Proceedings of the 6th WSEAS International Conference on Robotics, Control and Manufacturing Technology, Hangzhou, China, April 16-18, 2006 (pp242-247)

Fuzzy Behaviour Based Navigation of a Mobile Robot for Tracking Multiple Targets in an Unstructured Environment

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Abstract: - This paper presents fuzzy behaviour based control for a differential drive mobile robot in an unstructured environment capable of tracking priority based multiple targets. Behaviours implementation is done by incorporating the obstacle range data from each ultrasonic range finder, current location of mobile robot and selected target location based on its priority. This behaviour based control architecture is composed of two layers; the first layer selects a group of behaviours and second implements controller actions for the selected group. The layered architecture reduces the rule base as well as allows further decomposition of behaviours. The behaviour conflict management is done by using inhibition at first layer and suppression at second layer. The selection of the next target to be tracked is done on the basis of predefined priorities and conflict among equal priority targets is resolved by minimum Euclidean distance measure. Simulation results verify the effectiveness of proposed method by implementing Obstacle Avoidance, Wall Following, Corridor Following, Target Steering and Emergency behaviours successfully in a single, and multiple target environments. Moreover the conflict management scheme for tracking multiple targets with equally priority is also validated.

Key-Words: - Fuzzy Behaviour Controls, Multiple Target Tracking, Obstacle Avoidance, Ultrasonic Range Finders

1 Introduction

The environment for mobile robot navigation is classified into structured, semi-structured and unstructured. The architecture for autonomous navigation systems depends not only on the area of application but also on the information that a robot posses about the environment. The collision avoidance capability of mobile robot is one of the major building blocks for autonomous mobile robot navigation system. The aim of intelligent mobile robotics is to develop more and more autonomous machines possessing perceptive and cognitive capabilities. The information fusion from multiple sensors is found to be useful in the implementation of correct and rapid decision mechanism. Behaviour based controls first proposed by Brooks [1] used the stimulus response for providing perspective and cognitive capabilities. Behaviour based controls has been established as the main alternative to conventional robot controls and serve as building blocks for the robotic actions [2].

The type of the sensors and their number to be used are decided on the basis of behaviours that a robot has to perform. Even more than one type of sensors can be used to extract the same information. The selection among the sensors can be done by keeping in mind some of the key factors like area of application, information contents, processing time and overall cost of the system.

Ultrasonic Sensors are used in environment detection and found to be low cost, simple structure, small volume, light gravity and have a little information to process [3][4][5]. Elfes used the occupancy grid for the spatial information from the ultrasonic sensors whereas Lim and Cho developed a system that uses sonar range data to build a map of robot's environment. Alves proposed an ultrasonic sensing system for mobile robot navigation using step motors to turn direction of the ultrasonic sensors so one sensor can give the capability of two or more sensors to a system.

The data from multiple sensors are fused together in one representation format which makes the detected environment information more useful [6]. In [7] an evidential approach is used for navigation of a mobile robot. The literature [8] [9] [10] describe a strong mathematical model for behaviour coordination for navigation problem, but limitation is the insufficient knowledge perception of the environment. So expertise human knowledge is essential to develop the navigation strategies for a mobile robot. This paper presents fuzzy logic based behaviour controls for tracking multiple targets in an unstructured environment.

This paper is organized as follows: Section 1 is introduction. Fuzzy Logic behaviour based controls is presented in Section 2 while Section 3 includes the vehicle, sensors description and behaviour realization. The simulations are presented in Section 4. Finally conclusions and future work is presented in Section 5.

2 Fuzzy Logic Behaviour Based Controls

2.1 Fuzzy Logic

Fuzzy logic and fuzzy set theory was first introduced by L. A. Zadeh in 1965 [11]. There are three steps for designing a fuzzy controller: fuzzification interface, inference mechanism, and defuzzification interface.

Fuzzification interface is the mapping from a real world point to fuzzy set. Singleton, Gaussian, Triangular membership functions can be used to map the non-fuzzy input data to fuzzy sets. Fuzzy inference mechanism is used to combine the fuzzy IF-THEN in the fuzzy rule base and to convert the input information into output membership functions. A defuzzification interface converts the conclusions of the inference mechanism into actual inputs for the system. Different methods like Centre of Gravity (COG), Centre of Average etc. can be used for defuzzification.

