\dot{\theta}_R = \frac{1}{2\pi r}\cdot v_R \qquad \text{and} \qquad \dot{\theta}_L = \frac{1}{2\pi r}\cdot v_L \tag{4}$$

where v_R and v_L are the translational velocities of robot's tires. The relation between robot's translational v and rotational ω velocities and both tires velocities are

$$v = r\frac{\dot{\theta}_R + \dot{\theta}_L}{2}, \qquad \text{and} \qquad \omega = \frac{r}{2L}\left(\dot{\theta}_R - \dot{\theta}_L\right) \tag{5}$$

The pose in (1) and velocities in (4) are given the non-holonomic constraint of this type of mobile robot in

$$v = \dot{x}\cos\theta + \dot{y}\sin\theta \tag{6}$$

The non-holonomic constraints means that the robot can only move in curvature motion and not in lateral sideward motion, therefore in lateral motion the velocity of the robot is

$$0 = \dot{y}\cos\theta - \dot{x}\sin\theta \tag{7}$$

Finally, the modeling of robot shown in Fig. 1 is given by

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{8}$$

The derivation of v and ω is necessary to show the relation between the modeling and rule base of FLC design in mobile robots, and in this study, v and ω is defined as the control inputs. Fig. 1 also shows the proximity sensors arrangement indicated by FS (the proximity sensor attached to the front side of the robot), LS (the proximity sensor attached to the left side of the robot), and RS (the proximity sensor attached the right side of the robot).

2.2. Fuzzy Logic Controller

Considerable research in navigating a mobile robot in an uncertain environment has been conducted. One of the developed controllers is soft computing, such as Fuzzy Logic Controller [21]- [29]. The improvement in computational method enables to design a controller based on designed robot's behavior without going through a specified complex model of the robot and the world. The mobile robot is designed to use perception derived from a natural language the way a human does. The fuzzy logic system represents a linguistic modeling that permits robot designer intuitively defining abstract behavior. This approach works well in sensor-based navigation control.

The fuzzy logic controller design is given in Fig. 2. Fuzzy inputs from sensors are fed to the fuzzy controller represented by the membership function. Once the inputs are fuzzified, the rules applied to determine a response to inputs. The main objective of this paper is to show the application of FLC simulation as the teaching-learning media. Therefore the application variations are required. Rules are set based on the inputs and inputted to the inference engine. Rules are set based on the behavior design of the robot and inputs from the applied sensor. FLC gives room for students to modify the rules based on the kind of robot they want to realize. The simulation can provide an interesting learning environment.

The result from the rule evaluation is translated into a crisp value in the defuzzification stage. FLC in this paper consists of fuzzification, fuzzy rule base, fuzzy interference engine, and defuzzification. The fuzzification proses measure the values from input variables (in this case data from sensors), creates a scale mapping to transfer the ranges of input variable into the corresponding the universes of discourse, and converts those inputs data into suitable linguistic values that given as fuzzy sets. The rule base is the database and linguistic control where the database provides necessary definitions which are used to define linguistic control rules and fuzzy data manipulation in an FLC, characterizes the control goal and setting the linguistic control rules. The defuzzification performs a scale mapping that converts the range of values of output variables into the corresponding scale of the universe and yields a non-fuzzy control action from an inferred fuzzy control action. Inference engine creates a fuzzy output by finding the firing level of each rule, the output of each rule, and the individual rules outputs to obtain the overall system output.

Fig. 2 shows that FLC ensures the robot to track the robot's desired position given by the reference inputs. The steps to get the desired position are

1) Obtain the position of the robot and the obstacles/target given by sensors
2) Fuzzify the result of these measurements
3) Set the rules based on step no 2
4) Set a priority value for each position
5) Repeat the algorithm for all the positions until reaching the target.

In this paper, FLC rules and the relationship between inputs and outputs are shown by SCILAB (Fig. 3a) [32] and the simulation complete with the environment shown by MobotSim (Fig. 3b) [33].

3. Result and Discussion

The scenario taken for this paper is a firefighter robot equipped with four proximity and temperature sensors for navigating to the target, a burning candle. Proximity sensors arrangement is shown in Fig. 1.

