Autonomous Robot Navigation of Corners with Uncertain Sensor Information Using Fuzzy Control

Abhimanyu Bhargava, Rohit Narula and Satish Kumar

Dayalbagh Educational Institute

Abstract—**This paper presents implementation of microcontroller programming blended with fuzzy logic for smooth and economic corner navigation by an autonomous robot. The application considered has a robot (Nex Robotics Fire Bird IV) placed in the vicinity of a corner. With no prior knowledge about the environment and its own orientation, the robot is capable of aligning itself parallel to a wall and then proceeding to negotiate a turn around the corner. Evaluation has shown that the robot can perform the above task with sufficient accuracy, maintaining a safe distance from the wall. Use of a fuzzy control system for navigation helps compensate for sensor errors, thus providing for a robust implementation.**

I. Introduction

The aim of an autonomous mobile robot navigation system is to move purposefully in a real-world environment without any human intervention. Such systems are potential substitutes for humans in carrying out hazardous tasks such as surface exploration of celestial bodies [1], deep sea exploration [2], unmanned ground vehicles [3] (UGV's) for spying and mapping, service robots [4] for hospitals, offices and other indoor areas. The development of techniques for autonomous robot navigation constitutes one of the major research areas in the field of robotics. Design and development of a complete autonomous navigation system is a complex task which can be broken down into sub-tasks such as algorithm design, path planning, motion planning, obstacle avoidance, microcontroller architecture design, microcontroller programming.

The focus of our paper is on corner navigation. The navigation system has been developed on an AVR microcontroller based robot platform named Firebird IV manufactured by Nex Robotics [5]. The Firebird platform is primarily made for carrying out experimentation and research. The motivation for taking up the above problem came from the fact that corners are frequently encountered in real-world situations. They require more attention from the perspective of both path and motion planning. Secondly, the existing technologies in autonomous navigation are hardware dependent [6]. Costly SONAR sensors and Gyros are used for better perception, localization and reducing the amount of programming. To economize the implementation of an autonomous navigation system, we considered the design of the system using simple hardware elements. In particular, our main objective here is to develop an autonomous corner navigation system using inexpensive Infra-Red (IR) sensors. The inaccuracy of sensors is compensated by the fuzzy controller and sensor calibration curves.

Considerable amount of work has already been done with the idea of integrating fuzzy logic with robotics. A lot of literature which includes research papers and technical articles related to the field are available for study. Various fuzzy computation techniques [7] have been used in the SRI International mobile robot Flakey. These techniques have been used for designing simple behaviors that guarantee robust operation and for coordinating the activity of several competing behaviors in order to perform a complex task. Context dependent blending of robot behavior is dealt with in reference [8]. In [9], a fuzzy control system that incorporates sensing, control and planning to improve the performance of the wall-climbing micro robots in unstructured environments has been discussed.

The web based course on Robotics by National Program on Technology Enhanced Learning [10] (NPTEL) gives a very good idea of velocity analysis, forward position control, trajectory planning, robot dynamics and control. The hardware and software literature provided by the robot platform manufacturers provide sufficient information to familiarize us with the platform and its programming interface. A clear explanation of using MATLAB for implementing fuzzy logic has been described in [11].

The paper has been divided into the following sections. Section II describes the algorithm of the navigation system and the flow of control in the program. Section III provides details of the robot platform used by us. The kinematics, motion planning and control of the robot are dealt with in Section IV. Section V is dedicated to the fuzzy controller and its functioning. The experiments and results are presented in section VI.

II. The Algorithm of Program

It is the backbone of entire navigational system. The flow chart shown in Fig. 1, describes the flow of control of instructions in microcontroller and MATLAB. At the same time it gives an idea of the physical process of corner navigation.

Abhimanyu Bhargava and Rohit Narula are currently pursuing their third year of Engineering in Mechanical and Electrical Engineering respectively, Faculty of Engineering, Dayalbagh Educational Institute.

Email: bhargav.abhimanyu@gmail.com, rohitnarula19@gmail.com.

Satish Kumar is Professor and Head, Department of Physics and Computer Science, Dayalbagh Educational Institute.

Email: skumar_db@ieee.org.

