The Fuzzy Control Applied to the Predefined Path Based on Lego-NXT System

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Abstract— **With a auxiliary wheel, the Lego-NXT mobile robot, is a small two-wheeled and a mobile platform, which is controlled by a ARM7 microcomputer. The robot could sense its surroundings with the ultrasonic sensor, distinguish the reflected light intensity with the light sensor and move it forward by two DC motors. Robot behaviour was determined by the program which was made by fuzzy control theory and loaded to the ARM7 microcomputer. In that way, it could be used as a general robotics fuzzy control theory experimental perform. In this paper, it's shown that the path following robot with light sensor is used under the robot to sense a black line drawn on a white surface and a fuzzy logic algorithm is used to move the robot to follow the line. The predefined path is having varied turns, the fuzzy reasoning monitor power between two DC motor to keep Lego-NXT mobile robot in the pre-defined path. The results are proved experimentally and fuzzy control theory for stability is verified by Matlab utility. Hardware details of the robot and the software implement of the fuzzy control algorithm are also given in the paper.**

Keywords: Fuzzy Control, robotics, Path Following, Lego-NXT

I. INTRODUCTION

Traditional methods to control any dynamic system require the use of some knowledge, or model, of the system to be controlled. An accurate model is crucial for the successful implementation of a control algorithm. Unfortunately, most systems in real life are nonlinear, highly complex, and too difficult or impossible to model accurately. Fuzzy logic, a mathematical system developed by Zadeh [1], helps to reduce the complexity of controlling nonlinear systems. Fuzzy systems employ a mode of approximate reasoning, which allows them to make decisions based on imprecise and incomplete information in a way similar to human being. A fuzzy offers the advantage of knowledge description by means of linguistic concepts without requiring the complexity and precision of mathematics models [2]. For quickly test and verification, Matlab utility provides a flexible simulate tools to model the relationship between input sensor and steel output.

The aim of this article has been to use a Lego-NXT embedded ARM7 microcomputer and then develop fuzzy control algorithms with Matlab for modeling quickly and implemented by NXC programming Language to control the movements of the robot to follow a track made of a black line drawn on a white surface.

II. LITERATURE REVIEW

A quick literature search reveals many papers on this topic and the contents of some of these papers are given very briefly in this section.

Olsen [3] describes the fuzzy control of an autonomous robot using the Motorola MC68HC12 microcontroller. This microcontroller has four built-in fuzzy logic instructions, allowing the development of low-level applications that can utilize the unique features of fuzzy logic. It is shown in the paper that the development of a fuzzy-logic-based robotic application is considerably simplified by using these specific instructions.

Hurley et al. [4] describe the use of fuzzy logic for controlling an educational mobile robot that can avoid obstacles. The robot called Rug-Warrior Pro was developed by the Massachusetts Institute of Technology for use in robotics courses, and was based on the Motorola MC68HC811E2 microcontroller with extended memory and real-time operating system. The objective was to teach students how to develop fuzzy-control-based robot control and obstacle avoidance algorithms in an unmapped and changing environment.

A microprocessor-based fuzzy logic controlled line following robot is described by Reuss and Lee [5]. The robot is based on the RCX Lego Mindstorms which incorporates an on-board Hitachi H8 microprocessor. Two light sensors are used under the robot to sense a white line drawn on a black surface and a fuzzy logic algorithm is used to move the robot to follow the line.

Another interesting paper on fuzzy logic and robot control is by Pawlikowski [6] where the development of a fuzzy logic speed and steering control system for an autonomous vehicle is described. Using an integrated vision system, the vehicle senses position relative to the angle of a line drawn on the ground, and processes that information through a fuzzy logic algorithm. The algorithm selects drive powers for two independent motors, thereby providing the ability to go forward, or turn left or right while following a path.