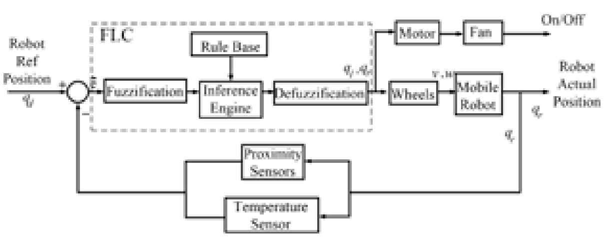
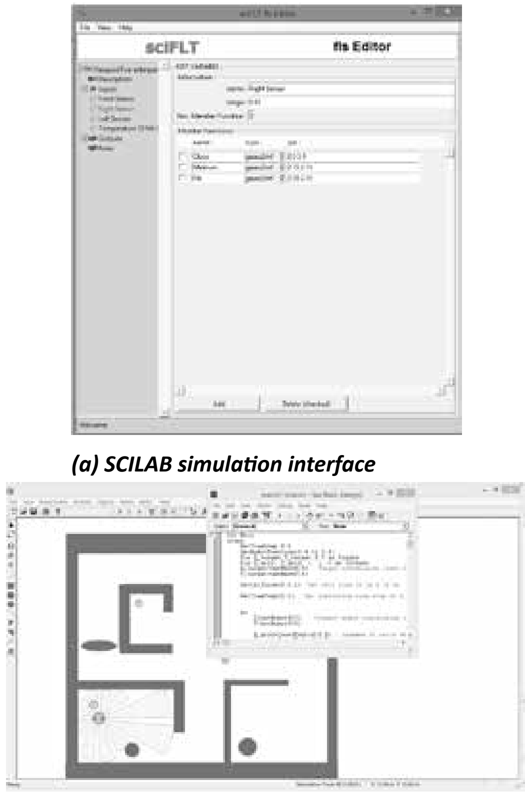


Fig. 2. Fuzzy logic controller application for a mobile robot equipped with sensors



(a) SCILAB simulation interface

(b) MobotSim simulation interface

Fig. 3. Fuzzy logic editor interface in SCILAB [32] and MobotSim [33]

Firefighter robot is popular among students due to the popularity of firefighter robot contest. A fan is attached to the robot and designed to be "on" when the robot detects a burning candle in a certain distance.

Table. 1 shows the rules when the temperature sensor detection is cold and table. 2 is the rules when the temperature sensor detects the burning candle, where FS is the proximity sensor attached to the front side of the robot, LS is the proximity sensor attached to the left side of the robot, RS is the proximity sensor attached to the right side of the robot, TS is temperature sensor, RM is robot motion, F is fan, C is close, M is medium, F is far, St is "stop", S is "straight motion", TR is "turn right", SL is "slightly turn left", GTW is "go to the wall", and SS is "straight slowly".

Fig. 4 shows the inputs membership function for firefighter robot and Fig. 5 shows robot's output. Fig. 6 shows the relationship between front sensors and the right sensor with robot navigation. The right sensor functions as a wall detection and uses input from the right sensor to follow the wall. The robot follows the wall within a safe designed distance. If the front sensor detects an obstacle, the robot will turn left and consider the obstacle like a wall.

The rules are applied in a MobotSim BASIC programming to show the 2D robot motion in its design environment shown Fig. 7. Robot moves from the start point, follows the wall and scans each rooms looking for the burning candle (target). If

