Obstacle Avoidance Fuzzy System for Mobile Robot with IR Sensors

C. G. RUSU[1], I. T. BIROU[2]
[1]Technical University of Cluj-Napoca
[1]calin.rusu@edr.utcluj.ro, [2]iulian.birou@edr.utcluj.ro

Abstract — **The goal of this research was to develop a fuzzy obstacle avoidance system for an autonomous mobile robot using IR detection sensors. This paper presents implemented control architecture for behavior-based mobile robot. The mobile robot is able to interact with an unknown environment using a reactive strategy determined by sensory information. Current research in robotics aims to build autonomous and intelligent robots, which can plan its motion in a dynamic environment. Autonomous mobile robots are increasingly used in well structured environment such as warehouses, offices and industries. Fuzzy behavior able to make inferences is well suited for mobile robot navigation because of the uncertainty of the environment. A rule-based fuzzy controller with reactive behavior was implemented and tested on a two wheels mobile robot equipped with infrared sensors to perform collision-free navigation. The experimental results have shown that the proposed architecture provides an efficient and flexible solution for small wheeled mobile robots.**

Index Terms — **Fuzzy system, IR sensors, Mobile robot, Obstacle avoidance**

I. INTRODUCTION

The work presented in this paper deals with the navigation problem of mobile robots in unknown indoor environment. The robot has the ability to plan motion and to navigate autonomously avoiding any type of obstacles. This is a reactive strategy and is completely based on sensory information [1]. An absolute localization is not requisite and the structural modeling of the environment is unnecessary. The robot is expected to carry out only simple tasks through its sensory inputs as a set of stimulus–response mechanisms [9].

The differential robot is used extensively in many fields, such as intervention in hostile environments or in warehouse as a solution of transport, inspection and operation. The control problem for the two-wheel mobile robots is how to independently control the left-wheeled motor and right-wheeled motor.

Classical control strategy have proposed a simple PI feedback controller with feed-forward compensator for each of motor drive. This approach control method use extensively inverse kinematics and dynamics of the robot [2], [3]. In our application, we considered a small two wheels mobile robot. For this type robot the use of mathematical model to control the robot motion is too "expensive" in terms of computer processing power and memory [17].

Autonomous navigation is related to the ability of a mobile robot moving around in an unknown environment to achieve a goal without hitting any obstacles. The last research activities cover many aspects including, but not limited to *wall following*, *collision avoidance*, *corridor following* or *goal seeking*.

The mobile robot is guided by online sensor information acquired while navigation is performed. An approach called the behavior-based or sensor-based methods is proposed. This approach takes the way of driving a mobile robot by direct mapping between sensors and motors without building predefined environmental maps [6]. Fuzzy logic unlike classical logic is tolerant to imprecision, uncertainty and partial truth. This makes it easier to implement fuzzy logic controller to nonlinear models than other conventional control techniques. More than it, the fuzzy controller offers a possibility to mimic expert human knowledge [7].

The paper presents the implementation of fuzzy based reactive control for a two wheels mobile robot motion which moves in an unknown indoor environment with obstacles.

Present paper is organized as follows: Section 1 Introduction. Section 2: Mobile robot system presentation. Section 3: Rule based fuzzy navigation system. Section 4: Conclusions.

II. MOBILE ROBOT SYSTEM

The used robot is a full autonomous wheeled robot intended for indoor environment. It has two identical parallel, wheels (attached to both sides of the vehicle) which are controlled by two independent DC gear motors. Also it assumed that each wheel is perpendicular to the ground and the contact between the wheels and the ground is pure rolling and non-slipping. The velocity of the center of mass of the robot is orthogonal to the wheels' axis - *L*. The center of mass of the mobile robot (*x, y*) is located in the middle of the axis connecting the wheels (*L*), likes in Fig. 1.

