Fuzzy Logic Controller For An Autonomous Mobile Robot

NAFIPS

June 24, 2005

Vamsi Mohan Peri

Dr. Dan Simon

Outline

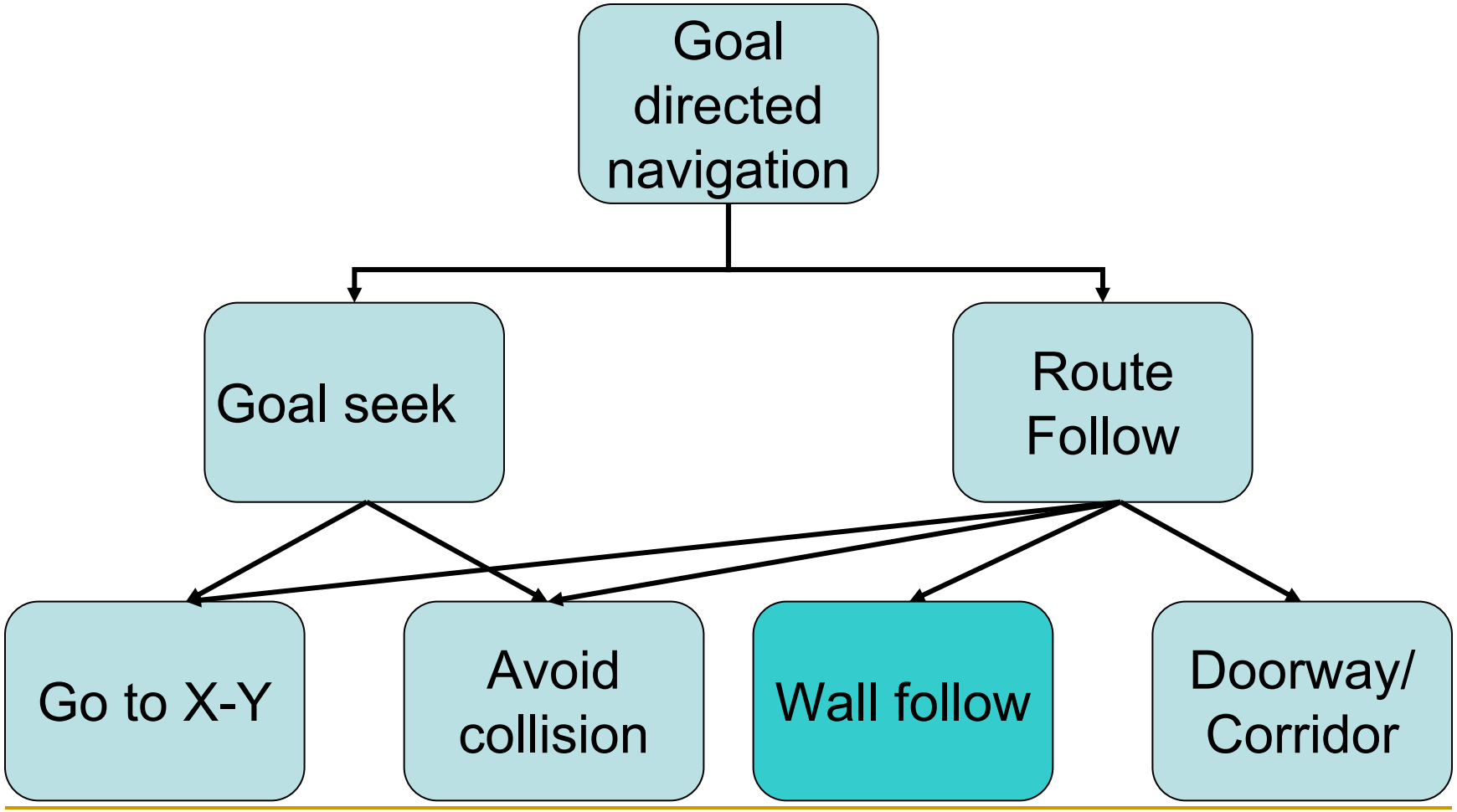
- Introduction
- Design of the Robot
- Fuzzy Logic Controller
- Hardware Description
- Software Description
- Results
- Applications
- Conclusions

Introduction

- Maintaining a fixed path on the course in order to keep the robot from getting lost.
- It should be totally autonomous, shouldn’t transmit or receive signals.