2.2. Behaviour Based Controls

Behaviour based controls includes the selection of appropriate behaviour building blocks for a particular robotic system and how the coordination between the behaviour is done. The system control is divided into a set of control actions. One or more actions are selected on the basis of sensory information. The decomposition of behaviours into multiple parallel behaviours is done to reduce the complexity and rule base.

The field of behaviour based controls has evolved drastically and many different techniques are presented by Arkin [2], Kasper, Fricke, and Puttkamer [12]. The mobile robot navigation control systems combine different behaviours like obstacle avoidance, corridor following, wall following, target steering etc. to perform the desired task.

2.2.1 Obstacle Avoidance Behaviour

This behaviour includes avoidance of obstacle if some obstacle comes in front of it when steering towards the target. The obstacle avoidance behaviour uses the sonar sensor data to generate a fuzzy set that represents distance of the mobile robot from obstacles. The fuzzy inputs are the data from sensors placed in front side of the mobile robot. Further decomposition of this behaviour is left obstacle avoidance, right obstacle avoidance and front obstacle avoidance. The selection among decomposed behaviours is also done on the basis of sensory information.

2.2.2 Corridor Following Behaviour

When the mobile robot is moving in an environment where both sides have obstacles then it tries to maintain equal distance with both side walls to avoid any type of collision.

2.2.3 Wall Following Behaviour

In an indoor environment the mobile robot may encounter wall on any one side and has to follow it unless it gets its way towards the target. This behaviour is divided on the basis that either left wall following or right wall following needed.

2.2.4 Target Steering Behaviour

Mobile robot navigation incorporates different actions to finally reach a target. The target may be an x-y location in a plane or any particular location whose information is either previously known or being supplied online to it using some localization system.

2.2.5 Emergency Behaviour

This behaviour is executed either when there is no target left to be tracked or no other behaviour can be executed. This condition eventually stops the mobile robot.

2.3 Behaviour Coordination

The simultaneous activation of multiple desired behaviours affects the output tremendously. The behaviour coordination mechanism ensures simultaneous activity of several independent behaviours and obtains a coherent behaviour that achieves the intended navigational task. The correct coordination among different behaviours can be accomplished by using suppression as well as inhibition subject to sensory information. In behaviour coordination the main emphasis is on the command fusion in case of conflicts between simultaneously activated behaviours.

Fig.1 shows that there is a need of behaviour conflict management when the wall following behaviour is required and the obstacle avoidance behaviour puts unwanted effects and drags the mobile robot to execute obstacle avoidance behaviour.

The inhibition of certain behaviour can be done by stopping the behaviour or multiple behaviours execution based on the sensory information. The simultaneous activated behaviours output are fused together by assigning appropriate weights by the weight assignment mechanism and combining the effect by suppression the less wanted behaviours using formula given in (1)

$$y_0 = \frac{w_h y_h + \sum_{i \in s} w_i y_i}{w_h + \sum_{i \in s} w_i} \quad (1)$$

Where the values of the weights w_h and w_i for output is computed by using the min-max inference and the COG deffuzification method.

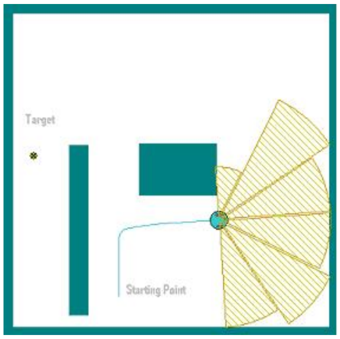

Fig. 1 Obstacle Avoidance Executed Wall Following Required

2.4 Target Selection Criterion

The activation of the target among multiple targets is done by predefined priorities and the conflict among the two or more targets possessing equal priorities is resolved by Euclidian distance measure.

3 Vehicle, Sensor Arrangement, and Behaviour Based Controls Realization

3.1Vehicle and Sensor Arrangement

The differential drive control system uses relative velocities of both wheels to steer towards right, left and front and can also pivot around a point and change its direction. Six ultrasonic range finders are placed on the front side of the robot at an angle of 30 degree from each other as shown in the Fig. 2. The range data from six ultrasonic sensors and information of heading angle i.e. angle of the target from orientation angle of the vehicle is used as an input to the fuzzy controllers.

