ICROS-SICE International Joint Conference 2009
August 18-21, 2009, Fukuoka International Congress Center, Japan

Modified Fuzzy Behavior Coordination for Autonomous Mobile Robot Navigation System

Handy Wicaksono[1,2], Prihastono[1,3], Khairul Anam[4], Rusdhianto Effendi[2], Indra Adji S.[5], Son Kuswadi[5], Achmad Jazidie[2], Mitsuji Sampei[6]

[1] Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2] Department of Electrical Engineering, Universitas Kristen Petra, Surabaya, Indonesia
(Tel : +62-31-2983115; E-mail : handy@petra.ac.id)
[3] Department of Electrical Engineering, Universitas Bhayangkara, Surabaya, Indonesia
[4] Department of Electrical Engineering, Universitas Jember, Jember, Indonesia
[5] Department of Mechatronics, Politeknik Elektronika Negeri Surabaya, Surabaya, Indonesia
[6] Department of Mechanical and Environmental Informatics,
Tokyo Institute of Technology, Tokyo, Japan

Abstract: In behavior based robotics, development of behavior coordination method is very important. Fuzzy Behavior Coordination (FBC) can be used here, but it still have weaknesses, because it can result in slow robot movement, too long time to reach the target and fail to avoid trap. In this paper, modification of FBC, by combining it with Subsumption Architecture, is proposed to overcome those weaknesses. The simulation result shows that MFBC give the faster robot movement and decrease the amount of time to reach the target.

Keywords: behavior-based robotics, behavior coordination, fuzzy logic

1. INTRODUCTION

Robot architecture that had been developed in early days is deliberative architecture. The robot senses its environment, "thinks" by creating a world model, and after that robot will act. This approach has these disadvantages : planning process (world modelling) takes a long time, no direct relationship between sensor and actuator, and a very sophisticated controller is needed [1]. To overcome them, Brooks [2] suggest reactive architecture (sometimes called behavior based architecture). In this approach, we do not need a world model mathematically. The real environment is the only model which needed by robot. Another advantage is all behaviors run in parallel, simultaneous, and asynchronous way. So the sophisticated controller isn't need anymore, and it can be replaced with a small-low cost microcontroller [3].

In behavior based architecture, the problem will arise when there are many behaviors in a robot. So it has to decide which behavior will be executed at one time. Because of that, robot must have behavior coordinator (sometimes called arbiter). First approach that is also suggested by Brooks [2] is Subsumption Architecture that can be classified as competitive method. In this method, at one time, there is only one behavior that applied in robot. It is very simple method and it gives the fast performance result, but it has disavantage of non-smooth response and inaccuracy in robot movement.

To overcome competitive method weakness, Arkin [4, 5] suggest Potential Fields Method that can be classified as cooperative method. In this method, at one time, there can be more than one behavior that applied in robot, so every behavior has contribution in robot's action. It results in a smoother response and more accurate robot movement. In the other hand, this method is more complex than competitive method. The complete list of behavior coordination method can be found in [6].

Another cooperative method is by using Fuzzy Logic as tool for coordinate the behaviors. There are many approaches to apply Fuzzy Behavior Based Control. Abreu [7] uses fuzzy behavior arbitration that combines some behaviors in its defuzzyfication process to control autonomous vehicle. Thongchai [8] use fuzzy to process each behavior, but use priority based arbitration to combine its behaviors. Saffiotti [9] suggest "context dependent blending" to improve ordinary Fuzzy Logic weakness because of behaviors conflict.

Perez [10] has the idea to blend the cooperative and competitive method by using some linear equations to control an underwater robot. In this paper, other idea to blend those methods is proposed by blend fuzzy behavior based control (that has been mentioned above) with priority based one. By using this combination, performance of autonomous mobile robot navigation will be improved.

2. BEHAVIOR COORDINATION METHODS

In behavior based robotics approach, methods pf behavior coordination are significant. The designer needs to know how robot coordinate its behaviors and take the action in the real world. There are two approaches : competitive and cooperative. In competitive method, at one time, there is only one behavior that applied in robot. The first suggestion in this class is Subsumption Architecture that suggested by Brooks [2]. This method divides behaviors to many levels, where the higher level behavior have higher priorities too. So it can subsume the lower level ones. The layered control system figure is given below.