Design of the Robot

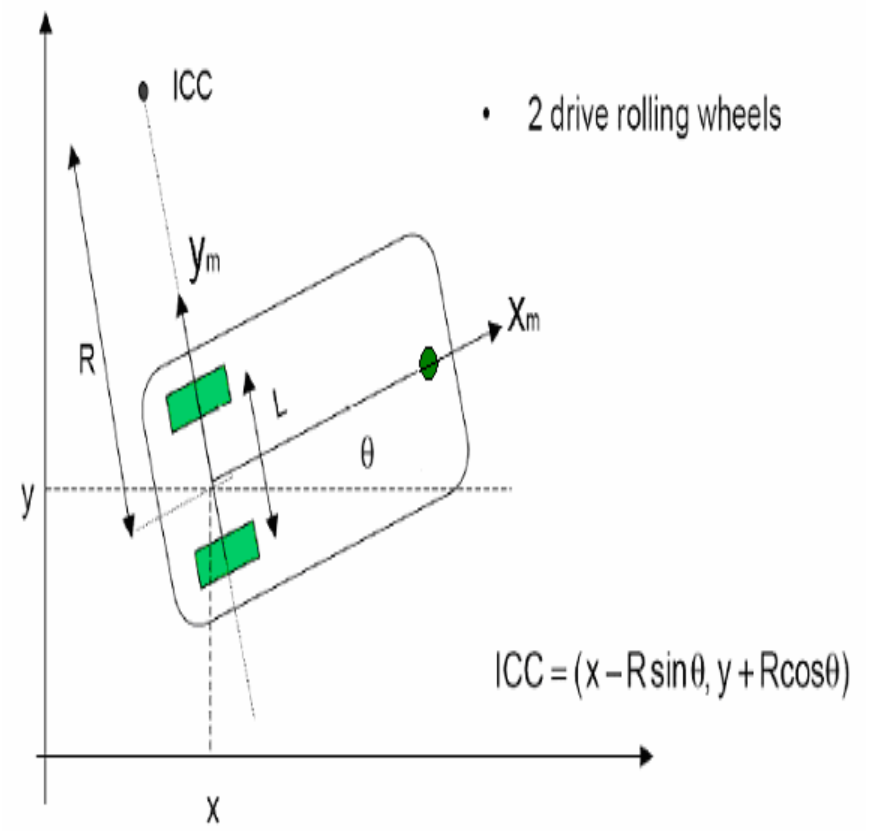
Types of Robotic Behavior



Components of the Robot

- Two wheels driven by servo motors.
- Translatory wheel for stability.
- Ultrasonic sensors to measure distances.
- PIC16F877 microcontroller.

Mathematical Model



- r = nominal radius of each wheel
- L = distance between the two wheels
- $w_r(t)$, $w_l(t)$ = angular velocities of wheels
- $v_r(t)$, $v_l(t)$ = linear velocities of wheels

System equations:

$$\dot{x}(t) = v(t)\cos\theta(t)$$
$$\dot{y}(t) = v(t)\sin\theta(t)$$
$$\dot{\theta}(t) = w(t)$$

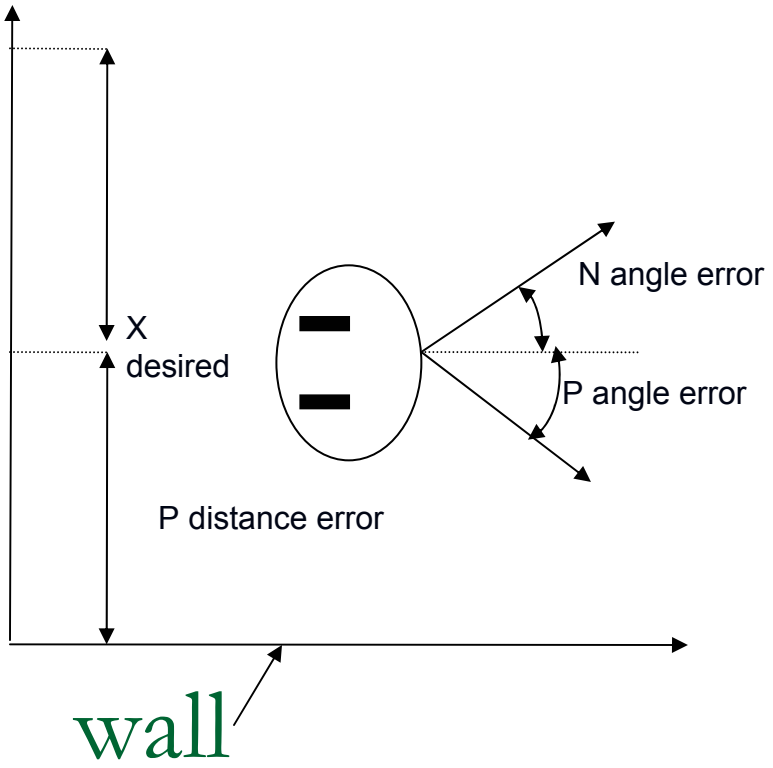
$$\begin{bmatrix} v_x(t) \\ v_y(t) \\ \dot{\theta}(t) \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\cos\theta & \frac{1}{2}\cos\theta \\ \frac{1}{2}\sin\theta & \frac{1}{2}\sin\theta \\ -1/L & 1/L \end{bmatrix} \begin{bmatrix} v_r \\ v_l \end{bmatrix}$$

Linear Velocity:

$$v(t) = w(t)R = \frac{1}{2}(w_r(t) + w_l(t))$$

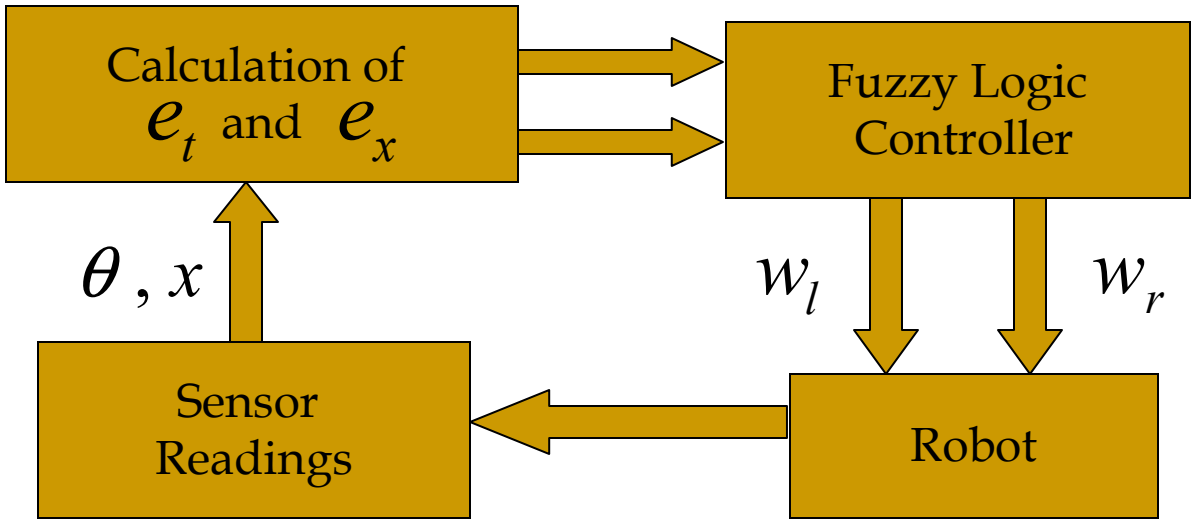
Control Objective

- Maintain the desired x distance.
- Maintain a zero degree angle with respect to x axis.
- Controlled variables
  - Right wheel angular velocity.
  - Left wheel angular velocity.



Fuzzy Logic Controller

Block Diagram of the System



- Two inputs are error in angle of orientation θ and error in distance x.

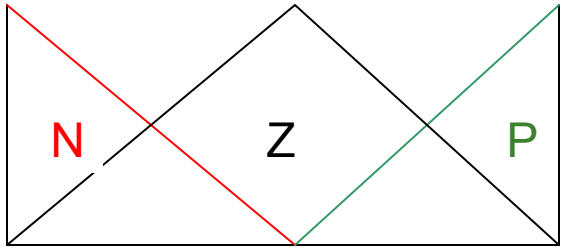
- The outputs of the controller would be pulse-width-modulated signals to control the angular velocity of the two servo wheels.

Universe of Discourse

- The range of error in angle e_t is -0.3 to +0.3 radians.
- The range of error in distance e_x is -4 to 4 inches.
- The angular velocities of the two wheels w_l and w_r range from -3 to 3 radians per second.

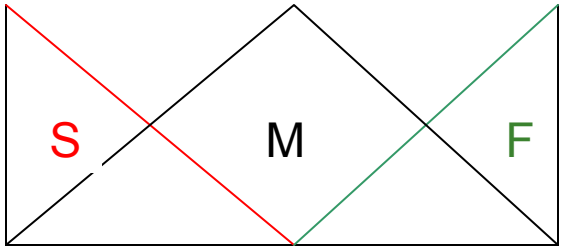
Membership Functions and Linguistic Variables

- The linguistic variables error in angle and error in distance have linguistic values N (negative), Z (zero), P (positive).



e_t	-0.3	0	0.3	radians
e_x	-4	0	4	inches

- The angular velocities of the two wheels and have linguistic values S (slow), M (medium) and F (fast).



w_r	-3	0	3	rad/sec
w_l	-3	0	3	rad/sec

Rule Base

e_x / e_t	N(Negative)	Z(Zero)	P(Positive)
N(Negative)	S(Slow)	S(Slow)	S(Slow)
Z(Zero)	S(Slow)	F(Fast)	M(Medium)
P(Positive)	S(Slow)	M(Medium)	F(Fast)

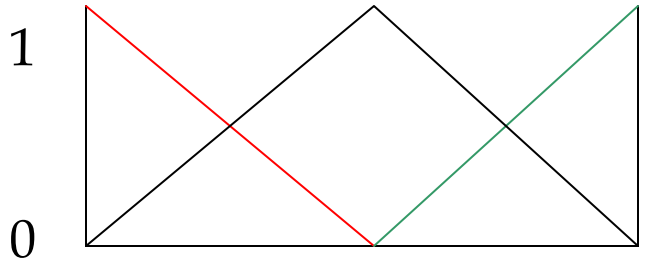
Angular velocity of left wheel

e_x / e_t	N(Negative)	Z(Zero)	P(Positive)
N(Negative)	F(Fast)	M(Medium)	S(Slow)
Z(Zero)	M(Medium)	F(Fast)	S(Slow)
P(Positive)	S(Slow)	S(Slow)	S(Slow)