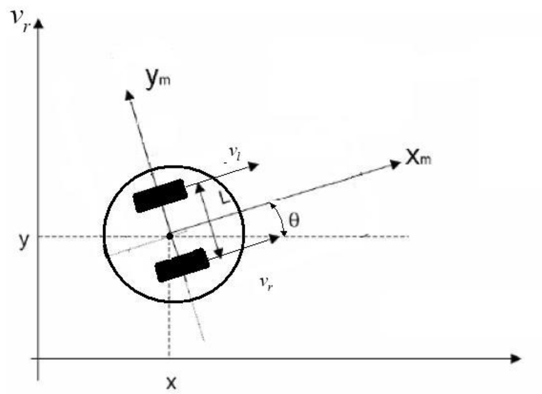


Figure 1. Kinematics model of the robot

This robot type is relatively easy to model and build. The angular velocities (ω_l and ω_r) of the two wheels are independently controlled. This mobile robot is an under actuated system, because it has two inputs (*translational velocity* – v_c and *angular velocity* – ω_c) and three outputs (*center positions x, y and heading angle θ of the mobile robot on two dimensional Cartesian workspace*) [16]. The equations that are used to build a Matlab-Simulink model of the robot are given by relation (1).

$$\begin{bmatrix} v_x(t) \\ v_x(t) \\ \dot{\theta}(t) \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\cos\theta & \frac{1}{2}\cos\theta \\ \frac{1}{2}\sin\theta & \frac{1}{2}\sin\theta \\ \frac{-1}{L} & \frac{1}{L} \end{bmatrix} \cdot \begin{bmatrix} v_r \\ v_l \end{bmatrix} \quad (1)$$

This model is the simplest and the most suitable for a small-sized and light, battery-driven autonomous robot.

A picture of this robot is presented in the Fig. 2. For allowing obstacle avoidance, the robot is equipped with a set of proximity infrared sensors. They are used real time to detect the obstacles by measuring the reflected light. Three IR proximity sensors are mounted in front of the robot, like in Fig. 2.

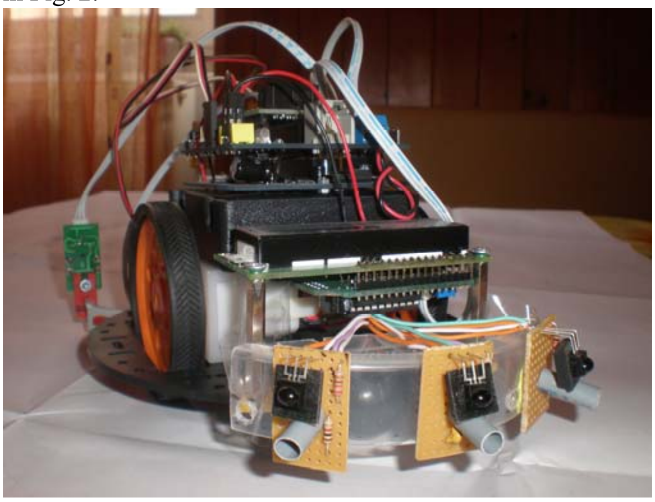


Figure 2. Two wheels differential robot with IR sensors.

Each IR detectors have built-in optical filters that allow very little light except the 980 nm infrared that we want to detect with its internal photodiode sensor. The infrared detector also has an electronic filter that only allows signals around 38.5 kHz to pass through. In other words, the detector is only looking for infrared that's flashing on and off 38,500 times per second. This prevents IR interference from common sources such as sunlight and indoor lighting. The key to making each IR LED/detector pair work is to send 1 ms of 38.5 kHz frequency signal and then, immediately store the IR detector's output in a variable. The IR detector's output state when it sees no IR signal is high. When the IR detector sees the 38500 Hz harmonic reflected by an object, its output is low.

The sensors are mounted on the front platform at 60° one each other from the central axis, like in Fig. 3. The sensors include the left side, front and right side locations of the robot, namely *Left_Sensor* (*SL*), *Front_Sensor* (*SF*), *Right_Sensor* (*SR*).

