AN EMBEDDED FUZZY TYPE-2 CONTROLLER BASE SENSOR BEHAVIOR FOR MOBILE ROBOT

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ABSTRACT
This paper presents a type-2 fuzzy logic system can be applied to a mobile robot which is a project associates with using eight ultrasonic sensors as distance sensors. The inputs are obtained from ultrasonic sensors mounted. These inputs are sent to a microchip PIC 16F84 microcontroller onboard the robot, which analyses the data and provides the necessary control signal. The behavior based control for mobile robot was designed, which consist of three task obstacle avoidance, wall following, and emergency condition. The result obtained demonstrate the efficiency of type-2 fuzzy logic control system. From the experimental result show the better performances than those using on-off and type-1 fuzzy logic controls.

Keyword:
Embedded Controller, Fuzzy type-2, Mobile Robot, Sensor Behavior

1. INTRODUCTION
In many robotic applications, such as autonomous navigation in unstructured environments, it is difficult if not impossible to obtain a precise mathematical model of the robot’s interaction with its environment. Even if the dynamics of the robot itself can be described analytically, the environment and its interaction with the robot through sensors and actuators are difficult to capture in a mathematical model. The lack of precise and complete knowledge about the environment limits the applicability of conventional control system design to the domain of autonomous robotics. What is needed are intelligent control and decision making systems with the ability to reason under uncertainty and to learn from experience.

Fuzzy logic controller for a mobile robot navigating faces many sources of constrain or uncertainty imposed by the real world that make it a practical impossibility which are follows [2]:

- Resource limitation, such as time and hardware
- Sometimes incorrect or incomplete data from sensors
- The real world is dynamic and non-deterministic

All of these uncertainties translate into uncertainties about fuzzy set membership function [12].

The Application of fuzzy logic to robot navigation has motivated considerable research in this area in recent years. Behavior arbitration scheme introduced by Saffiotti et al. [1] uses fuzzy logic allows one behavior at time to be active. There are various strategies developed for behavior integration, some of them are, e.g., [7], based on brooks sub-assumption architecture [8] using a switching type of behavior arbitration. This method employs a priority scheme wherein the recommendation of only one behavior with the highest is selected, while the other behaviors with lower priorities are ignored. Another technique [9] focuses on combining the input of each behavior using predetermined weighting factors. Other strategies have employed fusion methodologies in which each behavior is allowed to provide the final output based on the situational context [1], [10] and [11]. Tunstel et al. [10] focus on adaptive hierarchies of multiple fuzzy behaviors are combined using the concept of degree of applicability.

The behavior fusion method employed in our research is motivated by the approaches used Saffiotti [11] and Tunstel et al. [10]. The differences in the present method of fuzzy type-2 behaviors process. The purpose of this paper present a new direction to develop the control problem for basic mobile robot behaviors, based on a type-2 fuzzy logic system. The motion of mobile robot to be taken an each movement is defined by a set of type-2 fuzzy rules based up on the obstacle position, distance between robot and wall and angle relative to the obstacle and also the speed of the motor. The method used in the construction of algorithms representing the basic fuzzy type-2 behaviors of mobile robot is described in the next following.
2. INTERVAL TYPE-2 FUZZY LOGIC SYSTEM

The structure of type-2 fuzzy system, which includes fuzzifier, rule base, inference engine and output processing, is very similar to the structure of type-1 fuzzy system. The difference between the structures of the type-1 fuzzy system and type-2 fuzzy system is only the output processing. When the operators define the type-1 fuzzy sets, the experience and knowledge of human experts are needed to decide both the membership functions and the rules based on the available linguistic or numeric information. As defining the type-2 fuzzy set, the expert knowledge is always represented by linguistic terms and limited uncertainty, leading to the uncertain antecedent part and/or consequent part of the fuzzy rules [12]. The interval type-2 FLC depicted in Fig. 1, uses interval type-2 fuzzy sets such as shown in Fig. 2 to represent the inputs and/or outputs of the FLC. In the interval type-2 fuzzy sets all the third dimension values are equal to one [12]. The use of interval type-2 FLC helps to simplify the computation [4] (as opposed to the general type-2 FLC) which facilitates the design of a robot FLC that operates in real time [2].