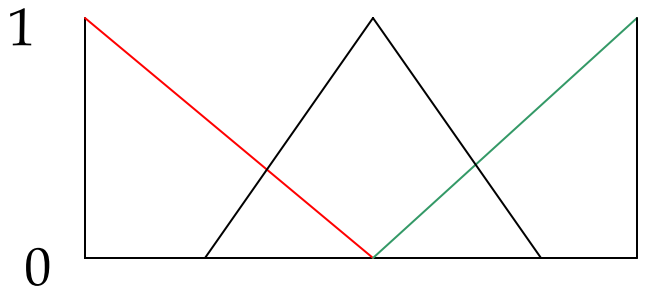
Angular velocity of right wheel

Types of Membership Functions Used

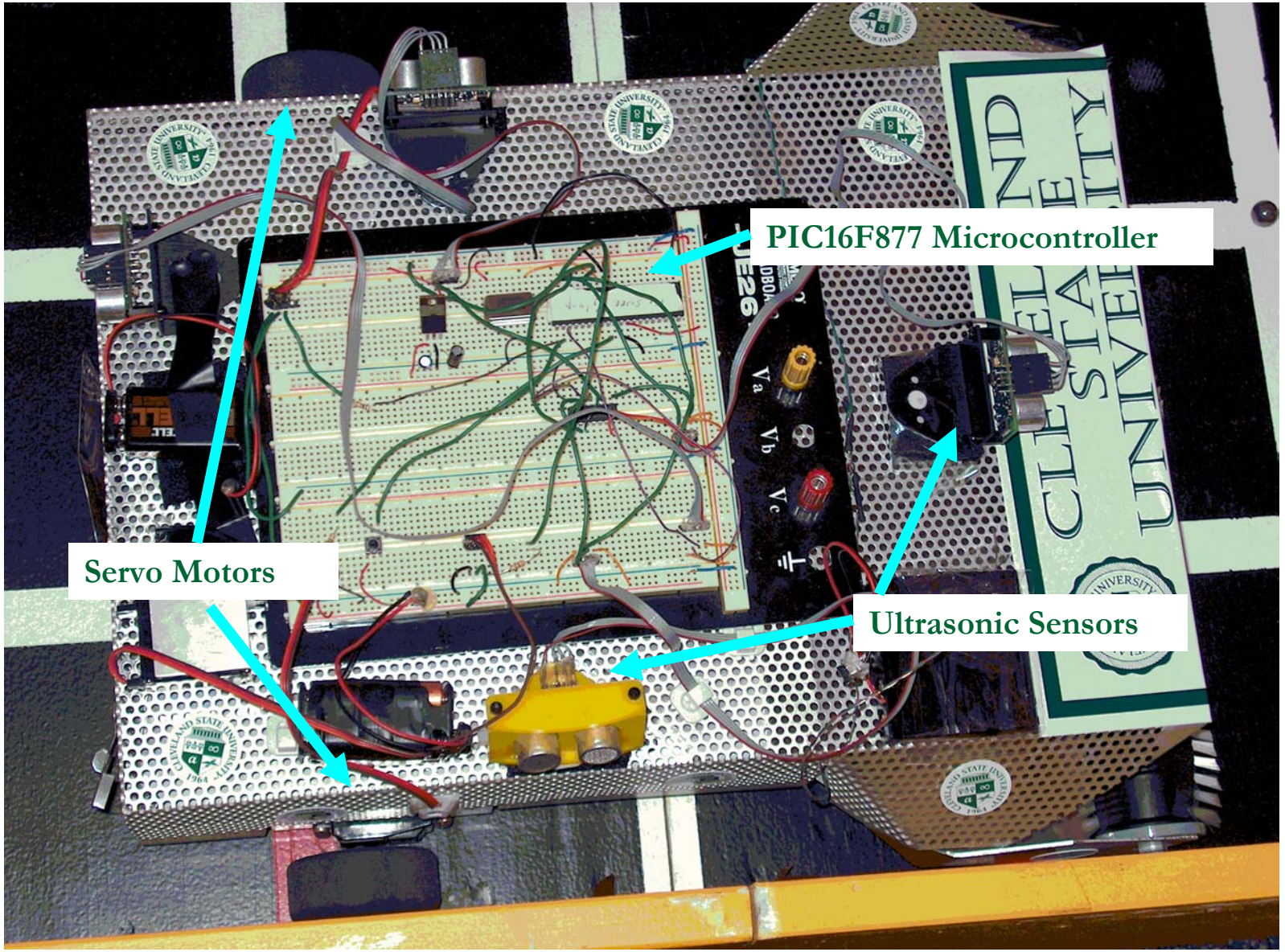
- Sum Normal Membership Functions.
  - Easier to implement.
  - Less computational effort.



- Non Sum Normal Membership Functions.
  - More versatile.
  - Computationally complex.



Hardware Description


PIC16F877 Microcontroller
Servo Motors
Ultrasonic Sensors

Servo Motor

- 0.15 second speed

through 60° revolution.

- Strong 44 oz-in operation

at 4.8 V .

- Weighs only 1.66 oz.

Ultrasonic Sensor

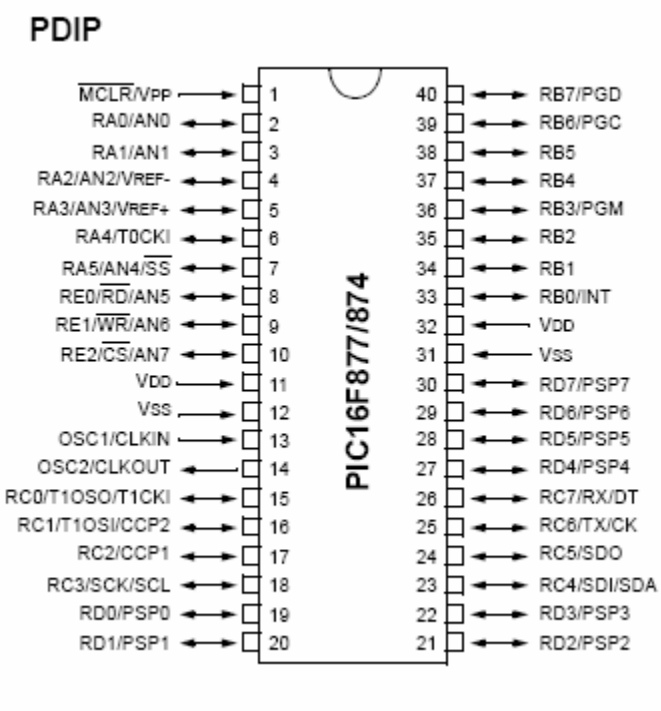
- Devantech SRF04 ultrasonic range finder.

- Offers precise ranging information from 3 cm to 3 meters.

- Easy interfacing, and minimal power requirements.

