This chapter describes individual fuzzy behavior control for robot navigation and low cost robot design methodology. It begins by pointing out individual behaviors and principle of operation. The standard behavior of a system is to react to a particular stimulus. Robot control behaviors are elementary units that lead the robot towards achieving specific goals. Different behaviors may share the same sensory information, but yield different reactions. Control activities are the actions that are taken by the behaviors in achieving their goals. These actions involve changing particular control parameters such as, changing the speed of right and left wheel.

The heading control activity controls the heading direction of the robot. This requires five behaviors to be satisfied 1) Obstacle avoidance, 2) Pit avoidance, 3) Wall following, 4) Goal seeking and 5) Slope riding etc. Its control command is to control the speed of right and left wheel. The Speed control of wheels is done by using PWM. Input and output parameters of various behaviors are fuzzified and they are related with fuzzy inference rules. The speed control activity determines whether the speed of right and left wheel should be increased or decreased; its control command is the speed change for different behaviors, like terrain-based behavior and slope riding behavior etc. Input and output parameters for controlling speed for various behaviors are fuzzified and related with fuzzy inference rules for taking final control activity.

3.1 FEATURES OF AUTONOMOUS ROBOT

Automated Guided Vehicle/ Autonomous Robot working in factory environment are considered to come across following features:

- Goal Seeking Behavior (GSB)/Way Point Steering (WPS)
- Obstacle Avoidance Behavior (OAB)
- Pit Avoidance Behavior (PAB)
- Edge Following Behavior (EFB)/Wall Following Behavior (WFB)
- Localization-Based Behavior (LBB) / Position Based Behavior (PBB)
• Slope Riding Behavior (SRB)
• Terrain-Based Behavior (TBB)

Localization Behavior: Initial positioning and target steering of mobile robot is done with low cost LDR sensors. Eight LDR sensors are positioned at an angle of 45° as shown in fig. 3.1. The angle selection depends on the incremental turn required for robot navigation.

![Forward Position](image)

<table>
<thead>
<tr>
<th>Source detected sensor</th>
<th>Desired Turn</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE1</td>
<td>0 Deg</td>
</tr>
<tr>
<td>CE2</td>
<td>45 Deg Right</td>
</tr>
<tr>
<td>CE3</td>
<td>90 Deg Right</td>
</tr>
<tr>
<td>CE4</td>
<td>135 Deg Right</td>
</tr>
<tr>
<td>CE5</td>
<td>180 Deg Right</td>
</tr>
<tr>
<td>CE6</td>
<td>135 Deg Left</td>
</tr>
<tr>
<td>CE7</td>
<td>90 Deg Left</td>
</tr>
<tr>
<td>CE8</td>
<td>45 Deg Left</td>
</tr>
</tbody>
</table>

Fig. 3.1: Sensor position and desired turn for localization

Fuzzy Input from the sensors:
LDR1, LDR2, LDR3, …, LDR8= [Detected (D), Not Detected (ND)]

Fuzzy output:
Right Wheel (RW) = [Stop (S), Turn (T)]
Left Wheel (LW) = [Stop (S), Turn (T)]

Fuzzy rules for the localization behavior:
Example:
IF <LDR1 is D> THEN <Desired Turn is – RW is S & LW is S>
IF<LDR2 is D> THEN < Desired Turn is – RW is S & LW is T >
IF<LDR3 is D> THEN < Desired Turn is – RW is S & LW is T >
IF<LDR4 is D> THEN < Desired Turn is – RW is S & LW is T >
IF<LDR 5 is D> THEN < Desired Turn is – RW is S & LW is T >
IF<LDR6 is D> THEN < Desired Turn is – RW is T & LW is S >
IF<LDR7 is D> THEN < Desired Turn is – RW is T & LW is S >
IF<LDR8 is D> THEN < Desired Turn is – RW is T & LW is S >
**Obstacle Avoidance Behavior:** The robot is equipped with 9 Infrared range sensors to avoid obstacles. These sensors identify the obstacle, which is present in right, left and front. When the IR sensors detect that there are obstacles appearing around the robot, the controller has to slow down the speed of the robot and then it has to start avoiding the obstacles. To enable the robot to avoid obstacles, all required fuzzy rules should be installed in the controller.