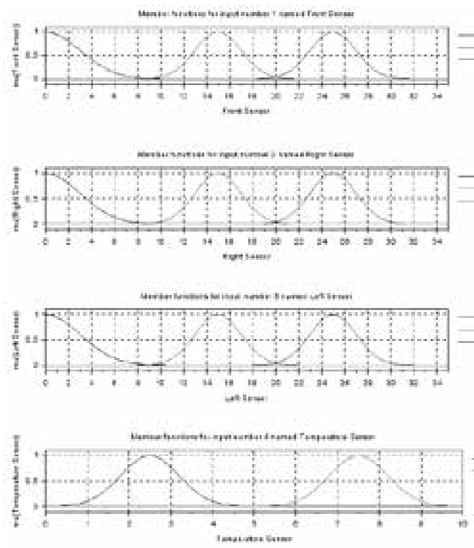


Fig. 4. Inputs membership function

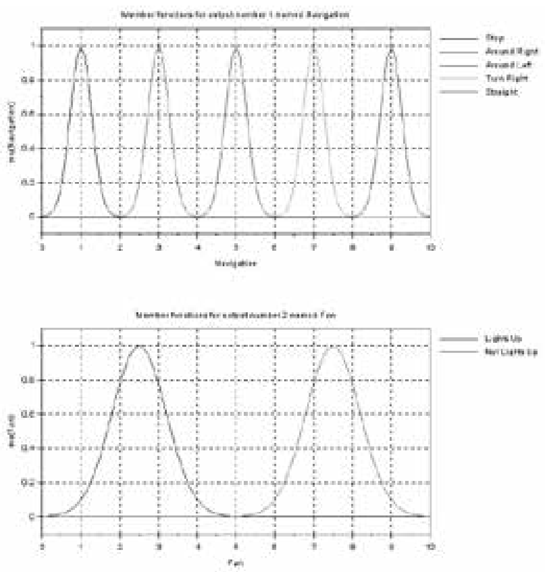


Fig. 5. Robot outputs

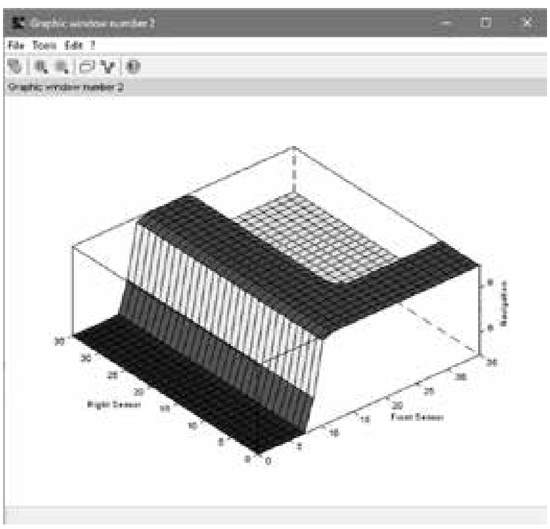


Fig. 6. The relationship among front and right sensors with robot navigation

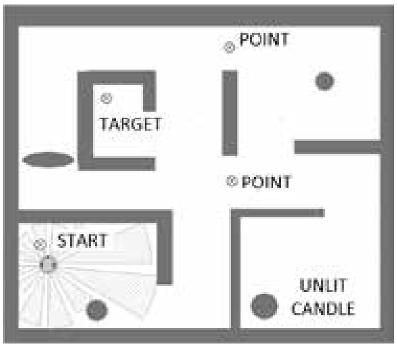
the robot finds the burning candle, it will stop at a safe distance, and the fan will be on to turn off the fire. As the temperature sensor does not detect the fire anymore (detection is cold), the robot returns to the starting point. Fig. 7a to 7d are the screenshots from the simulation in MobotSim. The green line is the robot's trajectory as the robot moves from the starting point to the target and returns to the starting point. "Point" in Fig. 7 is the checkpoint to show that the robot has scanned the room, and the green dot is the unlit candle. The environment and robot motion is designed identically to a firefighter robot contest environment. The simulation shows the

Tab. 1. Rules when temperature sensors detection is cold

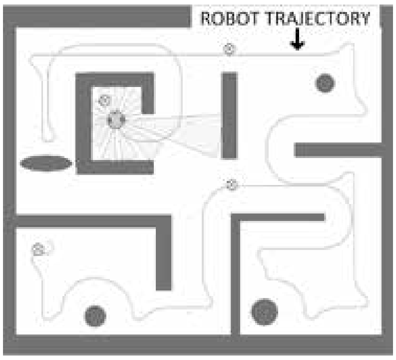
NO	FS	LS	RS	TS	RM	F
1	C	C	C	Cold	St	Off
2	C	C	M	Cold	S	Off
3	C	M	F	Cold	TR	Off
4	M	M	C	Cold	SL	Off
5	M	F	M	Cold	S	Off
6	M	F	F	Cold	GTW	Off
7	F	C	C	Cold	SS	Off
8	F	C	M	Cold	S	Off
9	F	M	F	Cold	GTW	Off
10	C	M	C	Cold	SL	Off
11	C	F	M	Cold	S	Off
12	C	F	F	Cold	GTW	Off
13	M	C	C	Cold	SS	Off
14	M	C	M	Cold	TR	Off
15	M	M	F	Cold	GTW	Off
16	F	M	C	Cold	SS	Off
17	F	F	M	Cold	S	Off
18	F	F	F	Cold	GTW	Off

Tab. 2. Rules when the temperature sensor detection is hot

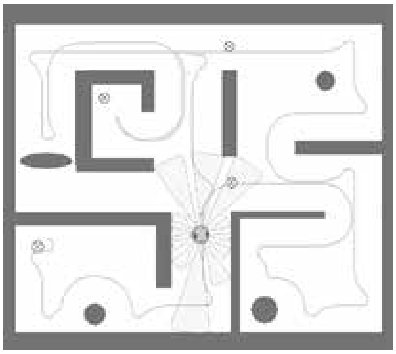
NO	FS	LS	RS	TS	RM	F
1	C	C	C	Hot	St	On
2	C	C	M	Hot	St	On
3	C	M	F	Hot	St	On
4	M	M	C	Hot	St	On
5	M	F	M	Hot	St	On
6	M	F	F	Hot	St	On
7	F	C	C	Hot	St	On
8	F	C	M	Hot	St	On
9	F	M	F	Hot	St	On
10	C	M	C	Hot	St	On
11	C	F	M	Hot	St	On
12	C	F	F	Hot	St	On
13	M	C	C	Hot	St	On
14	M	C	M	Hot	St	On
15	M	M	F	Hot	St	On
16	F	M	C	Hot	St	On
17	F	F	M	Hot	St	On
18	F	F	F	Hot	St	On



