Steering Control of an Ackerman Mobile Robot Using Fuzzy Logic

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Abstract. In this study, we implement a rule based on fuzzy logic algorithms, on a micro controller PIC16F84, to control the steering of an Ackerman mobile robot. The robot has three frontal infrared sensors that send a set of signals through a block of rules to determine the steering velocity. The task of the robot is to follow a moving object of reference. The implementation is realized in Language C, to make the structure of the programs easier.

1 Introduction

In this work we implement a modern control algorithm based on fuzzy logic rules to control the steering motion of an Ackerman mobile robot that we made[1]. The robot has three front-placed infrared sensors that send information to the robot to generate the direction of the navigation in an unfamiliar environment.

This investigation is divided into two parts: First, the design, construction and proofs of our mobile robot of type Ackerman, based on a micro controller PIC 16F84, the mechanical chassis, the electronic design and the electronic cards, including the infrared sensors and the batteries. We make some proofs using a preliminary software downloaded into the micro controller[2-4]. These proofs have the main task of determining if the steering system, wheel traction and sensing have perform correctly.

Secondly, we have developed fuzzy control software for controlling the steering of the mobile robot. The task of the robot consist in following a moving object, that is, the sensor actives the steering direction to determine the wheels velocity necessary to follow the object without losing it.

2 The Mechanical Structure of the Robot

The mechanical structure of the mobile robot consists of a plastic base with four wheels. The pair on the back is motorized, generating the traction of the motion, and the pair in the front has the steering power. Thus, we have a wheeled mobile robot of

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Ackerman configuration with three frontal infrared sensors and a board micro controller (Figure 1).

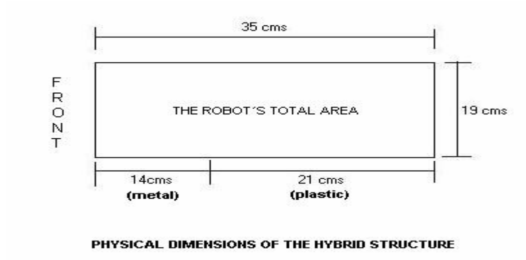

Figure 1. The space distribution of the chassis.

The robot is constructed plastic and metal components with rigid mechanisms of articulation. In this context we can propose a model for the mobility of the robot in terms of the analysis of a number of free movement unions.
A mobility definition depends on the number of independent parameters necessary to specify the position of each of the mechanism links or degrees of freedom (Figure 2).

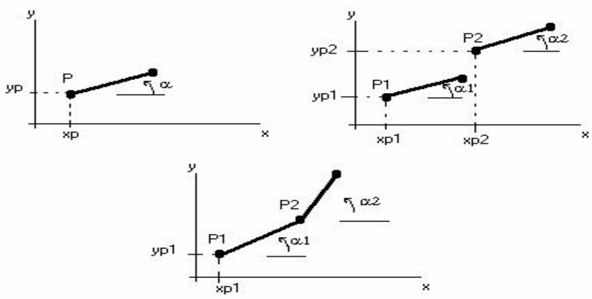

Figure 2. Degrees of Freedom of the links.

Through an analysis of the Figure 2, in Ref.[5] the equation for the mobility of our mobile robot is:

$$M = 3(n) - 2f1 - f2 \qquad (1)$$

M = mobility or degree of freedom, n = total number of arms, f1 = links with one degree of freedom, f2 = links with two degrees of freedom.
In our case we have,

$$M = 3(2) - 2(1) - 0 = 6 - 2 = 4. \qquad (2)$$

However, the corrected Eq.(1) used to determine the degree of freedom of the specific steering mechanism is,

$$M = 3(n - 1) - 2f1 - f2, \qquad (3)$$

because the mechanism is in contact with the surface.

The articulations are as follows: The power traction is an articulation of torsion, which realizes a torque stress between the input and output links. The output axis is parallel to the input ones (Figure 3).

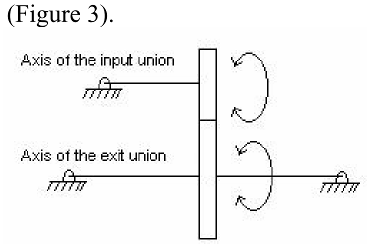

Figure 3. Relationship between input and output axis.

In our case, each rotational link has one degree of freedom (pure rotation) between the connecting links. Then we have n=2 arms, f1=1 links of a degree of freedom, f2=0, and M=1.
A revolution articulation is used for the steering mechanism. The rotational axis is parallel to the link input axis and orthogonal link output axe, i.e. the output link rotate around the input link (Figure 4).