Inputs from sensor to microcontroller:
IR1, IR2, IR3, IR4, IR6, IR7, IR8, IR9 = [Near Range (NR), Far Range (FR)]

Outputs to differential drive motors:
Right Wheel (RW) = [Stop (S), Turn (T)]
Left Wheel (LW) = [Stop (S), Turn (T)]

Fuzzy rules for the Obstacle avoidance behavior:
Example: (Preference given to Right)
IF<IR4 is FR> and <IR6 is FR> THEN<RW is T and LW is T>
IF<IR4 is NR> THEN<RW is S and LW is T>
IF<IR4 is NR> and <IR4 is NR> and <IR6 is NR> THEN<RW is S and LW is T>
IF<IR3 is NR> and <IR4 is NR> and <IR6 is NR> and <IR7 is NR> and <IR8 is NR> THEN<RW is S and LW is T>
IF<IR2 is NR> and <IR3 is NR> and <IR4 is NR> and <IR6 is NR> and <IR7 is NR> and <IR8 is NR> THEN<RW is S and LW is T>
IF<IR4 is FR> and <IR6 is NR> THEN<RW is T and LW is S>
IF<IR3 is FR> and <IR4 is NR> and <IR6 is NR> and <IR7 is NR> THEN<RW is T and LW is S>
IF<IR2 is FR> and <IR3 is NR> and <IR4 is NR> and <IR6 is NR> THEN<RW is T and LW is S>
IF<IR1 is FR> and <IR2 is NR> and <IR3 is NR> and <IR4 is NR> and <IR6 is NR> and <IR7 is NR> and <IR8 is NR> and <IR9 is NR> THEN<RW is T and LW is S>

**Pit Avoidance Behavior:** The robot is equipped with four IR sensors for pit detection and avoidance. Four IR sensors are used to obtain information from the dynamic environment that the robot travels through. The sensors are so mounted that they can detect pits which are in the left, front and right side of the vehicle.
Inputs from sensors: Infra Red Extended Sensors (IRE):
IRE1, IRE2, IRE3, IRE4, IRE5, IRE6 = [Reference Range (RR), Pit Range (PR)]

Outputs to differential drive motors:
Right Wheel (RW) = [Stop (S), Turn (T)]
Left Wheel (LW) = [Stop (S), Turn (T)]

Fuzzy rules for the Pit avoidance behavior:
Example: (Preference given to Right)
IF <IRE3 is RR> and <IRE4 is RR> THEN <RW is T and LW is T>
IF <IRE3 is PR> THEN <RW is S and LW is T>
IF <IRE4 is PR> THEN <RW is T and LW is S>
IF <IRE3 is PR> and <IRE4 is PR> THEN <RW is S and LW is T>
IF <IRE3 is PR> and <IRE4 is PR> and <IRE5 is PR> THEN <RW is T and LW is S>
IF <IRE2 is PR> and <IRE3 is PR> and <IRE4 is PR> and <IRE5 is PR> and <IRE6 is PR> THEN <RW is T and LW is S>

Wall or Edge Following Behavior: This behavior allows the robot to follow the wall while maintaining its navigation with reference. In this behavior, there is a need for sensing along wall. The side sensors sense how far the wall is and also on which side. Behavior action keeps the robot moving forward keeping a wall reference. Left wall following behavior is sensed by sensors IR1 and IR2, whereas the right wall is sensed by sensors IR8 and IR9.

Inputs from sensor to microcontroller:
IR1, IR2, IR8, IR9 = [Wall Reference (WR), Near to Wall (NW), Far from Wall (FW)]

Outputs to differential drive motors:
Right Wheel (RW) = [Stop (S), Turn (T)]
Left Wheel (LW) = [Stop (S), Turn (T)]

Fuzzy rules for the Wall or Edge following behavior:
Example:
IF <IR1 is WR> and <IR2 is WR> THEN <RW is T and LW is T>
IF<IR8 is WR> and <IR9 is WR> THEN<RW is T and LW is T>
IF<IR1 is WR> and <IR2 is FW> THEN<RW is T and LW is S>
IF<IR8 is FW> and <IR9 is WR> THEN<RW is S and LW is T>
IF<IR1 is WR> and <IR2 is NW> THEN<RW is S and LW is T>
IF<IR8 is NW> and <IR9 is WR> THEN<RW is T and LW is S>

**Slope Riding Behavior:** This behavior is activated by using IR5 sensor along with sensors IR 4 and IR 6. If the front three sensors detect the obstacle then it treats it as obstacle, but in case only the sensor IR5 detects the object at low range, then it treats it as slope and it moves over the slope to reach the goal point.

Inputs from sensor to microcontroller:

IR4, IR6 = [Detected (D), Not Detected (ND)]
IR5 = [Detected (D), Not Detected (ND)]

Outputs to differential drive motors:

Right Wheel (RW) = [Stop (S), Turn (T)]
Left Wheel (LW) = [Stop (S), Turn (T)]

Fuzzy rules for the Slope Riding behavior:

Example:

IF<IR4 is ND> and <IR5 is ND> and <IR6 is ND> THEN<RW is T and LW is T>
IF<IR4 is ND> and <IR5 is D> and <IR6 is ND> THEN<RW is T and LW is T>
IF<IR4 is D> and <IR5 is D> and <IR6 is ND> THEN<RW is S and LW is T>
IF<IR4 is ND> and <IR5 is D> and <IR6 is D> THEN<RW is T and LW is S>
IF<IR4 is D> and <IR5 is D> and <IR6 is D> THEN<RW is S and LW is T>

**Terrain Based Behavior:** This behavior works out with six IR sensors (IRE1, IRE2, IRE3, IRE4, IRE5 and IRE6) which are directed towards the ground. Depending on the range of values obtained from these sensors decision is taken. If the sensors give same range of values then speed is higher, if it gives different range of values, then robot moves with lower speed.