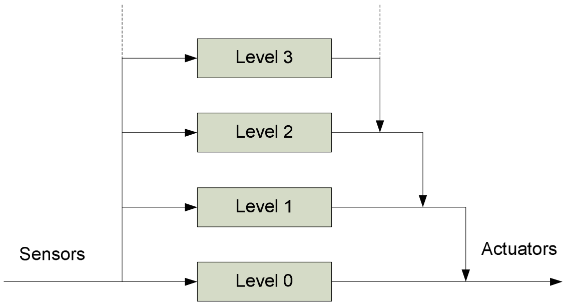

Fig. 1 Layered control system [1]

The example of behavior coordination that using Subsumption This architecture can be seen below.

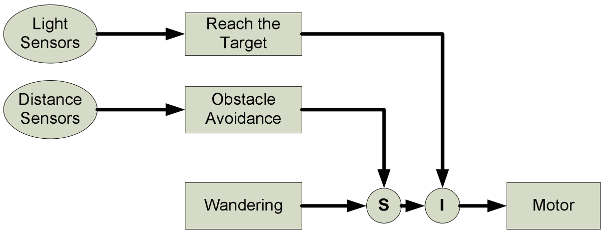

Fig. 2 Subsumption architecture example for navigation

The method above is very simple and fast, but it still has disavantage of non-smooth response and inaccuracy in robot movement.

The cooperative method overcomes these weakness. In this method, at one time, there can be more than one behavior that applied in robot, so every behavior have contribution in robot's action. Arkin [4] suggest the potential fields method, which every object will be described as vector that have magnitude and direction. The result behavior is mixing between each behavior. The motor scheme for this method appear in the figure below.

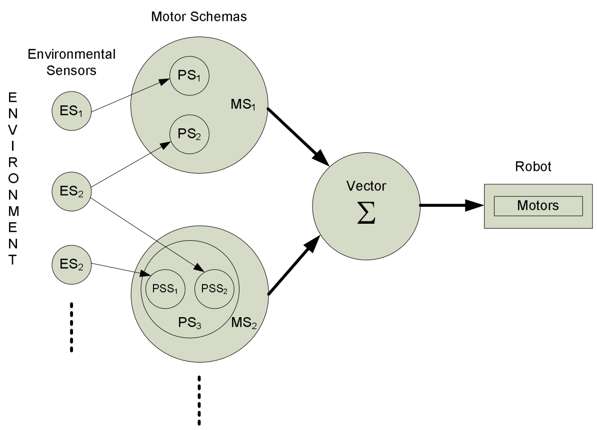

Fig. 3 Motor schema for potential field method [4]

This method results in a smoother response and more accurate robot movement. In the other hand, this method is more complex. It also can result in slow movement, it needs long time to reach the target and it may fail to avoid trap.

Another cooperative method is by using Fuzzy Logic as tool to combine the behaviors. After input from sensor is fuzzified, then it will be processed in rule base with other fuzzified input. Rule base represent the behavior. Defuzzification process will combine the behaviors (Abreu, 1999). The scheme of fuzzy behavior coordination is shown below.

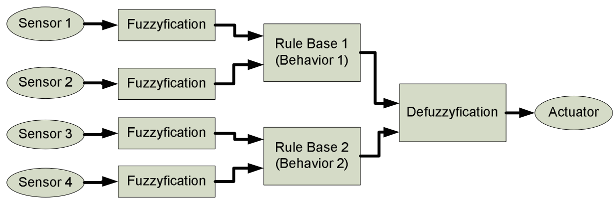

Fig. 4 Scheme of fuzzy behavior coordination

In this paper, modification of fuzzy behavior coordinator above is proposed to overcome weaknesses that mentioned above. It will be done by combine the original one with priority based method in order to get the faster performance when the robot found the target. There will be a switching mechanism between those two methods. The switching is happened when the target is close and the obstacle is far enough from the robot. The complete scheme of modified fuzzy behavior coordination is shown below.

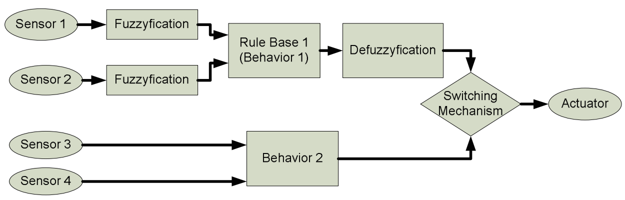

Fig. 5 Scheme of modified fuzzy behavior coordination

3. BEHAVIOR DESCRIPTION

3.1 Behaviors in Subsumption Architecture

There are some behaviors that robot should have in order to succeed in autonomous navigation. They are :

- Obstacle avoidance
- Search the target
- Wandering

The scheme of these architecture can be seen on Figure 2.