The range data from right most to the left most ultrasonic sensors are termed as S0, S1, S2, S3, S4, and S5 respectively. SL is minimum of S4 and S5, SF is minimum of S2 and S3, SR is minimum of S0 and S1, dS5 is difference between S5(n) and S5(n-1), dS0 is difference between S0(n) and S0(n-1), and dS05 is the difference between S5 and S0. H is the heading angle for approaching target and T is the target's spatial information.

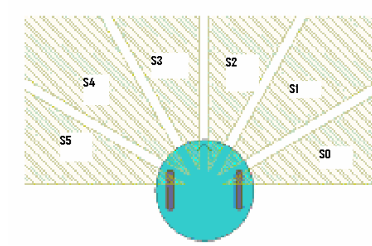

Fig. 2 Sensors Arrangement

Left and right wheel velocities L_Vel and R_Vel respectively are the systems output. The control architecture for implementation of behaviours is shown in Fig. 3.

The two layered architecture implements selection of a group of behaviours and inhibition of rest at the first layer based on the sensor information. The suppression is done by assigning weights to the output of the behaviours by weight assignment mechanism.

3.2 Behaviour Realization

The behaviours are implemented on the basis of location of obstacles from sensors and heading angle to the target from mobile robot. The inputs and outputs membership functions are shown in Fig. 4 and Fig. 5.