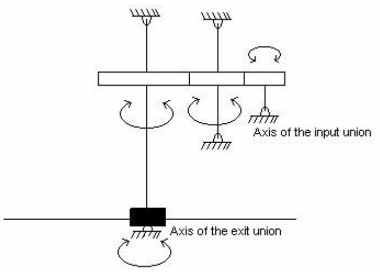

Figure 4. Revolution link has one degree of freedom.

The analysis of the steering components using the above description gives us n=4 arms, f1=4 links with one degree of freedom, f2=0 links with two degrees of freedom, M= 3(n-1)-2f1-f2=3(4-1)-2(4)-0 =1. Hence this articulation has one degree of freedom.
Based on the above description of the mechanical components of the mobile robot, we have constructed a prototype which is represented in Figure 5. An electronic card, based on the PIC-16F84[4], is used to realize the control the drive motors and infrared sensors. Because the algorithms are in Language C, an interface is required to download code to the control card.

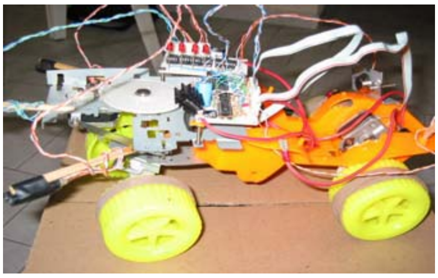

Figure 5. Mobile Robot of Ackerman configuration based on the PIC-PIC16F84.

3 Fuzzy Control of the Robot's Steering

Fuzzy logic has a variety of applications for solving engineering control problems. Here is used as a means of controlling the steering. Because the robot functions we can obtain smooth direction changes. If the steering angle is small, a robot makes a smooth direction change. If angle is large, the direction change is rapid and smooth with a deceleration as it attains the target direction.
The linguistic variables that have been proposed to control the steering of the mobile robot are shown in Table 1.

Input variables			Output variables	
Right Sensor	**Left Sensor**	**Frontal Sensor**	**Steering velocity**	**Position**
All left	All right	All right	Fast right	Right
Medium left	Medium right	Medium right	Slow right	Center
Aligned	Aligned	Aligned	Zero	Left
Medium right	Medium left	Medium left	Slow left	
All right	All left	All left	Fast left	

Table 1. Set elements of the linguistic variables.

We have three input variables and one output variable, which feedbacks into the process control as shown in Figure 6.

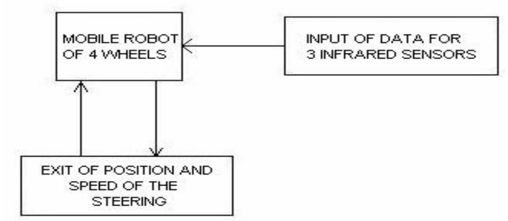

Figure 6 Block diagrams of interaction for the linguistic variables.

The ranks of the linguistic variables establish some limits present in the physical system, like maximum torsion angle and the response time of the electronic signals, as shown in Table 2. The sensor variables admit only two values because its electronic circuits do not accept analogical values.

Variable	**Range**		**Type**
Right Sensor	0	1	Integer
Left sensor	0	1	Integer
Frontal Sensor	0	1	Integer
Position	-45^{o}	45^{o}	Integer
Velocity	50mSec	100mSec	Integer

Table 2. Ranks of the linguistic variables.

The fuzzy functions are established under the desired constraints. There are four basic sets of fuzzy functions [2]: Type Z, type PI, type LAMBDA, type S, (Figure 7).

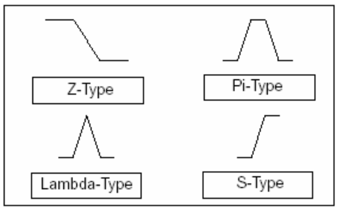

Figure 7. Four types of fuzzy functions.

In our case we utilize a *lambda* fuzzy function. This function involves the values for its "defuzzification" which must be define its degree of membership.

The fuzzy sets for the membership functions and their fuzzy accessible values are given for the same variables, as described above. We have defined the followed membership functions:

RIGHT_ SENSOR = {all_left, medium_left, aligned, medium_right, all_right}
LEFT_SENSOR = {all_right, medium_right, aligned, medium_left, all_left}
FRONT_SENSOR = {all_right, medium_right, aligned, medium_left, all_left}
VEL_POSITION = {fast_right, slow_right, zero, slow_left, fast_left}
POSITION = {left, center, right}

The membership function of fuzzyfication corresponds to VEL_POSITION. The input data sensor processed in the rules block, which provides feedback for the variable POSITION (Figure 8).