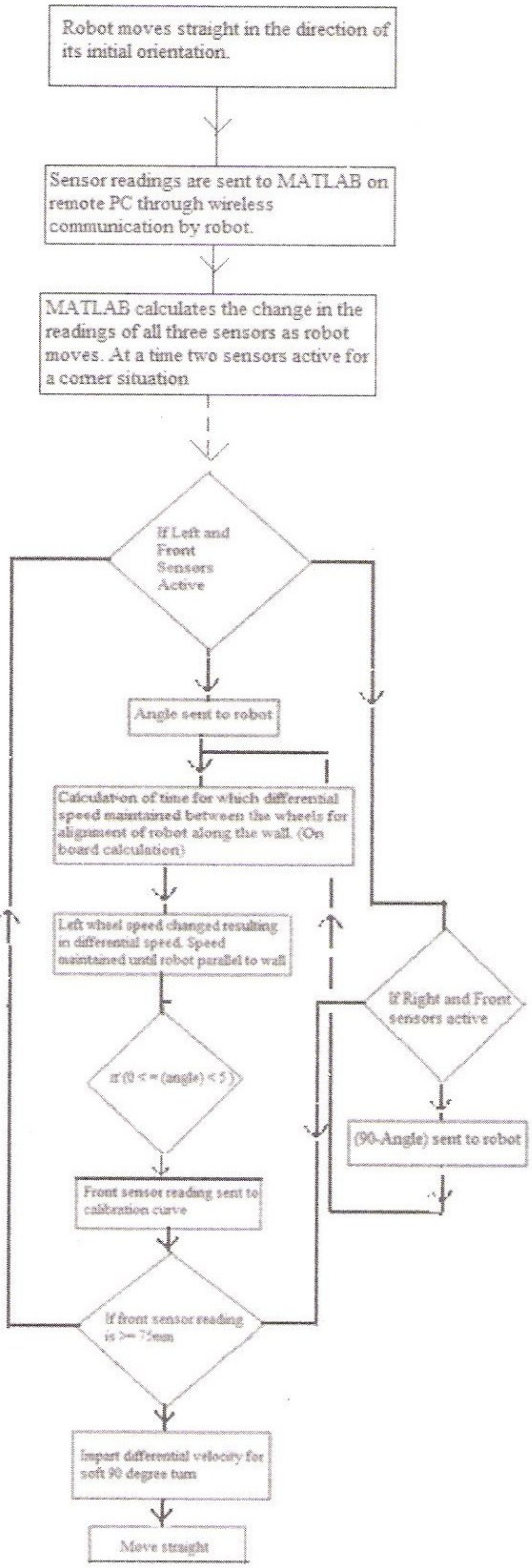

Fig. 1 Navigation Algorithm and Flow of Control

III. Robot Platform: Fire Bird IV

Fire Bird IV is designed by NEX Robotics in collaboration with Embedded Real-Time Systems Lab, Dept. of Computer Science and Engineering, IIT Bombay.

The diameter of the robot is 16cm, height 12.5cm and weight of 75 grams. The robot is powered by rechargeable 7.4V 660 mAh Li-io battery pack and can run on auxiliary power also. It uses ATMEG 128 microcontroller and have a crystal frequency of 11.0592 MH It has three white line sensors, three infrared sensors in forward, le and right directions, five bump sensors, two position encoders, or directional light intensity sensor, battery voltage sensors. Its thre infrared sensors are used for navigation purposes that have an ac curate detection range of 30 cm. A wireless color camera can also b mounted for capturing images. The operation modes are standalon PC as master and robot as slave, and robot as master and other robo as slave. Wired RS232 (serial) communication, Simplex infrare communication and Wireless 2.4 GHz CDMA communication serv the purpose of communication. In the present work the robot use wireless communication to communicate with the remote compute terminal. The robot moves with the help of two DC geared moto and a caster wheel at front as support with a maximum speed of 6. cm/s and wheel diameter of 40cm. Indication is served by a 2×1 characters LCD, LEDs and buzzer sound.

The development environment is both embedded C and assem bly programming. The platform supports software like Microso Robotic Studio, MATLAB, SCILAB. A block diagram of all i components is given in Fig. 2.