"Wandering" behavior is the lowest level behavior (in Subsumption Architecure) that will move the robot all around the arena in order to find the target. If the robot sees the obstacles, then it will avoid them because of presence of "obstacle avoidance" behavior. And then when the robot find the target (a light source), it will move closer to the robot. After the distance is close enough, then the robot will stop.

3.2 Fuzzy Behaviors

Behaviors that use in Fuzzy Behavior (FB) dan Modified Fuzzy Behavior (MFB) are almost same. Here are the description of them.

3.2.1. Obstacle Avoidance Behavior

Robot uses two distance sensors (which is put in left and right). Here are the triangular membership function (MF) for the sensor (their configuration are same). They can be divide to : small, medium, and big.

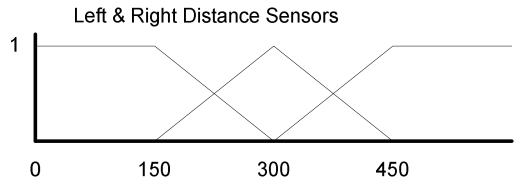

Fig. 6 Membership function of distance sensors

Those MF of two sensors will be combine by a rule base of left & right motor. The rule bases are not the same, but one is mirror of the other. Here are the rule bases for them.

Table 1 Rule base 1 for left motor

Right D.S / Left D. S	S	M	B
S	P	P	N
M	Z	Z	N
B	P	P	N

Table 2 Rule base 2 for right motor

Right L.S. / Left L.S.	S	M	B
S	P	Z	P
M	P	P	P
B	N	N	N

3.2.2. Search Target Behavior

Robot uses two light sensors (which is put in left and right). Here are the triangular membership function (MF) for the sensor (their configuration are same). They can be divide as : small, medium, and big.

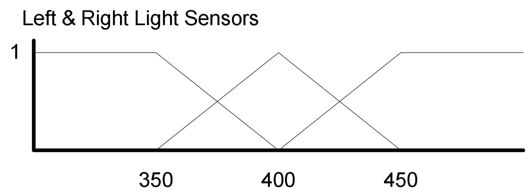

Fig. 7 Membership function of light sensors

Those MF of two sensors will be combine by a rule base of left & right motor. The rule bases are not the same, but one is mirror of the other. Here are the rule bases for them.

Table 3 Rule base 3 for left motor

Right L.S. / Left L.S.	S	M	B
S	Z	Z	P
M	Z	Z	P
B	N	Z	P

Table 4 Rule base 4 for right motor

Right L.S. / Left L.S.	S	M	B
S	Z	Z	N
M	Z	Z	Z
B	P	P	P

When Modified Fuzzy Behavior Coordination is applied in robot, this fuzzy behavior won't be used. It will use the ordinary one.

4. RESULTS AND DISCUSSIONS

Robot used here has two distance sensors and two light sensors. It only uses two motors. The complete parts of robot can be shown below.

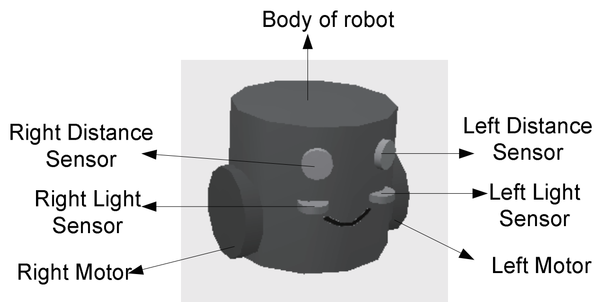

Fig. 8 Robot used in simulation

Webbots 5.5.2 software from Cyberbotics has been used to simulate and test the performance of robot.

Simulations that has been done will observe the performance of these three behavior coordination methods :

1. Subsumption Architecture (SA)
2. Fuzzy Behavior Coordinator (FBC)
3. Modified Fuzzy Behavior Coordinator (MFBC)

The simulation will measure how many time that robot used to reach the target, the performance of robot movement that can be seen by the robot's trajectory, and how well robot in avoid obstacle.

4.1 Target reaching simulation

This simulation will be done to measure how many times that needed by robot to travel from the start position until the target is found. There are three start positions in the arena, that can be seen in figure below.