III. FUZZY LOGIC THEORY

In robotics design, it is often desirable to have a robot act more like a human being than a machine. Traditional logic is based on two values, one (true) and zero (false). This is inadequate for approximating the human decision making process. Fuzzy logic uses the entire interval between one and zero, and can therefore be used to closely mimic human reasoning [7]. The design process of a fuzzy logic system can generally be separated into three stages:

- Fuzzification
- Rule Base
- Defuzzification

In the fuzziciation stage fuzzy inputs are sent into the fuzzy controller. The inputs are fuzzified by applying with the membership function. The membership functions change the input values into degree values of membership for each function. Once the inputs are fuzzified, the rules are applied to determine a response to the inputs. In the defuzzicication stage, the results of the rule evaluation are translated into discrete outputs. This can be done in varies ways, using different kind of algorithm. A common and easy approach to defuzzicication is Center-of-Gravity (COG) method.

3.1 Fuzzy Controllers

This paper presents a sensor-based navigation method using fuzzy control, of which the purpose is to construct an expert knowledge for efficient and better piloting of the robot. Here, function is provided for tracing a pre-defined path by sensing the intensity of reflected light. For simplified the system, one light sensor is used. The light sensor is always mounted on the black line and white ground 50% each. In that way, the strength of intensity of reflected light is 45±2. According that, the fuzzy control can select a best reasoning for selecting driver power for two independent motors, thereby providing the ability to go forward, or turn left or right while following a path.

The input and output membership functions are defined and are related with sets of rules. After a fuzzy controller is chosen based on the information obtained from the light sensor, the fuzzy controller has a process, which consists of three stages: fuzzification, rule evaluation and defuzzification. The outputs of fuzzy controllers control the power of two wheels of the mobile robot. fig. 1 shows fuzzy inference system with one input and two outputs.

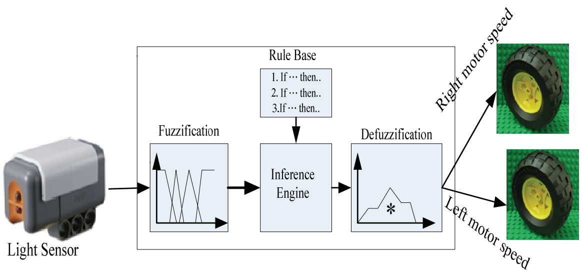

Fig. 1 Fuzzy inference system

3.2 Fuzzification

The membership function of input intensity of light reflected is designed to fuzzify the data deviated the central of dark line and white ground. Membership function shown in fig.2 is used to fuzzify the vale of variable. The membership function considered here is a trapezoid type. The input intensity is defined with linguistic variable Dark and Bright relative right side wheel.

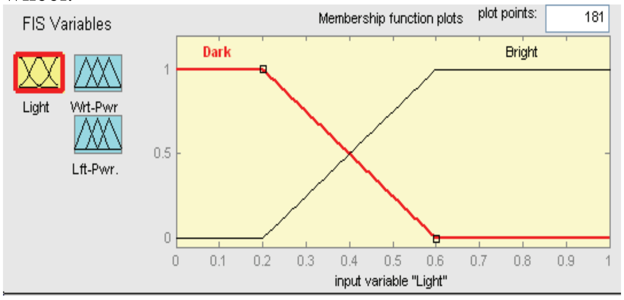

Fig. 2 Membership function for input intensity of light reflected

Power control: fig. 3 and fig. 4 show the membership function for the desired output of right side wheel and left side wheel. The membership function is still with a trapezoid type.