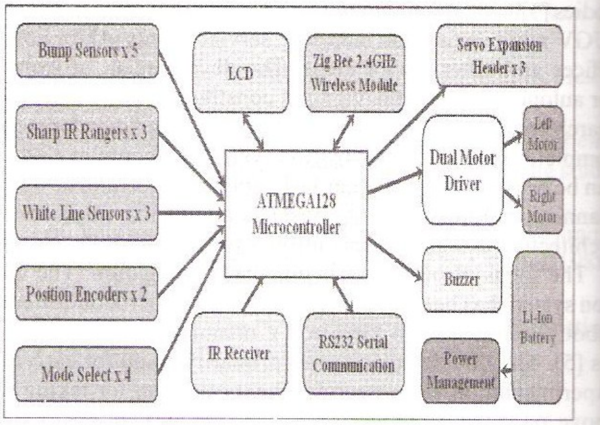

Fig.2. Architecture of Fire Bird IV.

IV. Kinematics of the Robot

Simple kinematic equations have been derived for calculatin time for which differential velocity has to be maintained betwee the wheels. It can be considered as superposition of two types o motion- translation + rotation. Figure 3 explains the approac more vividly.

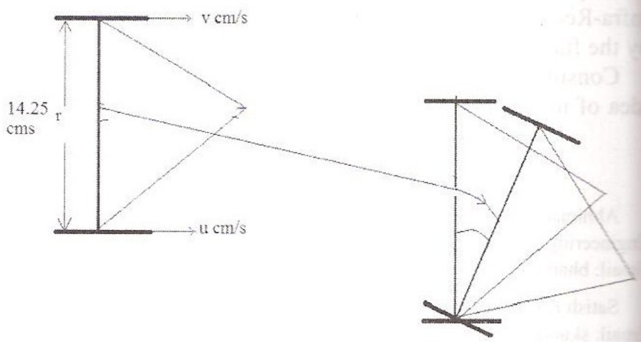

Fig.3. General Motion –Translatory +Rotatory.

We place the robot in an inertial frame of reference moving with velocity of *(-u)* cm/s. Then velocity of right wheel will be 0 cm/s and of left wheel will be *(v-u)* cm/s. Thus,*(v-u)* is the differential velocity.

$$(v-u) = r\omega$$

$$(v-u) = r\frac{d\theta}{dt}$$

$$\int(v-u)dt = \int r\, d\theta$$

$$(v-u)t = r\theta$$

$$t = \frac{r\theta}{v-u} \qquad (1)$$

where the symbols have the following connotations:

$(v-u)$ = differential speed of wheels in *cm/s*

r = distance between the rear wheels in *cm*

θ = angle in radians

t = time in seconds

The value of r =14.25 cm for our robot. We maintain a constant differential speed *(v-u)* = 3.3 cm/s. Substituting these values in Eqn. (1) we get following relation (Eqn. 2):

$$t = 4.344 \times \theta \qquad (2)$$

V. Fuzzy Controller Design

The novelty of the paper is due to the fact that fuzzy logic for sensor calibration drastically reduces the effect of sensor error and error in implementation of commands, reducing the effect of hardware inconsistencies in the robot. The function of the fuzzy controller in the corner navigation system is to receive changes in sensor readings as an input, and evaluate the angle that the robot makes with the wall. If the robot has to turn right at corner one pair of sensors is active. When it has to turn left, another pair of sensors is active.

Towards designing the controller we define the following fuzzy sets as shown in Fig. 4.

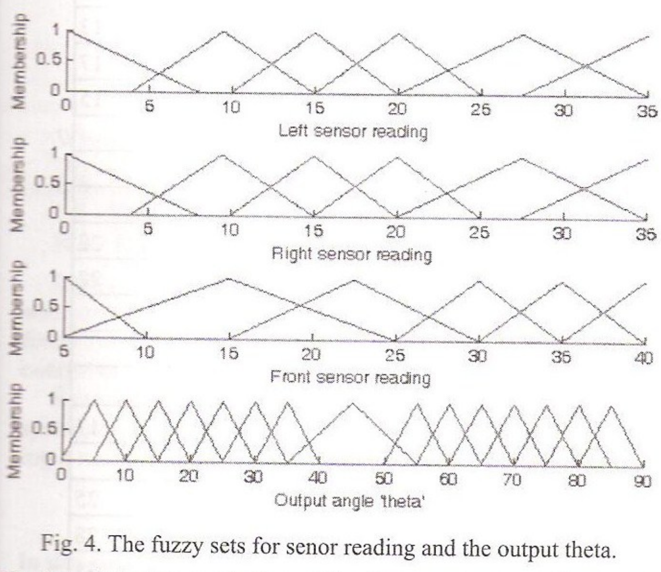

Fig. 4. The fuzzy sets for senor reading and the output theta.