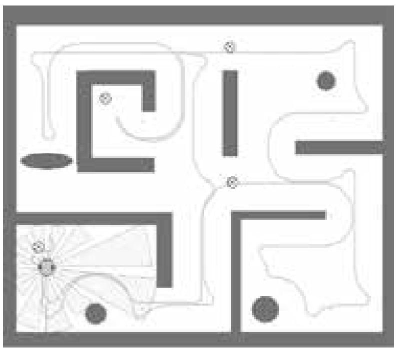
(a) Robot starts



(b) Robot reaches the target and stops for a moment



(c) Robot is on the way to the starting point

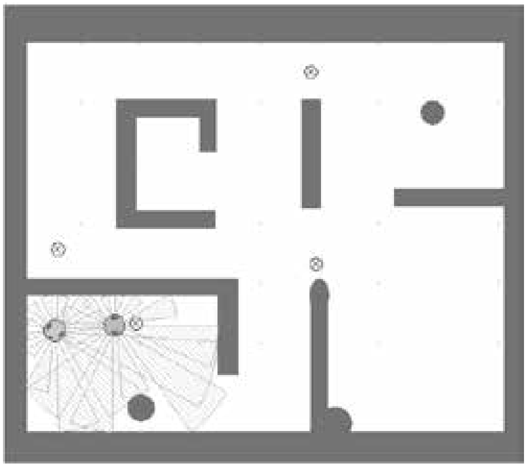


(d) Robot returns to the starting point

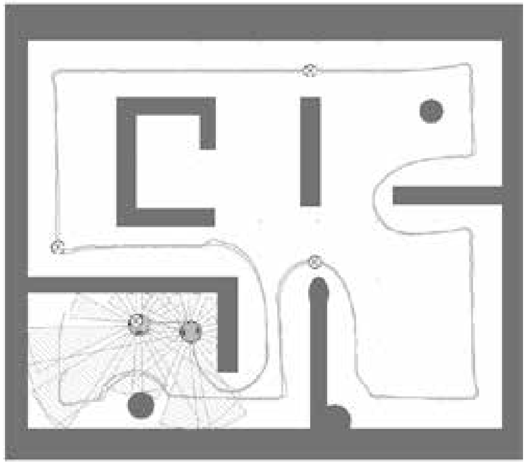
Fig. 7. Robot simulation in MobotSim

robot moves smoothly as designed, from one room to another until finally reaching the target and return to the starting point.

This proposed FLC designed can be extended to be leader-follower formation robots as shown in Fig. 8. The leader robot motion is the same with single robot motion in Fig. 7 and the follower robot



(a) Robots start



(b) Robots return to the starting point

Fig. 8. Leader-follower robots

front sensor is designed to detect the leader robot and keep a safe distance with the leader. Fig. 8 is to show the versatility of the proposed method that can be extended to any designs, therefore will enhance students' creativity and at the same time will increase their involvements in the teaching-learning process.

The leader-follower robots' environment in Fig. 8 is slightly different to show that the students can create any environments by setting the target(s), obstacles, and programming in BASIC. The results show that the proposed method allows the students to learn about fuzzy logic interestingly by drawing their attention and participating actively in the teaching-learning process in the classroom. This method had been applied to robotics class in Electrical Engineering Department of Politeknik Negeri Sriwijaya.

4. Conclusion

The interactive class involving students more in the teaching-learning process is essential in improving the academic atmosphere. More interested students mean better class outcomes. The interactive course can be achieved by creating project-based learning and encourage the students to develop projects. Simulation is the best option for learning robotics in a classroom since the students can focus more on designing the controllers without having to care about the complexity of the real system. However, not all the polytechnics and universities in some countries can afford the high-end software. The alternative of open source and low-cost software can be as good as the high-end ones. This paper has presented the feasibility of using SCILAB, an open source software, and MobotSim, a low-cost software, for designing and creating projects applying fuzzy logic controller. The firefighter robot contest scenario is designed and discussed. The proposed method for a single robot is extended to the leader-follower robot without really changing the FLC design. The result showed that the application of fuzzy logic controller could be fun and variant for students to enjoy the class. This method had been applied to robotics class in Electrical Engineering Department of Politeknik Negeri Sriwijaya.

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