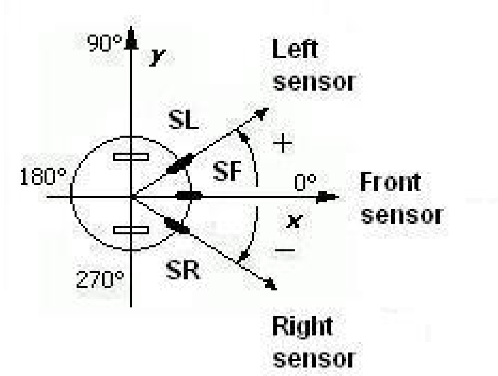


Figure 3. IR sensor locations.

The detection distance for each sensor is more than 10 cm with 80% sensitivity. After some tests we concluded that IR sensors have a detection range of 10 cm around the mobile robot platform and the detection angle is more about 90^0 in the front of the robot, like in Fig. 4.

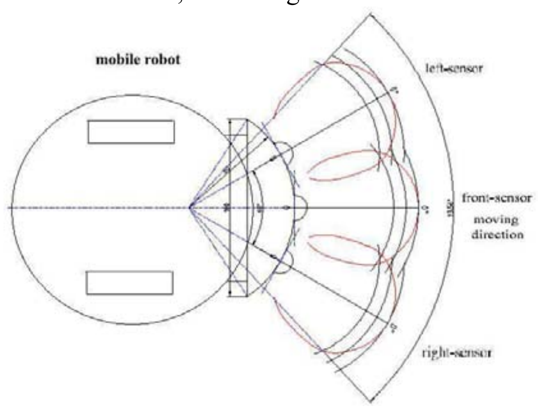


Figure 4. The sensitivity of IR sensors.

The mechanical structure handling this architecture is based on the two DC motors controlling through gears two differential wheels.

III. RULE BASED FUZZY NAVIGATION SYSTEM

Fuzzy logic unlike classical logic is tolerant to imprecision, uncertainty and partial truth. In the context of mobile robot control, a fuzzy logic based system has the advantage that it allows intuitive nature of sensor-based navigation and can easily transform linguistic information into control signals [15].

The basic structure of a fuzzy logic controller (FLC) consists of three conceptual components:

1. fuzzification of the input–output variables;
2. rule base that contains a set of fuzzy rules;
3. reasoning mechanism that performs the inference procedure on the rules and given facts to derive a reasonable output.

A general structure for a fuzzy inference system with crisp output is shown in Fig. 5 [17].

In order to avoid obstacles without hitting any obstacles, the mobile robot should take sensory information about obstacles into account. Our FLC uses the sensory information from three proximity sensors as inputs and controls the speed of the two motors.

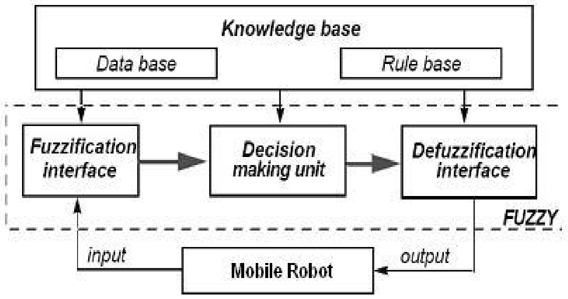


Figure 5. Configuration of a fuzzy logic controller.

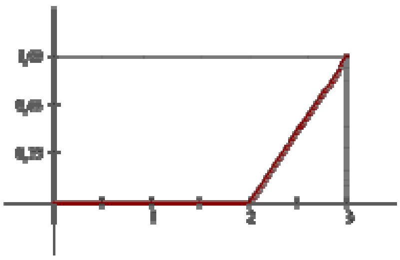
The fuzzifier maps crisp input into a fuzzy set, being input to the inference engine. The inference engine combines rules and gives mapping from fuzzy input sets for fuzzy output sets. The defuzzifier produces crisp output from a fuzzy set that is output by the inference engine. Defuzzification approaches include centroid, maximum-decomposition, center of maxima and height.