As defining the type-2 fuzzy set, the expert knowledge is always represented by linguistic terms and limited uncertainty, leading to the uncertain antecedent part and/or consequent part of the fuzzy rules. Assume that there are \( M \) rules in a type-2 fuzzy rule base, each of which has the following form [3]:

\[
R^i : \text{If } x_i \text{ is } F^i_1, \text{ and } ... \text{ and } x_n \text{ is } F^i_n, \text{ then } y \text{ is } [w^i_l, w^i_r], \quad (1)
\]

Where \( x_j, j=1,2,...,n \) and \( y \) are the input and output variables of the type-2 fuzzy system, the is \( F^i_1 \) the type-2 fuzzy sets of antecedent part, and \( [w^i_l, w^i_r] \) is the weighting interval set in the consequent part.

The inference engine combines rules and provides a mapping from input type-2 fuzzy sets to output type-2 fuzzy sets [3]. The inference engine computes the degree of firing of each rule by using the meet operation [4],[3], between the antecedent membership grades of each rule.

The operation of type-reduction is to give a type-1 set from a type-2 set. We will show the strategy as follows:

Similar to type-1 fuzzy system, the firing strength can be obtained by the following inference process:

\[
F^i \equiv \prod_{x \in X} \left( \prod_{k=1}^n \mu_{F^i_k}(x_k) \right) \quad (2)
\]

where \( \prod \) is the meet operation and \( \biguplus \) is the join operation [4]. We can derive the following result by computing (2)

\[
F^i = [\overline{f^i_j} \overline{f^i_j}] \quad (3)
\]

where

\[
\overline{f^i_j} = \mu_{\overline{F^i_j}}(x_j)^* * \mu_{\overline{F^i_j}}(x_n)
\]

and

\[
\overline{f^i_j} = \overline{\mu_{\overline{F^i_j}}}(x_j)^* * \overline{\mu_{\overline{F^i_j}}}(x_n) \quad (4)
\]

in which \( \mu_{\overline{F^i_j}}(x_j) \) and \( \overline{\mu_{\overline{F^i_j}}}(x_j) \) denote the grade of lower membership function and upper membership function of \( x \) in the type-2 fuzzy set \( F^i_j \), respectively. In this paper, the center-of-set type-reduction method [6] is used to simplify the notation. Therefore, the output can be expressed as

\[
y^\text{cos}(x) = [y_j, y_r] = \int \int \int \int \int \int \int \int \int \int [f^i_j w^i_l] \frac{\sum_{i=1}^M f^i_j w^i_l}{\sum_{i=1}^M f^i_j} \quad (5)
\]

where \( y^\text{cos}(x) \) is also an interval type-1 set determined by left and right end points \( (y_j, y_r) \), which can be derived from consequent centroid set \([w^i_l, w^i_r]\) and firing strength \( f^i \in F^i = [\overline{f^i_j} \overline{f^i_j}] \).

The interval set \([w^i_l, w^i_r](i=1,...,M)\) should be computed or set first before the computation of \( y^\text{cos}(x) \). For any value \( y \in y^\text{cos}, y \) can be expressed as

\[
y = \frac{\sum_{i=1}^M f^i_j w^i_l}{\sum_{i=1}^M f^i_j} \quad (6)
\]

where \( y \) is a monotonic increasing function with respect to \( w^i_l \). Also, in (5) is the minimum associated with \( w^i_l \), and \( y_r \) in (5) is the maximum associated only with \( w^i_r \). Note that \( y_j \) and \( y_r \) depend only on mixture of \( f^i_j \) or \( \overline{f^i_j} \) values.

Hence, left-most point \( y_j \) and right-most point \( y_r \) can be expressed as [6],

\[
y_j = \frac{\sum_{i=1}^M f^i_j w^i_l}{\sum_{i=1}^M f^i_j} \quad (7)
\]
and
\[ y_r = \frac{\sum_{i=1}^{M} f_i W_i}{\sum_{i=3}^{M} f_i} \]  \hspace{1cm} (8)

The defuzzified crisp output from an interval type-2 fuzzy system is the average of \( y_i \) and \( y_r \) \[6\], i.e.,
\[ y(x) = \frac{y_i + y_r}{2} \]  \hspace{1cm} (9)

The detail of type-2 fuzzy logic system can be found in [3],[4].