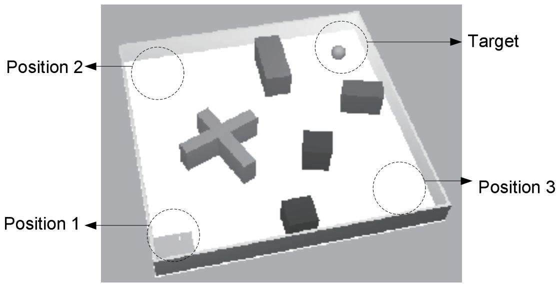

Fig. 9 Arena for the simulations

Each simulation have been done 5 times, and the best result is shown in table below.

Table 5 Target reaching test result

Pos	Start position of Robot (x,y,z,teta)	Time to reach target (minutes)		
		SA	FBC	MFBC
1	(-0.41, 0, 0.43, 2.03)	Reach in 1:09 m	Reach in 0:24 m	Reach in 0:11 m
2	(0.42, 0, 0.41, 0.93)	Reach in 1:05 m	Reach in 0:13 m	Reach in 0:13 m
3	(-0.41, 0,-0.42, 4.13)	Reach in 1:45 m	Reach in 1:21 m	Reach in 0:29 m

From the table we can see that SA needs most time (1:09 m, 1:05 m, 1:45 m) to reach target from each position. It is happened because SA is a competitive coordinator type , so there is a chance to ignore the search target behavior when other behavior is active.

The rough response from the robot can increase the time to reach target. FBC gives better result because evary behavior gives contribution in robot's decision making. But it tends to give slow result, because every behavior will processed in fuzzy inference engine. MFBC come with a fastest result, because the search target behavior is not a fuzzy behavior, and it considers as more important behavior than other.

4.2 Movement Performance Simulation

In this simulation, robot's trajectory will be observed in order to understand robot's movement. Here are the simulation figure of robot with SA.

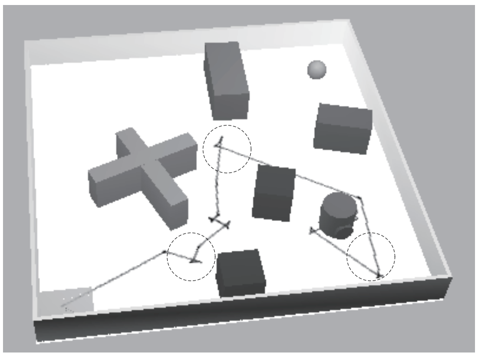

Fig. 9 Movement performance simulation result for robot uses SA

From the figure we can see that SA gives a sharp turn of robot. Look at the circle with the dash-line. This sharp turn happened because of the immediate change in robot's behavior. It has to switch from one behavior to another directly. So it make the robot's movement are little bit rough, although it gives faster movement than another approach.

While the simulation figure of robot with FBC can be seen below.

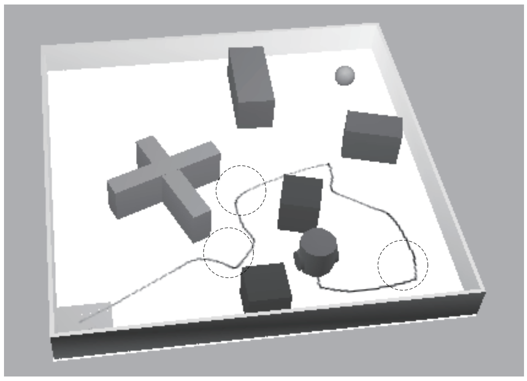

Fig. 10 Movement performance simulation result for robot uses FBC

From the figure above we can see that FBC gives smoother response, slighter turn. Once again, it is marked by the circle with the dash-line. This is happened because fuzzy process that mix all robot's behavior. So there is no immediate change between behaviors. In overall, robot movement is very smooth but it give the slowest motion.

The last simulation that has been done is with MFBC robot. The simulation figure is shown below.

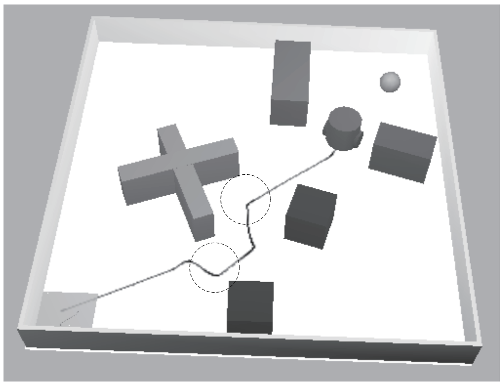

Fig. 11 Movement performance simulation result for robot uses MFBC

The MFBC robot do not give smoothest reponse (just like FBC),but it is much more smoother than the SA. Look at circle with the dash-line in the figure. The other important feature is it usually gives faster response than MFBC. This happened because the MFBC actually is combination between SA and FBC.