A. *Fuzzy Sets for Sensors*

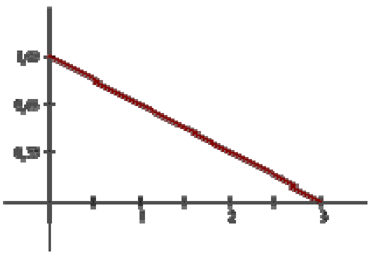
The triangular membership functions are used for their simplicity. It means the sum of the membership functions of any variables at any given point in the domain is equal to *one*. In a fuzzy set ***S***, each element *x* of the set is assigned with a degree of membership in $\mu_S(x): \mathrm{R} \rightarrow [0 \quad 1]$, which is measured by a membership function $\mu_S(x)$. The membership function is *zero* when *x* does not belong to ***S*** at all, *one* when *x* belongs to totally to ***S*** and $0 < \mu_S(x) < 1$ when belongs to partially to ***S*** [4], [6].

At first we have considered the 3 membership functions: μ_N – near, μ_F – far, μ_M – medium for each sensor. But it gives us a number of 27 rules for the inference system. The inference system demand a lot of time for calculation. For this reason we have decide to take only the following membership functions: μ_N – near and μ_F – far, defined by the following expressions:

$$\mu_N = \begin{cases} 0 & for \quad 0 \le n < 2 \\ n-2 & for \quad 2 \le n \le 3 \end{cases} \quad (2)$$



a) near



b) far

Figure 6. Membership functions $\mu_S(x)$ for the IR sensor.

$$\mu_F = -\frac{1}{3}n + 1 \quad for \quad 0 \le n \le 3 \quad (3)$$

The graphical representation of these membership functions for the IR sensors are given by Fig. 6.

The distance of area covered by each sensor can be set up on four level distances: 10, 20, 30 or more than 30 cm, respectively. The levels for each sensor are presented in the Table I.

Under the distance of 10 cm the obstacle is considered to be *very near* from the robot. The crisp values associated with the distance to the object detected by the sensors are defined by first column of Table I.

TABLE I. MEMBERSHIP FUNCTIONS FOR SENSORS

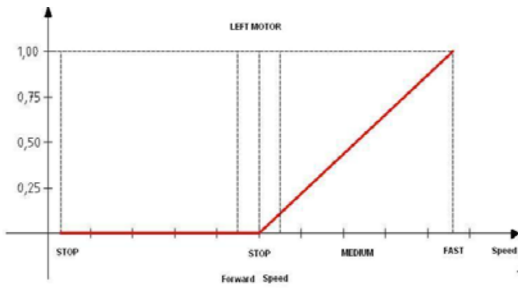
Crisp_Value	Near	Far	DetectC_var	Distance
0	0	1	0	> 30 cm
1	0	0,66	1	30 cm
2	0	0,33	2	20 cm
3	1	0	3	10 cm

B. *Fuzzy Sets for Motors*

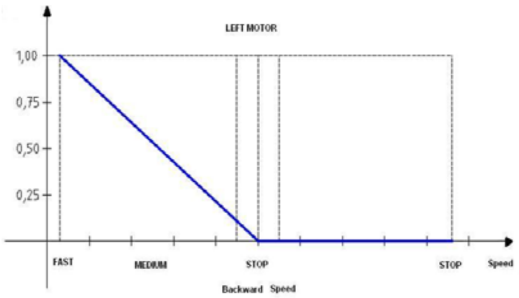
The control problem for the two-wheel mobile robot is how to independently control the left-motor and right-motor. Two fuzzy commands are used to control the left wheel and right wheel, respectively. Each wheel can be controlled to move *forward*, *stop* and *reverse*. Combined these commands, the robot movement can be described by the following 7 fuzzy sets: (*go_forward*, *go_reverse*, *go_on_right*, *go_on_left*, *quick_turn_left*, *quick_turn_right*, *stop*), as presented by Table II.