3. DESIGN OF THE MOBILE ROBOT
3.1. Hardware Model Description

The robot built is shown in Fig. 3 below. Its has a cylindrical shape, measuring 17 cm in diameter, and 11 cm height. This robot has two wheels and one free wheel located in the both side and the back of robot respectively. The two parallel wheels are driven by DC servo motors. These are run using PWM signals generated from the PIC16F84 microcontroller.

There are eight ultrasonic sensor located at the front, left and right side of the robot. The sensors used on the robot are SRF04 ultrasonic range finder. The transmitter works by transmitting a pulse of sound outside the range of human hearing at 40 KHz. This pulse travels at the speed of sound away from the ranger in a cone shape and the sound reflects back to the ranger from any object in the path of sonic wave. If received back at the ranger, the ranger reports this echo to the microcontroller and the microcontroller can then compute the distance to the object based on the elapsed time.

Due to the hardware limitations it is not possible to achieve good robot control results by doing the fuzzy calculations on board the autonomous robot, as the system clock is only 4 MHz. This results in about 0.4 seconds to complete the whole process of fuzzification and defuzzification, and thus the response of the system in real time is too slow to allow the robot to attain a steady state. Thus we have used instead for microcontroller AT89x51 for fuzzy logic control, and also eight PIC16F84 chips are used for process signal detection from ultrasonic sensors. One is exclusively used to generate the PWM signals to run the two servo motors. Microcontroller is connected to the sensors for calculates the present distance and sends the necessary control signals to the microcontroller connected to the servo motors. Figure 3 shows a block diagram of the hardware setup.

![Fig 1. . Structure of the type-2 FLC](image)

![Fig 2. An interval type-2 fuzzy set.](image)

![Fig 3. Block Diagram of hardware used](image)
3.2. Fuzzy Sensor based Behavior

The robot behaviors tested by eight input ultrasonic sensor, seven sensors for measuring distance and one sensor for emergency condition. Sensor behavior was divided into four behaviors namely obstacle avoidance, left wall following, right wall following, and emergency behavior. Fig. 4, is shown sequence of measured range values to the obstacle and follow the corridor. The sensors position in all array are fixed: one on back side, and seven facing outwards at 30-degree intervals starting from 1 -7. These sensors report the distance between the robot and the closest obstacle.

![Fig. 4 Position sensors of the mobile robot](image)

S1,S2,S3 = sensors for obstacle behavior
S4, S5 = sensors for left wall following behavior
S6, S7 = sensors for right wall following behavior
S8 = back sensor for emergency behavior

3.3. Fuzzy type-2 Control Design

There are eight ultrasonic sensors on the front, front left, front right, left side, right side and back side of the robot. The ultrasonic distance data must be adjusted and implemented. The robot has three inputs for obstacle avoidance, two input for left wall following, two input for right wall following, and condition emergency for turn back and output to control the robot. Each obstacle distance is represented by three linguistic input fuzzy set far, medium, near, and linguistic for corridor distance is represented by near and far. Output fuzzy set is represented by speed of the robot with linguistic are slow, medium, fast. The motor speeds use to control steering the wheels moving turn left, turn right, straight forward by the type-1 fuzzy sets of the consequent part with linguistic front left, front, front right.

![Fig. 5. Input membership function for wall following Behavior](image)

The meaning of these linguistic values of inputs controlling is defined by membership function as shown in fig. 5 from ultrasonic sensor for wall following behavior.

In our experiment, the first we will use four type-2 behaviors. For the obstacle avoidance type-2, behavior using three forward sensors and representing each sensors by only two type-1 fuzzy set will lead to a rule base of 27 rules, while for left and right wall following behavior using two left side sensor and representing 2 x 4 rules = 8 rules, thus the total number of rules required will be 35 rules for three behaviors. If we presented each input by only three fuzzy set then for a single rule base we need to determine 2187 rule, which is very difficult to design in the embedded fuzzy controller. Also this huge rule base translate directly to slower controller response.