PIC16F877 Microcontroller

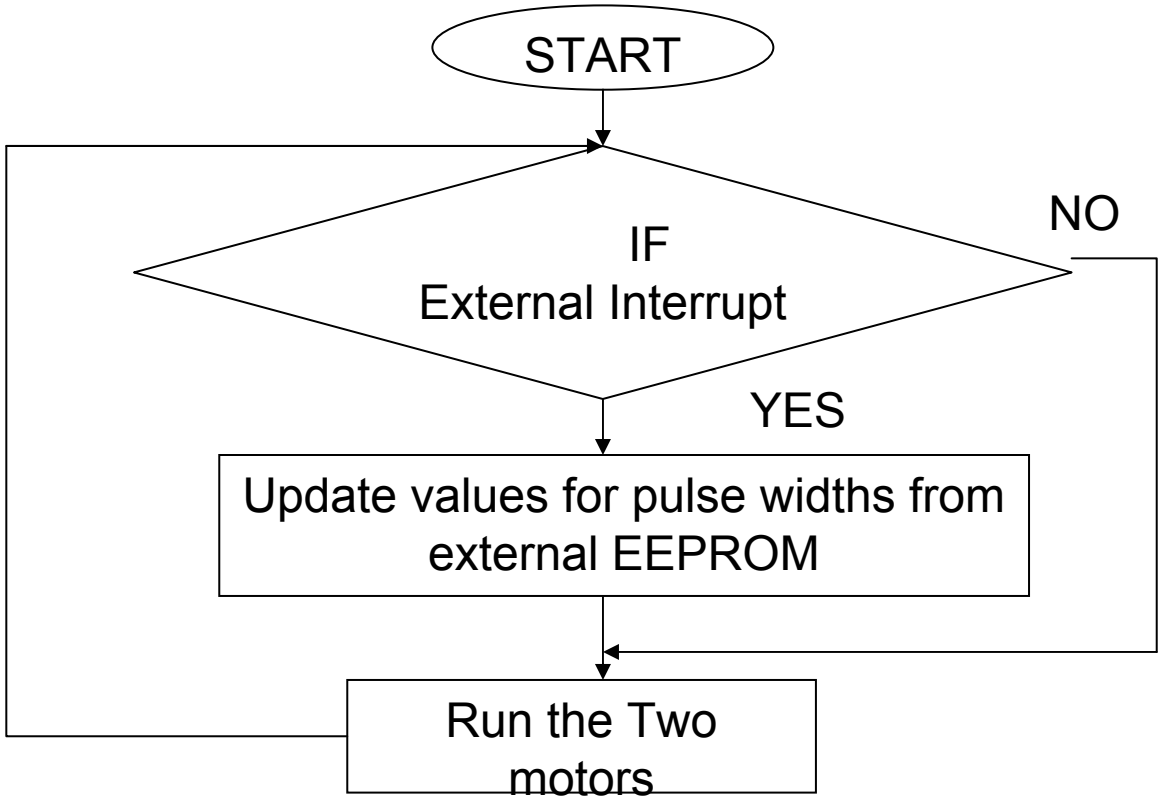
- High performance RISC CPU.
- Wide operating voltage range: 2.0 V to 5.5 V.
- Uses 4 MHz clock.
- 250 ns instruction cycle.
- Low-power consumption < 0.6 mA typical @ 3 V, 4 MHz



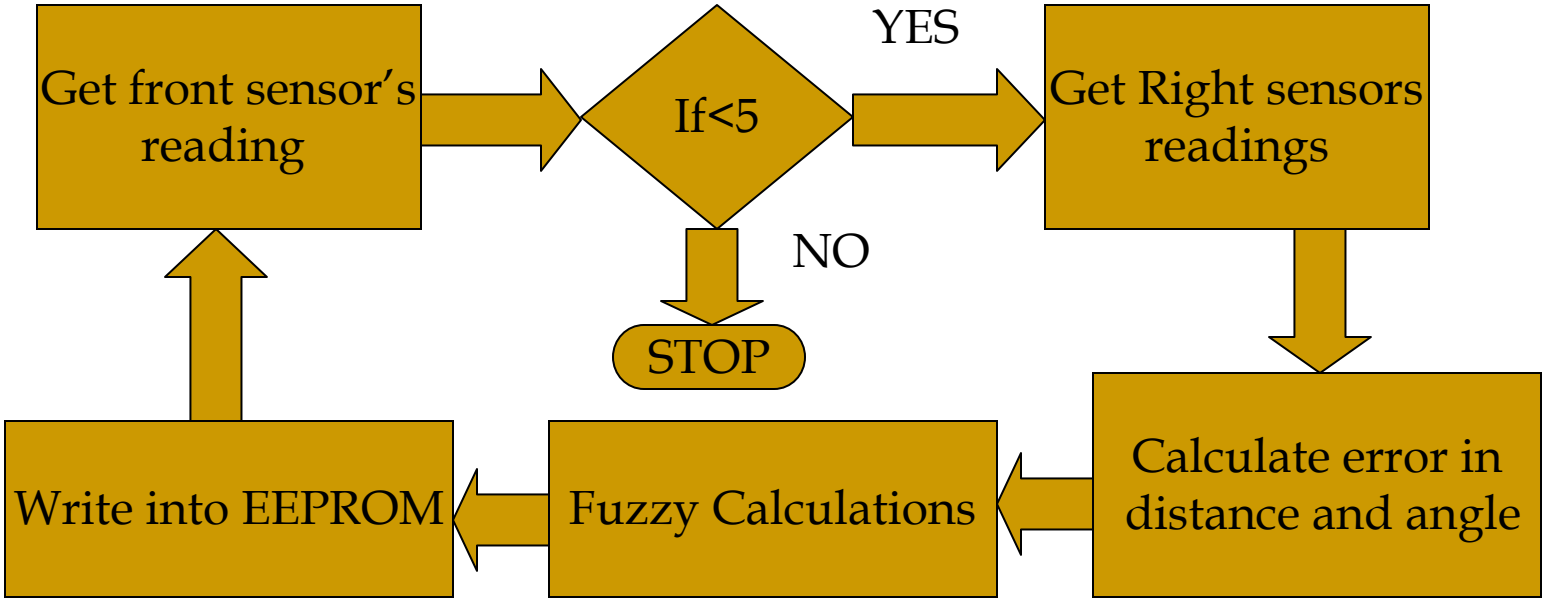
Software Description

- The mobile robot was first simulated in SIMULINK.
- Fuzzy logic toolbox was used initially.
- Next M-files were written to simulate the whole system.
- The microcontroller was programmed using a CCS C-compiler with debugger.