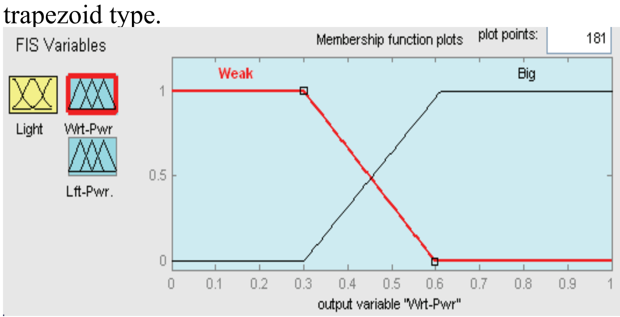

Fig. 3 Membership function of right-side wheel

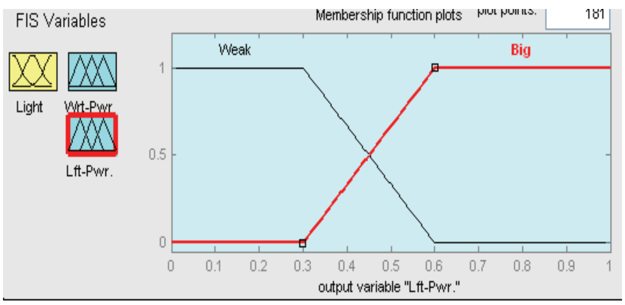

Fig. 4 Membership function of left-side wheel

3.3 Rule Base

Fuzzy controller rules for power control: fuzzy controller has total 8 rules for navigation desired power to follow the pre-defined path. To realize these navigation skills, following rules are defined.

Rule 1 >> If (Light is Dark) then (Wrt-Pwr is Weak) and (Lft-Pwr is Weak)

Rule 2 >> If (Light is Dark) then (Wrt-Pwr is Weak) and (Lft-Pwr is Big)

Rule 3 >> If (Light is Dark) then (Wrt-Pwr is Big) and (Lft-Pwr is Weak)

Rule 4 >> If (Light is Dark) then (Wrt-Pwr is Big) and (Lft-Pwr is Big)

Rule 5 >> If (Light is Bright) then (Wrt-Pwr is Weak) and (Lft-Pwr is Weak)

Rule 6 >> If (Light is Bright) then (Wrt-Pwr is Weak) and (Lft-Pwr is Big)

Rule 7 >> If (Light is Bright) then (Wrt-Pwr is Big) and

(Lft-Pwr is Weak)
Rule 8 >> If (Light is Bright) then (Wrt-Pwr is Big) and (Lft-Pwr is Big)
In above rules, only rule no. 2 and 7 are the desired power, the others should be conflicted or can be absorbed by other rules, like as rule 1, that physical meaning is , the light sensor is deviated to right-wheel (Wrt-Pwr) and left-wheel (Lft-Pwr) simultaneously. After examined those 8 rules, only 2 rules, rule 2 and 7, are reserved finally as following:
Rule 2 >> If (Light is Dark) then (Wrt-Pwr is Weak) and (Lft-Pwr is Big)
Rule 7 >> If (Light is Bright) then (Wrt-Pwr is Big) and (Lft-Pwr is Weak)

Obviously, a straight line of membership function is formed by those 2 rules.

3.4 Defuzzification

If the values considered in the fuzzy sets are in terms of degree variation then in the final output the fuzzy values should be converted into a crisp value by using any defuzzification method. The most easy and commonly used defuzzification method is Center of Gravity (COG) can be used. The COG defuzzification method can be expressed as following:

$$y_{coa} = \frac{\sum_{j=1}^{n} \mu_c(y_j).y_j}{\sum_{j=1}^{n} \mu_c(y_j)} \quad (1)$$

Where, $\mu_c(y_j)$ is the grade of j_{th} output of membership function, y_j is the output labeled for the value contributed by the j_{th} membership function and n is the number of rules.