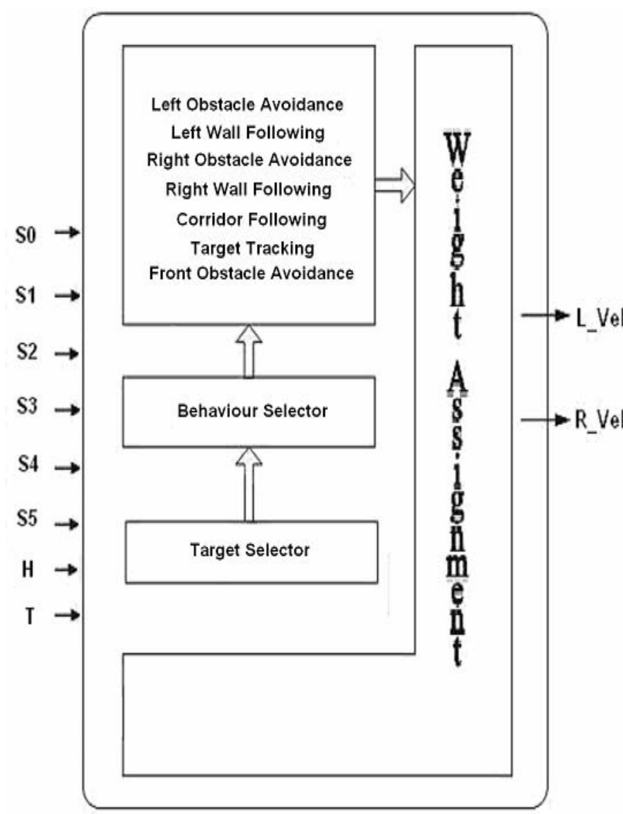

Fig. 3 Control System Architecture

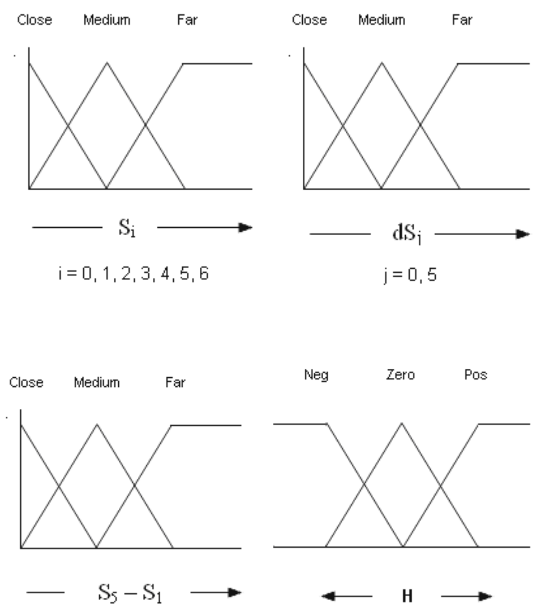

Fig. 4 Input Membership Functions

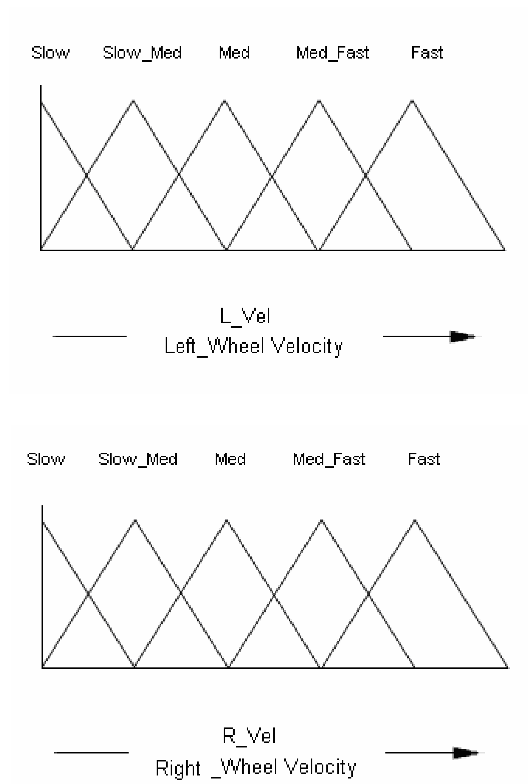

Fig. 5 Output Membership Functions

The input and output triangular membership functions have the following mathematical characterization

$$\text{Left:} \quad \mu^L(u) = \begin{cases} 1 & \text{if } u < c^L \\ \max\{0, 1 + \dfrac{c^L - u}{0.5 * w^L}\} & \text{otherwise} \end{cases}$$

$$\text{Centre:} \quad \mu^C(u) = \begin{cases} \max\{0, 1 + \dfrac{u - c}{0.5 * w}\} & \text{if } u \le c \\ \max\{0, 1 + \dfrac{c - u}{0.5 * w}\} & \text{otherwise} \end{cases} \qquad (2)$$

$$\text{Right:} \quad \mu^R(u) = \begin{cases} \max\{0, 1 + \dfrac{u - c^R}{0.5 * w^R}\} & \text{if } u < c^R \\ 1 & \text{otherwise} \end{cases}$$

The decoding of fuzzy set information produced by the inference mechanism to the real world output is done by Center Of Gravity (COG) defuzzification and is computed using (3).

$$\text{COG; } y = \frac{\sum_{i=1}^{n} \mu(y_i) * y_i}{\sum_{i=1}^{n} \mu(y_i)} \qquad (3)$$

The execution of obstacle avoidance behaviors, wall following behaviors, target steering behaviour, and corridor following behaviour depends on the status of flags. Behaivours are realized by the following rules

3.2.1 Left Obstacle Avoidance Behaviour

The left obstacle avoidance behaviour realization is done by using the following rules

If (S3 is Close and S4 is Close and H is any)
Then (L_Vel is Fast and R_Vel is Slow)
If (S3 is Close and S4 Med and H is any)
Then (L_Vel is Fast and R_Vel is Slow)

3.2.2 Right Obstacle Avoidance Behaviour

The right obstacle avoidance behaviour realization is done by using the following rules

If (S2 is Close and S1 is Close and H is Any)
Then (L_Vel is Slow and R_Vel is Fast)
If (S2 is Close and S1 Med and H is Any)
Then (L_Vel is Fast and R_Vel is Slow)

3.2.3 Front Obstacle Avoidance Behaviour

The front obstacle avoidance behaviour realization is done by using the following rules

If (SL is Close and SF is Close and SR is Close and H is any) Then (L_Vel is Fast and R_Vel is Slow)
If (SL is Med and SF is Close and SR is Close and H is any) Then (L_Vel is Slow and R_Vel is Fast)
If (SL is Close and SF is Close and SR is Med and H is any) Then (L_Vel is Fast and R_Vel is Slow)
If (SL is Close and SF is Med and SR is Med and H is any) Then (L_Vel is Med and R_Vel is Med)