The linguistic interpretation of the fuzzy sets moves from very low on the left hand side to very high on the right hand side. For brevity in designing the rule base, we number the fuzzy sets from left to right on each of the universes of discourse: Left sensor – 1 2 3 4 5 6; Right sensor – 1 2 3 4 5 6; Front sensor – 1 2 3 4 5 6; and Output angle theta – 1, …, 15. These numbers are employed to define the rule base shown in Fig. 5 and Fig. 6.

There are two sets of inputs: the combination of left sensor and front sensor readings; and the combination of right sensor and front sensor readings. For each such combination, we have a rule base. These two rule bases are formed on the basis of extensive experiments performed.

Table 1: Rule base for left and front sensors.

1	1	2	3	5	7	7
2	1	2	3	5	7	7
3	1	2	3	5	7	7
4	1	2	4	6	8	8
5	1	2	4	6	8	8
6	1	2	4	6	8	8
FS↑LS→	1	2	3	4	5	6

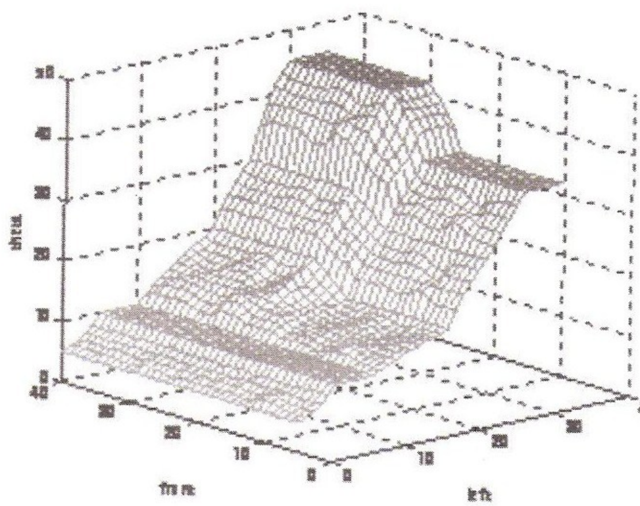

Fig. 5: The response surface for left-front sensor rule base.

Table 2: Rule base for right and front sensors.

1	15	14	13	11	9	8
2	15	14	13	11	9	8
3	15	14	13	11	9	8
4	15	14	12	11	9	8
5	15	14	12	11	9	8
6	15	14	12	11	9	8
FS↑RS→	1	2	3	4	5	6

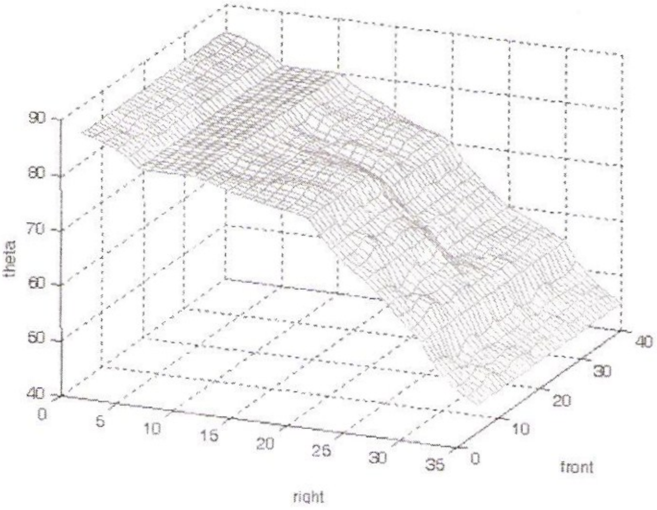

Fig.6: The response surface for right-front sensor rule base.

VI. Experiments and Results

Calibration of the front sensor was our first experiment. The robot was kept at a known distance from a wall perpendicular to the robot and sensor readings were noted.