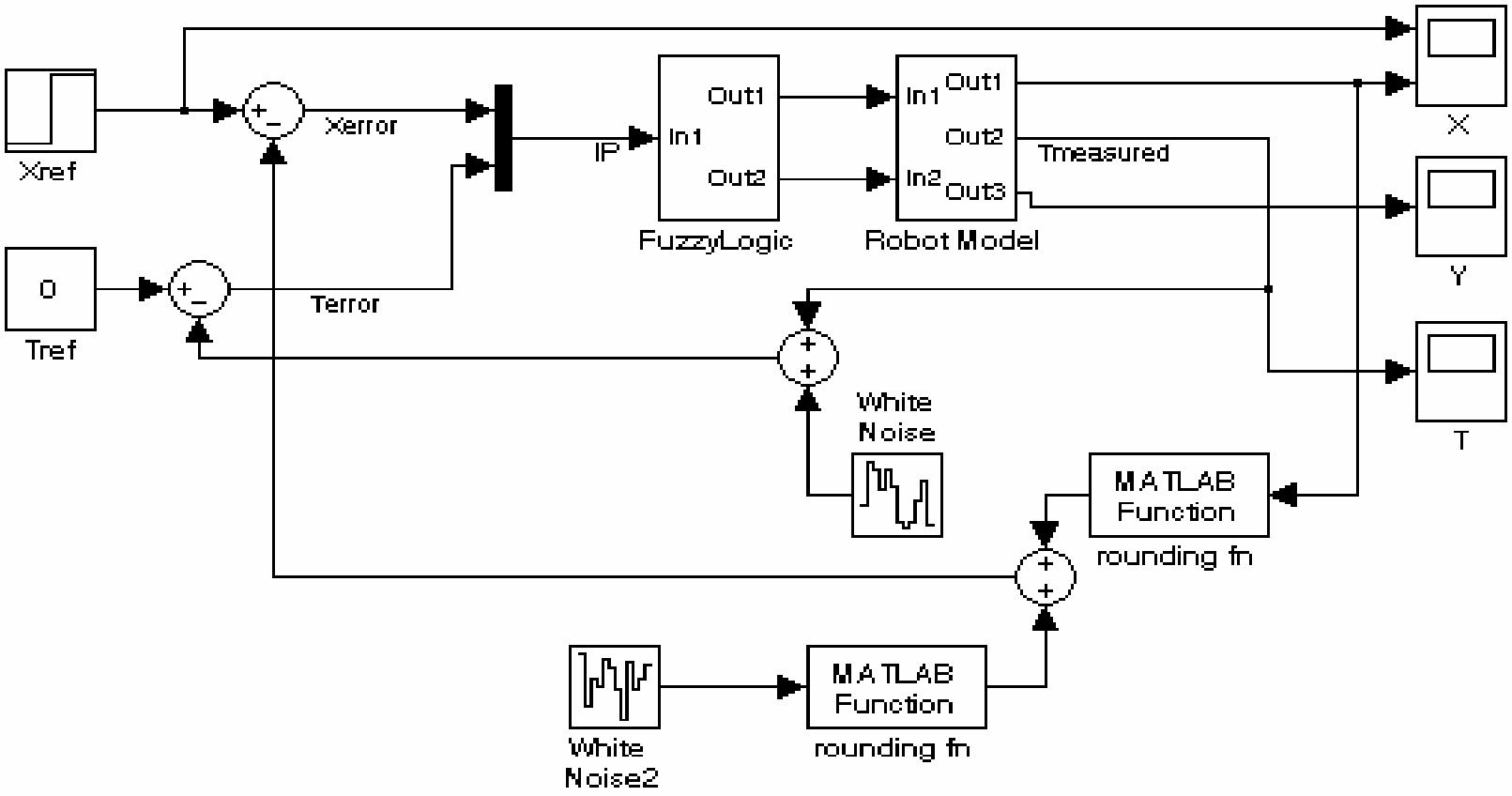
Flow chart for PIC16F877 controlling the servo motors.



Flow chart for PIC16F877 for fuzzy calculation and sensor control.