3.2.4 Left Wall Following Behaviour
The left wall following behaviour realization is done by using the following rules

If (d S5 is Neg and SF is Med and S5 is Close)
Then (L_Vel is Med_Fast and R_Vel is Slow_Med)
If (d S5 is Neg and SF is Far and S5 is Close)
Then (L_Vel is Med_Fast and R_Vel is Slow_Med)
If (d S5 is Zero and SF is Med and S5 is Close)
Then (L_Vel is Med and R_Vel is Med)
If (d S5 is Zero and SF is Far and S5 is Close)
Then (L_Vel is Med and R_Vel is Med)
If (d S5 is Pos and SF is Med and S5 is Close)
Then (L_Vel is Slow_Med and R_Vel is Med_Fast)
If (d S5 is Pos and SF is Far and S5 is Close)
Then (L_Vel is Slow_Med and R_Vel is Med_Fast)

3.2.5 Right Wall Following Behaviour
The right wall following behaviour realization is done by the following rules

If (d S0 is Neg and SF is Med and S0 is Close)
Then (L_Vel is Slow_Med and R_Vel is Med_Fast)
If (d S0 is Neg and SF is Far and S0 is Close)
Then(L_Vel is Slow_Med and R_Vel is Med_Fast)
If (d S0 is Zero and SF is Med and S0 is Close)
Then (L_Vel is Med and R_Vel is Med)
If (d S0 is Zero and SF is Far and S0 is Close)
Then (L_Vel is Med and R_Vel is Med)
If (d S0 is Pos and SF is Med and S0 is Close)
Then (L_Vel is Med_Fast and R_Vel is Slow_Med)
If (d S0 is Pos and SF is Far and S0 is Close)
Then (L_Vel is Med_Fast and R_Vel is Slow_Med)

3.2.6 Target Steering
The realization of target steering behaviour is done by the following rules

If (SL is Far and SF is Far and SR is Far and H is Zero) Then (L_Vel is Fast and R_Vel is Fast)
If (SL is Far and SF is Far and SR is Far and H is Pos) Then (L_Vel is Fast and R_Vel is Slow)
If (SL is Far and SF is Far and SR is Far and H is Neg) Then (L_Vel is Slow and R_Vel is Fast)

3.2.7 Corridor Following
The realization of the corridor following behaviour is done by the following rules

If (dS05 is Neg and SF is Med and H is any)
Then (L_Vel is Med_Fast and R_Vel is Slow_Med)
If (dS05 is Neg and SF is Far and H is any)
Then (L_Vel is Med_Fast and R_Vel is Slow_Med)
If (dS05 is Zero and SF is Med and H is any)
Then (L_Vel is Med and R_Vel is Med)
If (dS05 is Zero and SF is Far and H is any)
Then (L_Vel is Med and R_Vel is Med)
If (dS05 is Pos and SF is Med and H is any)
Then (L_Vel is Slow_Med and R_Vel is Med_Fast)
If (dS05 is Neg and SF is Far and H is any)
Then (L_Vel is Slow_Med and R_Vel is Med_Fast)

4 Simulations
A simulator MobotSim is used to demonstrate the effectiveness of proposed method. Following are the results for tracking single and multiple targets using obstacle avoidance, wall following, target steering, emergency and corridor following behaviour. Emergency behaviour is executed when no target is left to reach and stops the mobile robot. Fig. 6 illustrates obstacle avoidance behaviour and target steering behaviour to track the target.

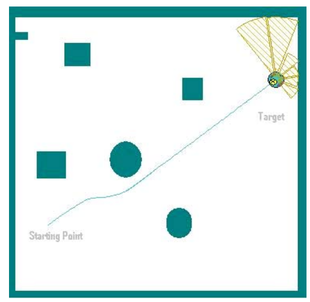

Fig. 6 Obstacle Avoidance And Target Steering

In Fig. 7 mobile robot uses the wall following behaviour, obstacle avoidance behaviour, and target steering behaviour to reach the target.

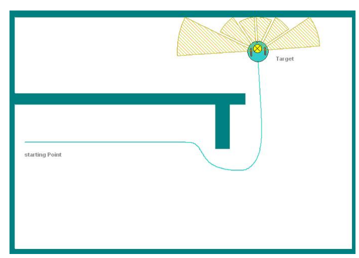

Fig. 7 Wall Following, Obstacle Avoidance And Target Steering

Fig. 8 demonstrates the wall following and target steering to reach a target.