Table 3: Front sensor calibration readings.

SENSOR READING (mm)	ACTUAL READING (mm)
293	300
283	290
273	280
264	270
255	260
247	250
239	240
225	230
213	220
202	210
192	200
183	190
174	180
163	170
153	160

The table above shows the readings of the front sensor. This gives us a calibration graph which will be used for correcting the readings of the sensors. The straight line approximation(Fig.7) was generated using MATLAB polyfit.

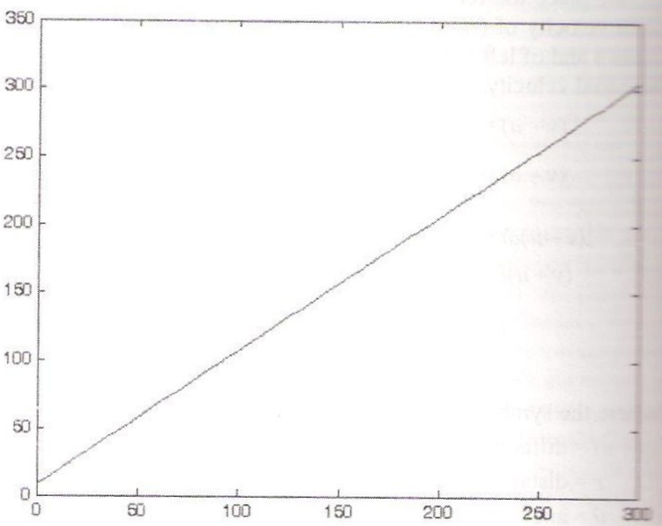

Fig.7: The calibration curve for front sensor.

In the second experiment we observed the change in sensor readings when the robot approaches the corner at known angles. The difference of two consecutive sensor readings of all the three sensors is sent though wireless to a remote PC. These readings are input to the fuzzy controller which is gives alignment angle of robot with the wall. The experiment forms the basis of forming the fuzzy rules.

10 Degree	F.S	L.S	Fit values of differences	
	293	65	29	8
	264	57	32	8
	232	49		
20 Degree				
	293	109	29	13
	264	96	32	17
	232	79	30	15
	192	64		
30 Degree	264	147	32	22
	232	125	35	22
	197	103		
	163	82		
40Degree	283	219	10	17
	273	202		
	232	178	19	25
	213	153	30	28
	183	125	33	31
	150	94		

50 Degree	F.S.	R.S.	Fit values of differences	
	183	232	23	30
	160	202		
	153	174	16	24
	137	150	14	23
	123	127		
60 Degree				
	232	239	19	30
	213	209		
			16	26
	197	183	10	20
	187	163	17	16
	170	147	17	26
	153	121		
	123	109		
	90	92		
70 Degree				
	232	132		
	213	121	16	11
	197	110	14	11
	183	99	13	10
	170	89	17	12
	153	77	11	8
	142	69		
80 Degree				
	283	103		
	273	96	18	6
	255	90	8	1
	247	89	22	9
	225	80	18	5
	207	75		

Where all readings are in mm

L.S – Left sensor readings
F.S - Front sensor readings
R.S - Right sensor readings

Lastly, after a few cycles of fine tuning, a test run of the robot was carried out. The initial orientation of the robot was kept different from the angles chosen previously for design of the fuzzy controller.

Evaluation of the test runs shows that the corner navigation system executes the task of alignment with the wall and negotiating a turn at the corner with sufficient accuracy.

VII. Conclusions

In this paper we present the design of a fuzzy control system for autonomous robot navigation of corners using inaccurate sensor information. Our test bed robot was the Fire Bird IV platform from Nex Robotics. We successfully demonstrate the control action using a 36 rule controller. The robot navigates the corners smoothly. The successful implementation of the corner navigation system using fuzzy controller proves the utility of fuzzy logic and its application to uncertain and unknown real-world environments.

In a country like India where cost is of paramount consideration; economic indigenous techniques are prime requisites in research. Fuzzy logic has been an important tool for autonomous navigation for obstacle avoidance, decision making and context dependent behavior blending. The idea of corner navigation using fuzzy control can be extended for eliminating errors in components like wheel position encoders, speed control in driving motors.

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