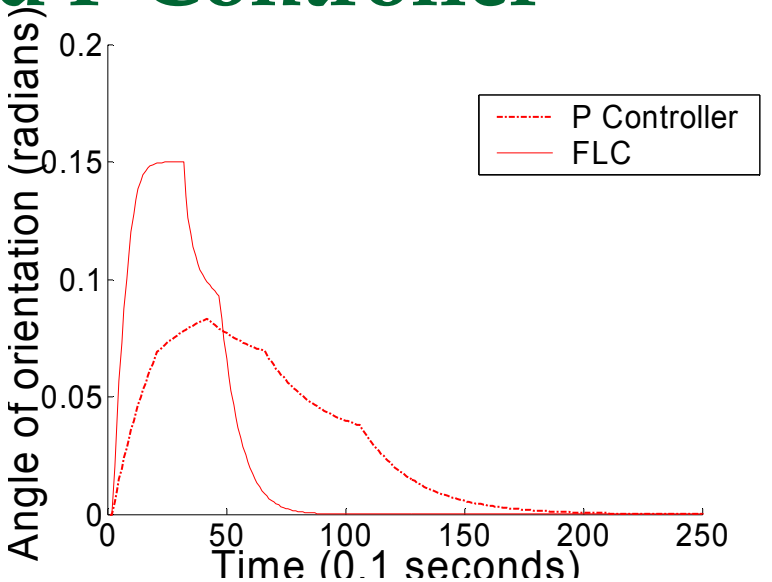
SIMULINK Model of the Robot

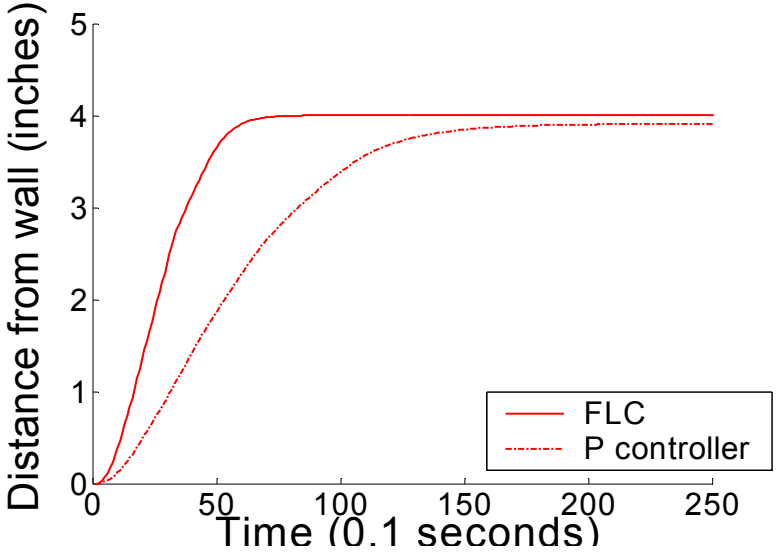


Results

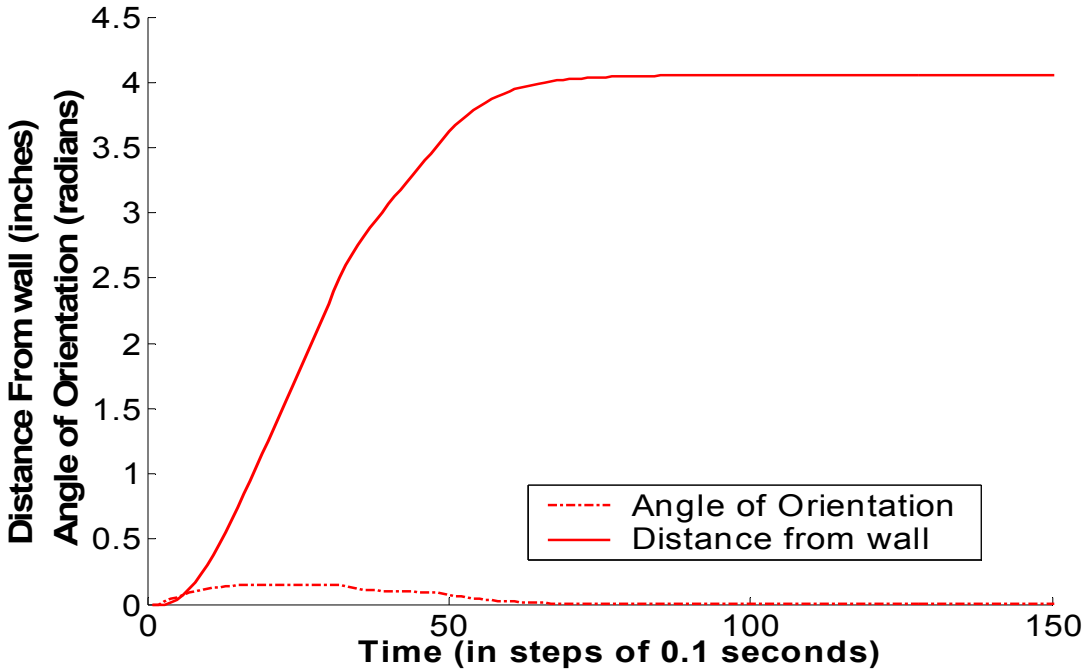
Comparison of FLC and P Controller

- The P controller is trained using Genetic Algorithm.
- Steady state error is smaller than the P controller.
- The P controller has a longer rise time than a FLC controller.