IV. The Experimental Lego-NXT Mobile Robot

The Lego-NXT Robot is mounted with two independent left and right driving wheels driven by two DC motors, respectively. It does not have any steering mechanism, but can change its navigation direction by change the power of the driving wheels independently. If the power of the right wheel is greater than the power of left wheel, the robot will turn left vice versa. Using ARM7 microcomputer with the light sensor controls the two motors of mobile robot. Six AAA 1.5V batteries are used to provide power to the motors and the control part respectively to reduce the switching noise induced by the motors. The robot uses a light sensor at the middle of the front robot to keep track of black strip on white background. The sensor is tuned to corresponding black and white colors to keep track of predefined path. The rules for the robot to keep track in form of program, ARM7 microcomputer decides the next moving according to the algorithm. The experimental Lego-NXT mobile robot is shown on fig. 5. The predefined path, as illustration in fig. 6, is total 320cm with a elliptical shape.

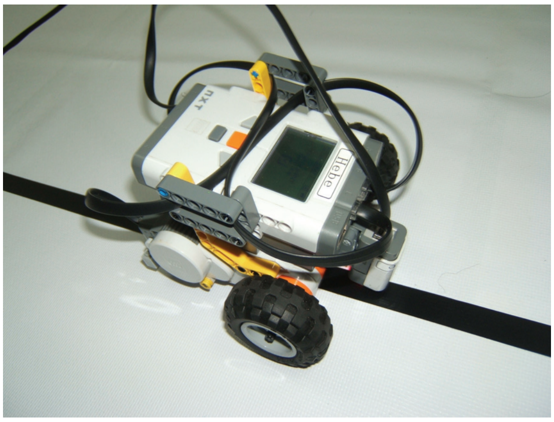

Fig. 5 The experimental Lego-NXT mobile robot

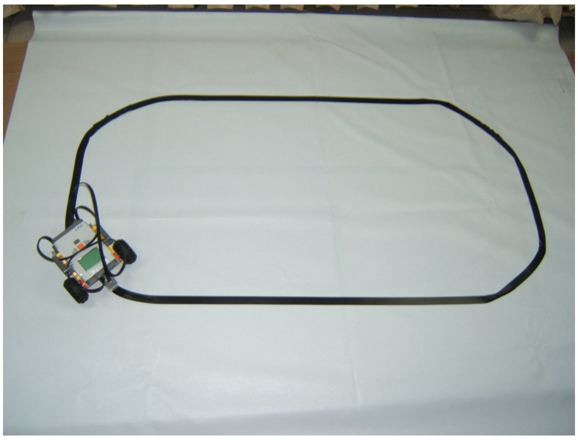

Fig. 6 The predefined path for experimental course

The features of Lego-NXT embedded ARM7 microcomputer, which used in this paper to develop fuzzy control algorithms, is as following：

- 64K RAM, 256K Flash
- 32-bit ARM7 microcontroller
- 100 x 64 pixel LCD graphical display
- Light sensor：Reports light reflected intensity as percentage
- Two DC motors
- six AAA batteries

A re-chargeable battery pack is recommended for experimental applications where it may be required to experiment with the robot for long durations.

V. Results

1. As inference with Matlab utility, the fig. 7 is shown for rules viewer of the membership function. We can get the power output of right-wheel and left-wheel, as shown upper words of fig. 7, while we drag the vertical red-line of light membership function with mouse in Matlab utility. And the vertical red-line is the power output of defuzzification with COA method, as shown with 0.723 and 0.231.
2. Because we can absorb and simplify rules into 2 rules, the surface viewer with the graph of desired power and the light reflected intensity appear a line curve which are shown in Fig.6 and Fig. 7