Inputs from sensor to microcontroller:

IRE3, IRE4 = [Near to Reference (NR), Far to Reference (FR)]

Outputs to differential drive motors:

PWM values High and Low
Right Wheel (RW) = [Low (L), High (H)]

Fuzzy rules for the Terrain based behavior:
Example:
IF <IRE3 is NR> and <IRE4 is NR> THEN <RW is H and LW is H>
IF <IRE3 is NR> and <IRE4 is FR> THEN <RW is L and LW is L>
IF <IRE3 is FR> and <IRE4 is NR> THEN <RW is L and LW is L>

Waypoint and Goal Point Behavior: The robot is equipped with eight LDR sensors which sense the light of different intensity. Here, different intensity lights are used for way point recognition. The inputs are received from LDR a sensor, first it aligns towards the desired direction and then it ahead’s towards the way point.

Fuzzy Input from the sensors:
LDR1, LDR2, LDR3, …, LDR8= [Detected(D), Not Detected (ND)]

Fuzzy output to the differential drive motors:
Right Wheel (RW) = [Slow (S), Fast (T)]
Left Wheel (LW) = [Slow (S), Fast (T)]

Fuzzy rules for the localization behavior:
Example:
IF <LDR1 is D> THEN <Desired Turn is – RW is S & LW is S>
IF <LDR2 is D> THEN <Desired Turn is – RW is S & LW is T >
IF <LDR3 is D> THEN <Desired Turn is – RW is S & LW is T >
IF <LDR4 is D> THEN <Desired Turn is – RW is S & LW is T >
IF <LDR 5 is D> THEN <Desired Turn is – RW is S & LW is T >
IF <LDR6 is D> THEN <Desired Turn is – RW is T & LW is S >
IF <LDR7 is D> THEN <Desired Turn is – RW is T & LW is S >
IF <LDR8 is D> THEN <Desired Turn is – RW is T & LW is S >

3.2 LOW COST FUZZY-BASED AUTONOMOUS ROBOT

Idea behind this concept generation is to provide easy methodology to develop low cost autonomous robot for research as well as for learning purpose. This can easily be adopted for executing any features of robots. Individual behavior listed
above is tested by using low cost conceptualizations. As LDR is a low cost sensor and this is not much reliable because of its variation to the natural light. It’s very difficult to tune the LDR sensors. So in this experiment light emitting objects are considered to execute the behaviors.

**Goal Seeking Behavior (GSB)/ Way Point Steering (WPS):** Eight LDR sensors are mounted on top of the robot for goal seeking/ way point steering purpose. While conducting experimental trials, lighted torch beam is made to fall on different LDR sensors to check the way point steering. Way points are differentiated by using different intensity light beams.

**Obstacle Avoidance Behavior (OAB):** Eight LDR sensors are mounted on front, right, front right, left, and front left of the robot for obstacle avoidance, while running experiment lighted torch beam is made to fall on different LDR sensors. Here LDR sensors treats light beam as obstacle. Algorithm execution is checked for single and multi-obstacle context.

**Pit Avoidance Behavior (PAB):** Six extended LDR sensors are used for pit recognition and avoidance, sensors are tuned for two values one without light, that treated as surface and other value is tuned to the light beam that acts as pit. The experiment is conducted and validated for front, left and right side pit.

**Edge Following Behavior (EFB)/Wall Following Behavior (WFB):** This feature uses the side LDR sensors (1, 2, 8, & 9). It’s very difficult to execute the edge or wall following behavior in its usual method. Hence, here new concept defined; according to this new concept, autonomous robot is rotating in its own place, until the beam of light is made to fall on the side sensors. Whenever the sensors sense the light, it starts following the torch light.

**Localization-Based Behavior (LBB) / Position Based Behavior (PBB):** Eight LDR sensors are mounted on top of the robot for localization purpose, while running experiment lighted torch beam is made to fall on different LDR sensors to check the localization with respect to its own place. Localization sensors share the same LDR sensors for the goal point.

**Slope Riding Behavior (SRB):** This feature execution is done using three front sensors. The sensor 5 is especially for slope riding behavior. During the
experimental run, if sensor 5 identifies light then it treats as slope, but in case if the entire three sensors recognizes the light, then it treats as obstacle.

**Terrain-Based Behavior (TBB):** This behavior execution in real time application requires costly sensors like camera, LIDAR etc. but in low cost concept different intensity of light is made to fall on the extended sensors by that it decides the unevenness of the surface. If the values are same then the controller detects the surface as flat surface then it sends the signal to the controller to move fast.