4.3 Trap Simulation

The last simulation that will be held here is called "trap simulation". The robot will be put into the "trap" to see how good their performance to escape from the trap. Here is the result figure.

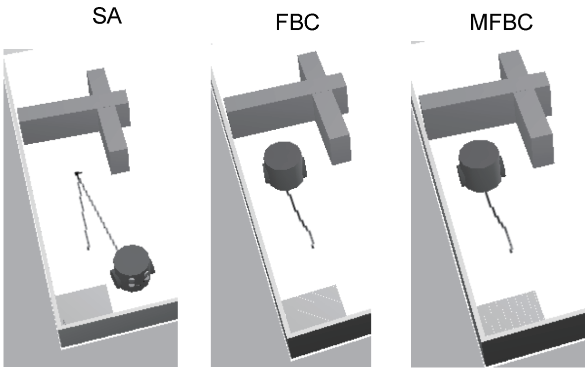

Fig. 12 Trap performance simulation result

From the figure we can see that SA give better performance in escaping from the trap. SA robot succeed to escape, but FBC and MFBC robot are failed during the simulation. Both of them are trapped.

5. CONCLUSION

This paper proposed a modification of fuzzy behavior coordination in navigation system of autonomous mobile robot. From the simulations result, it can be concluded that MFBC give fastest result (1:09 m, 1:05 m, 1:45 m) than SA and FBC in reaching the target from various position. It also gives smoother response (than FBC) and faster performance (than SA), so MFBC is a good way to compromize those approaches.

In the other hand, MFBC is still can not improve FBC robot performance to avoid the trap (difficult combination of obstacle). In the future, the improvement is needed to fix this weakness. The addition of learning capability to the robot will be good too, because it can make reaching target process faster.

6. ACKNOWLEDGE

This work is being supported by Japan International Cooperation Agency (JICA) through Technical Cooperation Project for Research and Education Development on Information and Communication Technology in Sepuluh Nopember Institute of Technology (PREDICT - ITS).

REFERENCES

[1] G. A. Bekey, *Autonomous Robot : From Biological Inspiration to Implementation and Control*, MIT Press, Massachusetts, 2005.

[2] R. Brooks, "A Robust Layered Control System For a Mobile Robot", *IEEE Journal of Robotics and Automation*, vol. 2, no. 1, hal. 14 – 23, 1986.

[3] M. Asadpour, and R. Siegwart, "Compact Q-Learning for Micro-robots with Processing Constraints", *Journal of Robotics and Autonomous Systems*, Vol. 48, No. 1, pp. 49-61, 2004.

[4] R.C. Arkin, "Motor Schema Based Navigation for a Mobile Robot : an Approach to Programming by Behavior", *IEEE Int. Conf. on Robotics and Automation* , pages 264-271, 1987.

[5] R.C. Arkin, *Behavior-Based Robotics*, England, Bradford Books, 1998.

[6] P. Pirjanian, *Behavior coordination mechanisms : State-of-the-art*, Technical Report IRIS-99-375, Univ. Southern California, 1999.

[7] A. Abreu, "Fuzzy Behaviors and Behavior Arbitration in Autonomous Vehicles", *Proceedings of the Portuguese Meeting in Artificial Intelligence EPIA99*, volume 1695 of LNC, 1999.

[8] S. Tongchai, S. Suksakulchai, D.M. Wilkes, and N. Sarkar, "Sonar Behavior-Based Fuzzy Control for a Mobile Robot", *Proc. of IEEE International Conference on Systems, Man and Cybernetics* , Nashville, Tennesse, October 8 – 11, 2000.

[9] A. Saffiotti, "Fuzzy Logic in Autonomous Robotics : Behavior Coordination", *Proceedings of the 6th IEEE Int. Conf. on Fuzzy Systems*, pp. 573 – 478, Barcelona, Spain, 1997.

[10] M. C. Perez, *A Proposal of Behavior Based Control Architecture with Reinforcement Learning for an Autonomous Underwater Robot*, Tesis Ph.D., University of Girona, Girona, 2003.