TABLE II. TYPE OF ROBOT MOVEMENT

Robot Movement	Left_Motor	Right_Motor
Go_Forward	Forward_Medium	Reverse_Medium
Go_Reverse	Reverse_Medium	Forward_Medium
Go_on_left	Forward_Fast	Stop
Go_on_right	Stop	Reverse_Fast
Quick_turn_left	Forward_Fast	Reverse_Fast
Quick_turn_right	Reverse_Fast	Forward_Fast
Stop	Stop	Stop

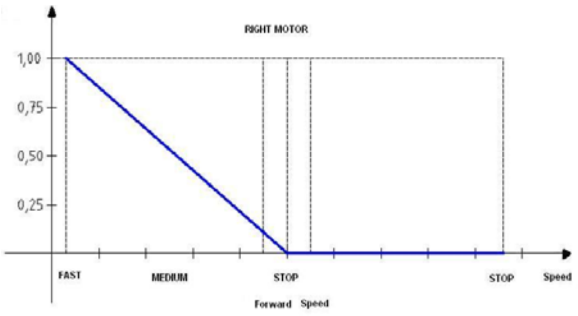


μ_{LFWD}



μ_{LREV}

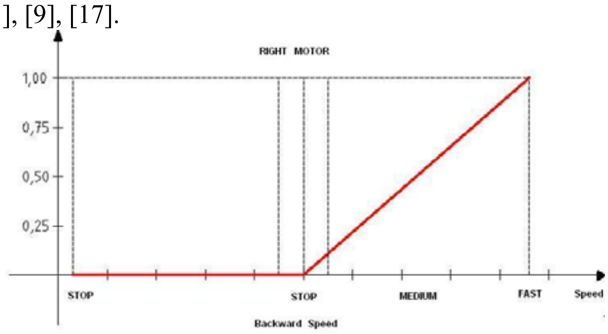
Figure 7. Left wheel membership functions – *forward* and *reverse*.



μ_{RFWD}

In the following figures, we have presented the membership functions for the *Left* and *Right* motors. There are four membership functions namely: μ_{LFWD}, μ_{LREV}, μ_{RFWD} and μ_{RREV}. Each of these functions are shown in Fig. 7 (μ_{LFWD} and μ_{LREV}) for the *left motor* and Fig. 8 (μ_{RFWD} and μ_{RREV}) for the *right motor*, respectively.

When the robot is moving and the sensors detect an obstacle, a reactive strategy is necessary. Behavior models are widely used for robots operating in uncertain dynamic environments, combining information from many sensors [1], [9], [17].



μ_{RREV}

Figure 8. Right wheel membership functions – *forward* and *reverse.*

The control structure is based on a task for avoiding obstacles; the input of the control system is sensors data and the outputs are the motor commands, like in Fig. 9. The mobile robot wheels' are independently controlled.

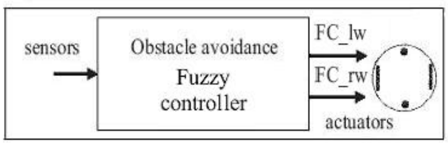


Figure 9. Control structure for avoiding obstacles.

C. *Fuzzy Inference System*

Suppose that we take all the available information. The controller must have 3 inputs and 2 outputs. The inputs are the distance between the robot and the obstacle and the outputs are the motor speeds. For every input, we defined 3 membership function (*far, medium* and *near*) and for every output 3 membership functions (*Reverse, Stop* and *Forward*). It means that there are 216 $\left(2^3 \cdot 3^3\right)$ possible rules. The minimum number of necessary rules is three but of course, the obtained behavior is very primitive. Another important factor is the computational time and this was one of the main reasons that led us to simplify the fuzzy algorithm. In order to reduce the number of the rule we consider only two membership function for the input IR sensors (*far, near*). Analyzing the rules and after some testing experiments we decided to take only 8 rules. These fuzzy control rules for avoiding collision with any obstacles are given in the Table III.