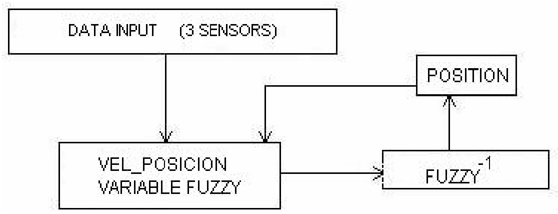

Figure 8. Flow of information of the fuzzy control as it goes through the electronic system.

4 Fuzzy Control Algorithms Programming

To implement the fuzzy control scheme, as described in the last section, we need to generate some code, that is understandable by the control electronic card, or specifically for the micro-controller.
The fuzzyfication of the set of values of the variable VEL_POSITION generate *lambda* type functions, (Figure 9).

Figure 9. Fuzzy variable for torsional velocity.

The intersections of the *lambda* functions, gives us some of the membership degrees.
The method used to calculate the membership degrees is the *center of maximum* (COM). Three types of membership are defined associated to each of the linguistic variables. The first type, corresponds to the maximum degree of membership fixed at 100 percent. The second one is the membership degree that which establishes its value in agreement with the corresponding *lambda* function. The third type is associated with the maximum argument that establishes the non fuzzy self value, Table 3.

Maximum argument (M)	Fast_ right	Slow_ right	Zero	Slow_ left	Fast_ left
Membership degree (MD)	0.7	0.7	0.7	0.7	0.7
Maximum MD	1	1	1	1	1

Table 3. Degree of membership of the linguistic variable of velocity.

4.1 Center of the Maximum (CoM)

For the defuzzification, we use the method of the CoM, first of all, we need to define the value *C* = CRISP as the value of defuzzing [2-3]:

$$C = \frac{\sum i[(I)(Max(M))(\arg(\max(M)))]}{\sum i[I]} \quad (4)$$

being,

I = membership degree, *Max(M)* = maximum degree of membership, *Arg(Max(M))* = Argument of the maximum degree of membership.

As an example of defuzzification, lets consider that the fuzzy value is SLOW_LEFT, to calculate the corresponding crisp value. The arguments of the maximum degree of membership are taken as: Arg(Max(SLOW_LEFT)) = 20, Arg(Max(FAST_LEFT)) = 37, Arg(Max(ZERO)) = 0. The degree of membership: I(SLOW_LEFT) = 0.7, I(FAST_LEFT) = 0.7, I(ZERO) = 0.7. Maximum degree of membership: Max(SLOW_LEFT) = 1, Max(FAST_LEFT) = 1, Max(ZERO) = 1.
Then the maximum of the center result is: C = 19.

5 Results

5.1 Object Follower Fuzzy Steering control

After downloading the fuzzy control code into the control card of the robot, we obtain a soft regulated steering velocity. The activity of the sensors is generated by a moving object of reference. The steering of the robot is oriented through the current active sensor. When the object movement activates another sensor, the steering direction changes into the new defined direction with sudden start follow a soft velocity brake. When two sensors are active simultaneously, the intermediate current velocity is preserved as a steering position of following or returning to the former position. The magnitude of the steering velocity depends directly on the separation of the sensors. The fuzzy control for the steering of our mobile robot constitutes a powerful tool for effectively following the reference object.

5.2 Code in Language C

The code of the program is written in Language C to be compatible with the compiler PICC of HITECH Software [4]. This compiler was chosen mainly due to the resulting code structure. The flow chart showing code is presented in Figure 10.

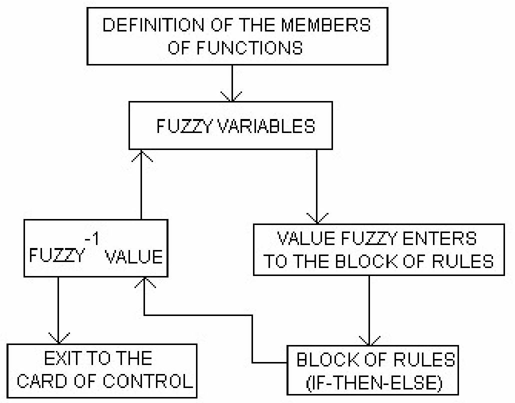

Figure 10. Fuzzy control flow chart.

6 Conclusions

It is possible to implement fuzzy control algorithms in a micro controller in the context of mobile robotics. We have used fuzzy control code to control the steering directions of a mobile robot of Ackerman configuration. We obtained good performance on the steering direction changes of the robot following a reference object, regulated by the sensor activity. The main complication in using fuzzy control algorithms in a micro controller, is that it uses a much of the program memory in the defuzzification process.

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