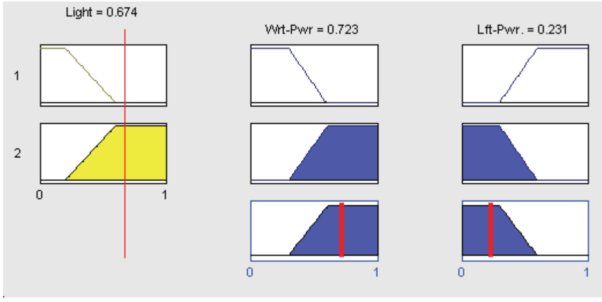

Fig. 7 Rules viewer for the membership function

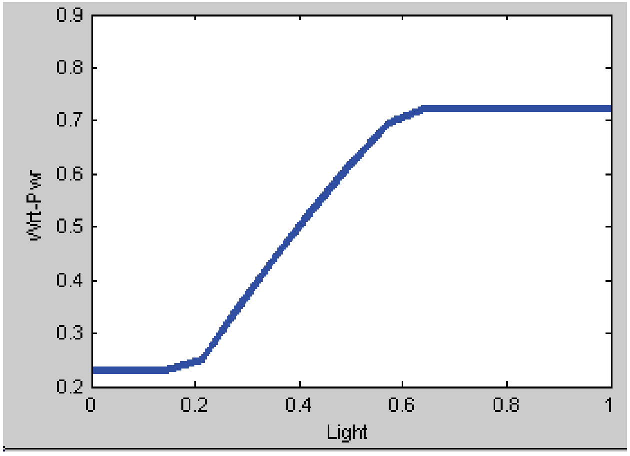

Fig. 6 Graph of Light Vs Right-Power

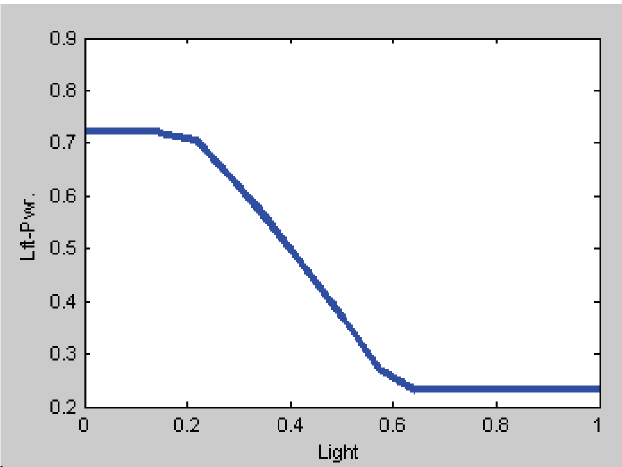

Fig. 7 Graph of Light Vs Left-Power

3. Difference with and without fuzzy control theory:

3.1 Without fuzzy control theory:

It spends 29 second to navigate elliptical round course with NXC language and swing and moving forward all the time.

3.2 With fuzzy control theory:

Because fuzzy rules can be simplified with a line curve, so we can plot the figure of power vs. light intensity, which is shown in fig. 8.

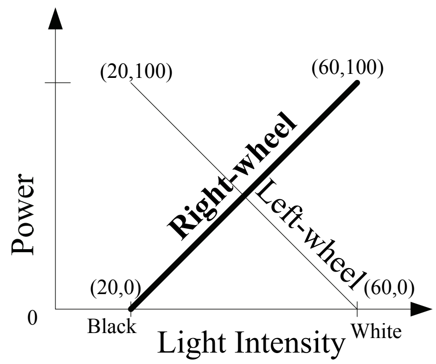

Fig. 8 Light intensity vs. Power

The right-wheel can be described as $y = 2.5(x - 20)$, and the left-wheel can be described as $y = -2.5(60 - x)$, where x is sensor input, light intensity, and y is the power output of the right and left motors. It spend 27 seconds to navigate elliptical round course with NXT-G language and smoothly moving forward all the time.

VI. Conclusion

From the result section, the mobile robot controlled by fuzzy control is more stable than without fuzzy control, which can be evidenced by Matlab utility and constructed by Lego-NXT. And only 2 second can be saved with fuzzy control is because NXT-G is high level language. If using NXC language, more time saving can be obtained. An autonomous Lego-NXT robot equipped with light sensor which are tuned to black and white color in order to trace the predefined path. Fuzzy reasoning is adapted to the navigation control of the mobile robot and it is tested on real platform, the experimental result shows that the developed robot could navigate along the strips with different power.

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