TABLE III. FUZZY RULES FOR THE ROBOT MOVEMENT

Left_Sensor	Frot_Sensor	Right_Sensor	Left_Motor	Right_Motor
Far	Far	Far	Forward	Forward
Far	Far	Near	Reverse	Forward
Far	Near	Near	Reverse	Forward
Far	Near	Far	Forward	Reverse
Near	Near	Far	Forward	Reverse
Near	Near	Near	Reverse	Reverse
Near	Far	Near	Forward	Reverse
Near	Far	Far	Forward	Reverse

The rules are presented below.

RULE 1
IF (LEFT_SENSOR_L IS FAR) AND
(FRONT_SENSOR IS FAR) AND (RIGHT_SENSOR IS FAR) THEN
(LEFT_MOTOR IS.FWD) (MOTOR_R IS FWD)

RULE 2
IF (LEFT_SENSOR IS FAR) AND
(RIGHT_SENSOR IS FAR) AND (RIGHT_SENSOR IS NEAR) THEN
(LEFT_MOTOR IS REV) (MOTOR_R IS FWD)

RULE 3
IF (LEFT_SENSOR_L IS FAR) AND
(FRONT_SENSOR IS NEAR) AND (RIGHT_SENSOR IS NEAR) THEN
(LEFT_MOTOR IS.REV) (MOTOR_R IS FWD)

RULE 4
IF (LEFT_SENSOR IS FAR) AND
(RIGHT_SENSOR IS NEAR) AND (RIGHT_SENSOR IS FAR) THEN
(LEFT_MOTOR IS REV) (MOTOR_R IS FWD)

RULE 5
IF (LEFT_SENSOR_L IS NEAR) AND
(FRONT_SENSOR IS NEAR) AND (RIGHT_SENSOR IS FAR) THEN
(LEFT_MOTOR IS.FWD) (MOTOR_R IS REV)

RULE 6
IF (LEFT_SENSOR IS NEAR) AND
(RIGHT_SENSOR IS NEAR) AND (RIGHT_SENSOR IS NEAR) THEN
(LEFT_MOTOR IS FWD) (MOTOR_R IS REV)

RULE 7
IF (LEFT_SENSOR_L IS NEAR) AND
(FRONT_SENSOR IS FAR) AND (RIGHT_SENSOR IS NEAR) THEN
(LEFT_MOTOR IS.FWD) (MOTOR_R IS REV)

RULE 8
IF (LEFT_SENSOR IS NEAR) AND
(RIGHT_SENSOR IS FAR) AND (RIGHT_SENSOR IS FAR) THEN
(LEFT_MOTOR IS FWD) (MOTOR_R IS REV)

All of these rules must act together so as that the mobile robot to avoid any obstacle meets on his way.

D. *Defuzzification*

Defuzzification is an operation with the aim to produce a non-fuzzy control action. It transforms fuzzy sets into a crisp value. Among many defuzzification methods, the center of gravity method was chosen because it is appropriate for our system to control the mobile robot. The method generates the centre of area of the resulting fuzzy set of a control action.

The next three examples present how the method works for the three different cases of IR sensors configuration. At first we have considered the input vector of IR sensors to be

$[1 \quad 0 \quad 0]$. It means that *left_sensor* detects an obstacle at *far* distance and *front_sensor* and *right_sensor*, respectively do not detect any object. Fig. 10 shows how the motor commands for this combination of the IR sensors are obtained by applying the center of gravity method. For the second scenarios considered is for an input vector of the IR sensors equal to $[2 \quad 0 \quad 0]$. For the interpretation of this combination please look to the Table I. Fig. 11 presents how we can get the *left* and *right* motor commands by applying the center of gravity method. For the last example we consider a $[3 \quad 3 \quad 3]$ combination of the input IR sensors. Fig. 12 presents the crisp values for the *left* and *right motor* commands obtained with the center of gravity method.