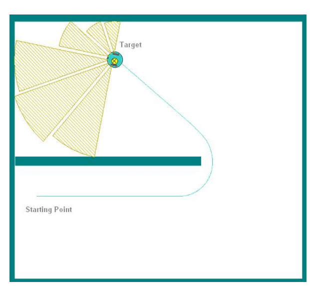

Fig. 8 Wall Following And Target Steering

In Fig. 9 multiple target tracking with unequal priorities are tracked by combining different behaviours.

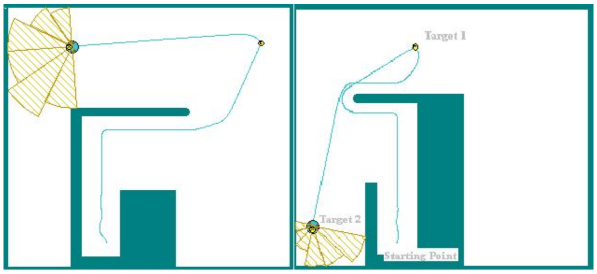

Fig. 9 Un-Equal Priority Multiple Target Tracking

Fig. 10 shows the multiple target tracking based on pre-assigned priority with conflict resolution among the equal priority targets, based on Euclidean distance.

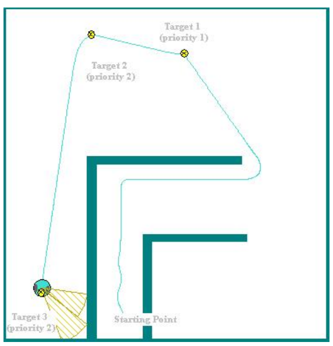

Fig. 10 Equal Priority Multiple Target Tracking

5 Conclusions and Future Work

In this paper, fuzzy logic is used to realize behaviour controls for a mobile robot for tracking single and multiple priority based targets. The two layered architecture implements the inhibition in the first layer and suppression among the selected behaviours in the second layer by weighting mechanism. The effectiveness of proposed method is confirmed by simulation results in an unstructured environment. In future the existing system can be enhanced by adding more behaviour for complex environment and moving targets.

References:

[1] R.A. Brooks, "A robust layered control system for a mobile robot", *IEEE Journal of Robotics and Automation*, RA-2, pp 14-23, 1986.

[2] R.C. Arkin, "*Behaviour-Based Robotics*", MIT Press, Cambridge Massachusetts, 1998.

[3] Elfes, "Sonar Based Real World Mapping and Navigation", *IEEE Transaction on Robotics and Automation*, 1987.

[4] J. Lim and D. Cho, "Experimental and Investigation of Mapping and Navigation Based on Certainty Grids using Sonar Sensors", *Robotica*, 1993.

[5] Antonio C. R. Alves and Henrique C. Junior, "Mobile Ultrasonic Sensing in Mobile Robot", *IEEE,* 2002.

[6] F. Matia and A. Timennes, "Multi- Sensory Fusion: Autonomous Mobile Robot", *Journal of Intelligent and Robotic Systems*, 1998.

[7] Xue-Song Wang, "An evidential approach to environment sensing for autonomous robot", *Proceedings of IEEE 2003, International Conference on Machine Learning and Cybernetics*, 2003.

[8] P. Maes, "*How To Do The Right Things*",Tech.Rep.NE, 43-836 AI-Laboratory, MIT, Cambridge, MA 02139, USA, 1989.

[9] O.Khatib, "Real-Time Obstacle Avoidance for Manipulators and Mobile Robots", *the Intl. Journal of Robotics Research* 5(1),pp.90-98,1986.

[10] R.C.Arkins, "Integrating Behavioural, Perceptual and World Knowledge in Reactive Navigation", *Robotics and Autonomous Systems* 6, pp. 105-122, June, 1990.

[11] L. A. Zadeh, "Fuzzy Sets", *Information and Control*, vol 8, 1965.

[12] M. Kasper, G. Fricke, and E. Von Puttkamer, "A Behavior Based Architecture for Teaching More Than Reactive Behaviours to Mobile Robots", *in Third European Workshop on Adcanced Mobile Robots*, EUROBOT 99, Zurich Switzerland, 1999.