![Fig. 6a. Output membership function for speed motor](image)

![Fig. 6b. Output Membership Function for steering angle](image)
In interval type-2 membership function, the footprint of uncertainty is obtained by specifying the bounding upper and lower type-1 membership function [4]. We have determined the lower and upper type-1 membership functions for the type-2 fuzzy set near and far by finding the lowest and highest type-1 membership functions that the robot needed to follow the wall at the desired distance in different environmental and robot conditions as shown in fig. 5. For wall following behaviors will have two outputs which are wheel velocity and steering angle, each output will be presented by three interval type-2 fuzzy set which are slow, medium, fast and front left, front, front right, as shown in fig. 6a and fig 6b.

4. EXPERIMENTAL RESULT

The behavioral architecture in this paper is based on fuzzy control. The behavior-based fuzzy control consists of several behaviors. Each behavior represents a concern in mobile robot control and relates ultrasonic sensor data, robot status data and goal information to control robot. A simple architecture is shown in Figure 7.

Based on the track that made on figure 8, mobile robot pass the track without obstacle with track distance is about 10 m, from figure can be concluded that to race 10 m distance, with based fuzzy controller needed time is about 62,35 second base fuzzy type-2 controller, 63,49 second base fuzzy type-1 controller and 85,68 second based on-off.

<table>
<thead>
<tr>
<th>distance (m)</th>
<th>On-off type-1 fuzzy logic</th>
<th>type-2 fuzzy logic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4,17</td>
<td>3,33</td>
</tr>
<tr>
<td>2</td>
<td>11,32</td>
<td>9,56</td>
</tr>
<tr>
<td>3</td>
<td>20,24</td>
<td>17,36</td>
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<tr>
<td>4</td>
<td>27,73</td>
<td>23,96</td>
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<tr>
<td>5</td>
<td>35,41</td>
<td>31,82</td>
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<td>45,12</td>
<td>38,08</td>
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<td>9</td>
<td>78,49</td>
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<tr>
<td>10</td>
<td>85,68</td>
<td>63,49</td>
</tr>
</tbody>
</table>

4.1. Corridor Following Behavior

The corridor following behaviors is used to control a distance to the wall of corridor. Four ultrasonic sensors are located at the front of the center, 30 degree of the front left side and 30 degree of the front right side of the mobile robot are used for the corridor following. The mobile robot can follow the wall on the left side or the right side as the corridor following is assigned. The distance between robot and wall about 23 cm. The mobile robot moves forward follow the corridor.

4.2. Obstacle Avoidance Behavior

The strategy for obstacle is to measure the obstacle-robot distance input to the type-2 fuzzy logic controller, which consist eight ultrasonic sensors. The information from sensor is fed to the controlled fuzzy rules. So we have identified and implemented to the following obstacle avoidance behavior is follows:

1. The robot turn right, if the obstacle is located on the front left side
2. The robot turn left, if the obstacle is located on the front right side
3. The robot forward, if the obstacle is not located on the front side or there is not obstacle anywhere

4.3. Emergency Condition

All data from sensors are used in this step. An emergency distance needs to be defined for emergency behavior, sensors from the front-left, front right, front, left side, right side for different emergency distances. All sensor data in front must add 5 cm for offset distance. From our experiments, it was shown that the closest distance should be greater than 10 cm after offset.

Therefore the results of emergency behavior are shown as follows:

- CHECK the obstacle from the front-left, front right, front, left side, right side
- STOP moving if obstacle are closer than the safety distance (10 cm) and turn back 180 degree

The behaviors will follow this process until all sensor data show the distance is greater than 10 cm.

5. CONCLUSIONS AND FUTURE WORK

In this paper a fuzzy logic controller type-2 has been used successfully in control system for robot avoidance and wall following. Each behavior work correctly. The mobile robot can avoid all obstacles that are detected by ultrasonic sensors. Furthermore, the mobile robot can move to the finish point or move to follow the wall of corridor by using corridor following behavior. Using type-2 fuzzy logic controller can control the distance between the robot and the wall of corridor. In some situation the mobile robot can be solved such as the corner of corridor problem. Then the sensors of robot detect the wall of the corner, then the mobile robot to avoid collision with the wall by turn back about 180 degree from the wall of corridor. This means that the wall following behavior is working. The major enhancement of the system would be to use a better, faster microcontroller so that the fuzzy calculation could be done precise. Also it would be possible to add a few behaviors. Finally, the membership function could be changed more parameter linguistic to have a more smooth control.

6. REFERENCES


