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Fuzzy Mamdani Controller Applied to Autonomous Navigation in Unknown Environment Variant in Time

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Abstract: This work deals with autonomous vehicular control in an unknown environment, using a miniature car, composed of a MEGA Arduino, a servo motor and a stepper motor, also having a body that includes the wheels and the other components. It was intended to obtain and compare three controllers, two of the fuzzy type Mamdani and one of the on/off type, both developed using the Arduino® platform. The results obtained demonstrate the efficacy of the fuzzy controllers in relation to the on / off, especially with respect to the stability and smoothness of the vehicle, and also show that the Mamdani with symmetrically adjusted pertinence functions performed the course more accurately than the others.

Key words: fuzzy mamdani, autonomous vehicle, intelligent control

1. Introduction

A stand-alone vehicle is characterized by being able to travel a certain route in the absence of a driver or human control action [3]. The autonomous vehicle locomotion process fits the scope of mobile robotics problems, a topic widely discussed in papers and articles in recent years [8]. Thus, several technologies arise to provide autonomy in the locomotion of vehicles, and computational intelligence techniques are notable tools for the development of mobile robotics, since they present to the system the adaptive capacity for unknown environments, besides being able to treat linearity and temporal changes in the model [4].

Among the computational intelligence techniques for the control of dynamic systems, we have fuzzy logic or nebulous logic, a considerable tool capable of mapping logical values (pertinences) in different levels, unlike binary logic [6]. In this way, fuzzy logic works with various input conditions, merging all of them with "weights" for each one and then discovering an output by some mathematical method, usually centroid. The good of this form of control is that it does not have any very abrupt variation as is possible in other control cases [2, 6].

One of the models of use of the Fuzzy Logic, known as Fuzzy Mamdani (1974), establishes a method of inference that has fuzzy relations through propositions formed by antecedents, mathematical and consequent logical operators. In this way, the fuzzy rules are described as shown in (1) [2].

If <antecedent> <operator> <antecedent>…,
So <consequent> (1)

According to the intensity of the rules that are activated during the inference process, after the fuzzyfication stage, regions are formed that map the output values that will be obtained after the defuzzification process [5]. The rule base of the Mamdani methodology uses max-min inference composition. Thus, the fuzzy relation **M** is the fuzzy subset of **X** × **U** whose membership function is given by:

$$\emptyset_{M(x,u)} = \max_{1\le i\le r} \emptyset_{Ri}(x,u) = \max_{1\le i\le r} \emptyset_{A_j}(x) \wedge \emptyset_{B_j}(u) \quad (2)$$

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where r is the number of rules that make up the rule base, and A_j and B_j are the fuzzy subsets of rule j [7].

Thus, the objective of this work is to use the fuzzy controller of the Mamdani type in order to provide autonomous navigation to a small vehicle, implemented in an embedded system, in an unknown environment subject to variations over time.

2. Material and Methods

For the implementation of the Mamdani fuzzy controller, an Arduino Mega 2560 board was used, using the eFLL (Embedded Fuzzy Logic Library) [1], implemented in C++ language, easily allowing the creation of functions of pertinence, antecedents, consequent and fuzzy rules, although it only shows good performance to a limited set of rules, has a restriction for the creation of pertinence functions accepting only triangular and trapezoidal functions and presents only two fuzzification operators (MAX-MIN) as well as a single defuzzification method (area center).

Two ultrasonic sensors (HC-SR04) were used in the front of the vehicle, with an angle of 30º in relation to the shock (Fig. 1). The distances read by the ultrasonic sensors were used as inputs of the fuzzy controller that had as outputs the angular values of the front wheels and the speed of the rear wheels applied to the micro-motor (Sg-90) and the step motor (28BYJ-48) respectively.

A course was constructed with 33 cm spaced styrofoam walls, having a total length of 280 cm (Fig. 2). Three run tests were performed using an On/Off

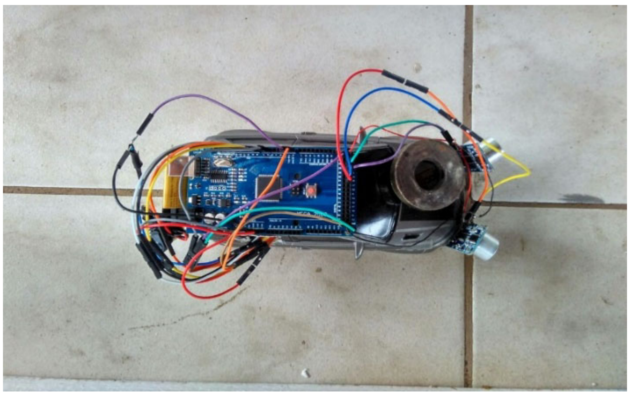

Fig. 1 Vehicle used in the project.

Fig. 2 Test track.

controller and two Mamdani fuzzy controllers by varying the pertinence functions used at the front wheel angled output. The driving times of each driver were collected and, finally, their performances were evaluated for the level of oscillation of the front wheels and distance of the vehicle to the center of the lane.