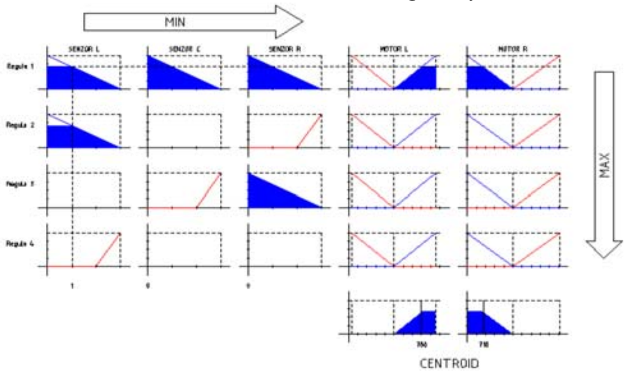


Figure 10. Center of gravity method - crisp value of commands for sensor input i=[1 0 0].

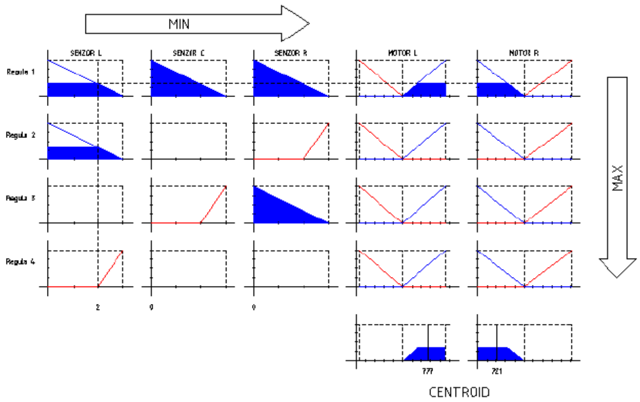


Figure 11. Center of gravity method - crisp value of commands for sensor input i=[2 0 0].

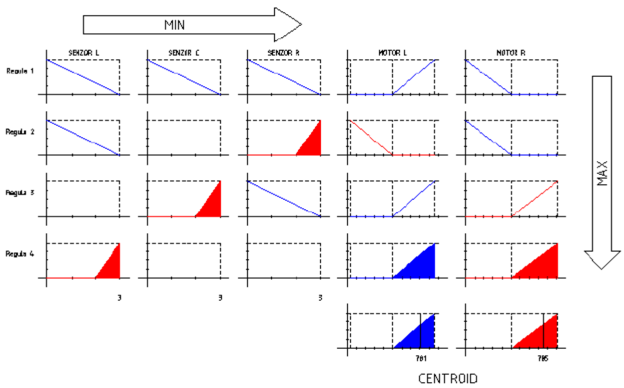


Figure 12. Center of gravity method - Crisp value of commands for a sensor input i=[3 3 3].

IV. CONCLUSION

In this paper, we present a sensor-based methodology for robot navigation in unknown environments where a fuzzy logic system translates the sensor measurements directly to actuator actions. The algorithm was implemented on the light differential mobile robot presented in Fig. 2. The robot has two independent wheels, driven by geared PM DC motors. The control of motors is accomplished by a microcontroller board. Each of motors being controlled by the PWM output of the microcontroller. The three groups of IR sensors mounted on the front of the robot are connected to the analog input port of the microcontroller. The microcontroller was programmed using a C compiler thus reducing the efficiency of the code [5].

The fuzzy controller was tested to perform *collision-free* navigation toward any given goal and *corridor following*. The experimental results have shown that the proposed architecture provides an efficient and flexible solution for the light autonomous differential mobile robots. It must be mentioned that learning methods for fuzzy controller can improve the robot behavior. A neuro-fuzzy controller with more IR sensors and fuzzy rules represents the next step of implementation. It means to replace present microcontroller with a dsPIC with larger RAM and higher speed of instructions execution.

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