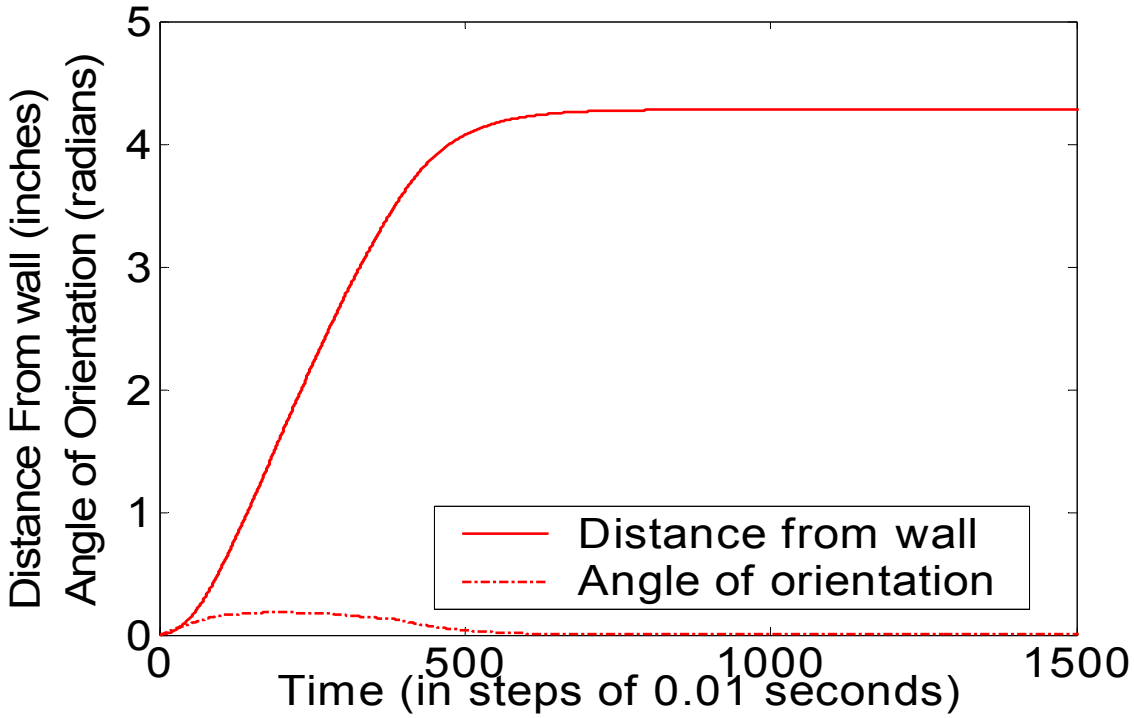


FLC with Non Sum Normal Fuzzy Membership Functions



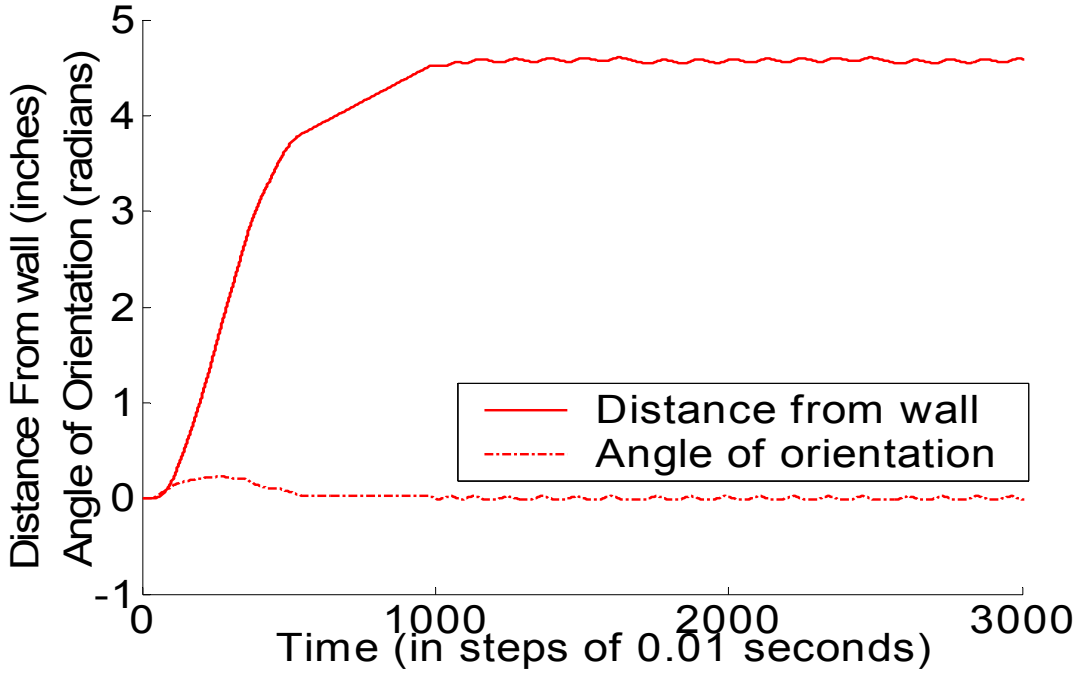
- Output obtained when using sensor values not taking its limitations into account.
- Time delay is not added to simulate the microcontroller.

Using FLC with Sum Normal Fuzzy Rules



- Output obtained when using sensor values not taking its limitations into account.
- Time delay is not added to simulate the microcontroller.

Using FLC with Sum Normal Fuzzy Rules



- The output from the sensors are rounded to the nearest inch.
- A delay of 360 milliseconds is added to simulate time delay in fuzzy calculations.

Comparison of P Controller, FLC with Sum Normal Membership Functions and FLC with Non Sum Normal Membership Functions

		Without lookup table		With lookup table	
	P Controller	FLC(NSN)	FLC (SN)	FLC (NSN)	FLC (SN)
Rise time x (distance from wall) (seconds)	7.32	4.23	3.73	3.49	3.49
Rise time θ (angle of orientation) (seconds)	4.26	0.53	0.78	0.77	0.89
Peak value Δe_t (radians)	0.0832	0.1657	0.2070	0.1500	0.1860
Peak value Δe_x (inches)	3.91	4.5004	4.9992	4.0034	4.2809
Steady state error (Δe_x) (inches)	0.0896	0.4971	0.4972	0.0034	0.2809
Computational time (MATLAB) (seconds)	0.0005	1.1344	0.088	0.0013	0.0013

Applications

- Agricultural applications.
- Military applications.
- Relief and rescue operations.
- Remote navigation and exploration.

Conclusions

- The highly nonlinear dynamic model of the mobile robot is developed.
- Fuzzy logic controller was implemented in real time.
- A traditional P controller and the fuzzy logic controller were compared and it was noticed that the fuzzy logic controller outperforms the P controller.

Thank You