3. Results and Discussion

To prove the effectiveness of the proposed methodology, the functions of pertinence for the inputs and outputs (Fig. 3).

The pertinence functions were based on expert knowledge and were distributed prioritizing the extremes. Identical functions were used for both sensors. For the output velocity of both fuzzy controllers the characteristics were maintained, changing only the FP relative to the exit of the steering wheel angle. These changes were made in order to prioritize the extremes even further, since the vehicle has a low maximum angulation of the front wheels (around 26°).

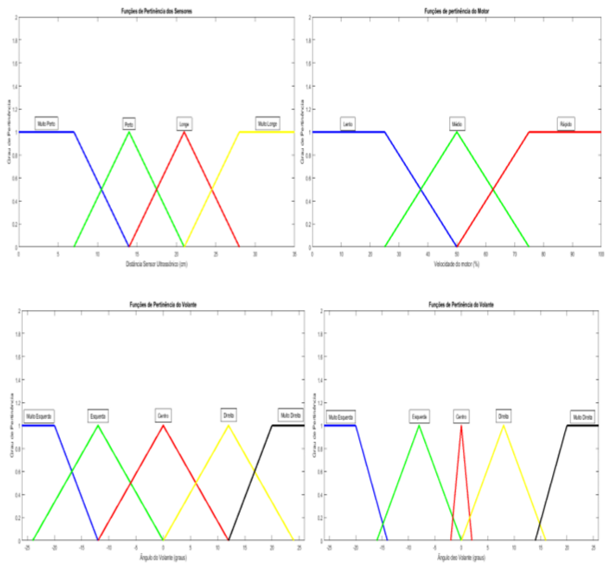

Fig. 3 Pertinence functions.

For the fuzzy controllers the following rules were applied as shown in Table 1.

In the design of the On/Off controller, it was determined that if the left sensor has a lower distance than the right, then the vehicle should converge as far as possible to the right, and vice versa. In case of equal distances in both sensors, the car should follow in a straight line. The On/Off controller does not have any type of speed control, being only responsible for controlling the position of the vehicle, thus the route is carried out with the maximum speed.

After running the tests for the three types of controllers, it can be seen that the On/Off control had a shorter travel time (214 seconds) compared to the others, since it had no weight in its speed. However, this controller indicated the greater oscillation of the angle of the front wheels, causing the vehicle to make sudden movements and follow a disordered trajectory.

Table 1 Fuzzy rules basis.

ANT 1	OPR	ANT 2	CONS
SLMN	-	-	WMR
SLN	-	-	WR
SLF	OR	SLMF	WC
SRMN	-	-	WML
SRN	-	-	WL
SRF	OR	SRMF	WC
SLMN	OR	SRMP	V_{Low}
SLN	OR	SRP	V_{Low}
SLF	OR	SRL	V_{Medium}
SLMF	OR	SRMF	V_{High}

Legend: S →Sensor; L→Left; R→Right; C→Center; M→Much; F→Far; N→Near; W→Wheel Angle V→Velocity.

On the other hand, the Fuzzy1 controller (with symmetrical pertinence functions for the output of the steering wheel) presented greater stability during the course, making curves smoothly along the course and maintaining its position close to the center of the track. However, due to speed control, the time (232 seconds) spent in the test was increased.

The Fuzzy2 controller (with pertinence functions that prioritize the ends for the steering wheel angle exit) also obtained good stability and smooth trajectory during the corners, but kept its position a little further from the center of the track when compared to Fuzzy1. This is due to the fact that their PF precludes the angles belonging to the central band, causing the vehicle to travel straight courses less frequently. This model made the race in 229 seconds.

Fig. 4 shows the paths in four instants for each controller. Each line in the figure illustrates a specific point of the path and each column a type of controller. The first, second, and third columns represent the Fuzzy2, Fuzzy1, and On/Off controllers, respectively.

Fig. 4 Path followed by the three controllers.

4. Conclusion

The On/Off controller, despite being able to carry out the proposed route with a higher speed, presented a rather abrupt movement, with sudden alternation of wheel angle. Considering the miniature model used, this is not a problem of great importance, but if considered real-size vehicles, these movements would greatly affect the comfort and safety of passengers, implying that this method is not applicable.

The fuzzy controllers did not present this problem, as expected [1, 4, 5, 7]. Concerning the adjustment of the parameters of the pertinence functions, it was observed that when the central angular range was neglected, an increase in velocity accompanied by a growth in distance with respect to the center of the runway was generated. In this way, it was not possible to infer on which of the two Mamdani models is superior, since each one is more appropriate for a given context.

In the future it is also intended to continue this work using some other kind of hardware, which is capable of multiprocessing, which could substantially improve the results, due to the possibility of implementing more advanced computational intelligence techniques, in addition to higher speed processing. Another point to be observed for future work is the implementation of fuzzy techniques, since the eFLL library is still quite limited and presents problems of execution.

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