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Fuzzy Logic Decision Maker on Indirect Sensor Fusion for Autonomous Mobile Soccer Robot (I'MROBOT3) Motion Control

Endah Suryawati Ningrum[1], Bambang Sumantri[2], Moh. Hisyam Fithrony[3],Indra Adji Sulistijono[4]
[1,4]Mechanical and Energy Engineering Department, [2,3]Electrical Engineering Department
Electronics Engineering Polytechnic Institute of Surabaya (EEPIS)
Kampus PENS, Jalan Raya ITS Sukolilo, Surabaya 60111 Indonesia
{endah,bambang,indra}@eepis-its.edu, mhskibar@student.eepis-its.edu

ABSTRACT

This paper propose the fuzzy logic algorithm for the decision making of an indirect sensor fusion which applied on soccer robot system. The inputs to the fuzzy system are feature-data extracted from both an embedded camera as an target sensor, and several numbers of ultrasonic sensors as obstacle sensor. The output from the fuzzy system is a decision in the form of a robot trajectory planning. Several experiment were performed in case that robot have to pursue a ball as a moving target while avoiding the static opponent. The results shown that the average success rate of the robot to complete the task is much more better than previous paper, which employ a direct sensor fusion using the Virtual Force Field method as a decision maker.

Keywords: *fuzzy logic, decision maker, direct sensor fusion, soccer robot , trajectory planning*

I. STATE OF ART

Autonomous soccer robot is an example of a complex robot system, where the robot is required not only but also be able to carry out tasks such as pursuing the ball while interact with other robots, moreover arranges game strategize[7]. The dynamic environmental conditions are also a big challenge that have to be perceived well by the robot, before it taking "appropriate" action for instant motion control. Those motion control must be design to deal also with specific criteria and constraint: the safety in move and the real-time execution. Therefore, a number of sensors and variety are equipped on soccer robot. These are sometimes complementary, sometimes redundant, and there exist architectures where sensors are used in both fashions[3]. Consequently, methods of sensor fusion are needed to translate the different sensory inputs into reliable estimates and environment models that can be used by the robot for estimating parameters and states needed for motion planning, and motion execution. The combination of readings from the two types of sensors can potentially provide a comprehensive and accurate view of the robot's environment, far superior to that achievable by each type operating alone. [6]. A complete intelligent system may involve multiplelevel hierarchical sensor fusion processes for final decision. For design and implementation it can be simplified to consider the following fusion processes based on I/O characterizations as Varshney's classification, i.e. data in–data out, feature in–feature out, decision in–decision out, data in–feature out, which is named direct fusion. While, feature in–decision out, and data in–decision out, are indirect fusion. The latest two fusion types of Varshney's classification are especially important in most intelligent motion control systems that required qualified performance of fast-response efficiency, high flexibility, and robustness[2].

This research propose to use indirect fusion technique that combines two types of characters data that is: "feature in-decision out" and "data in-decision out". However the system uses multiple sensors with different resolutions or with uncertain noisy outputs of data for motion decision, it is difficult to employ a method for accomplishing sensor fusion across levels. There are two major reasons, one is the little common of sensory output and the other is the different acquisition frequency of the sensor modules[1]. Therefore, an intelligent control method is deserved to use as in the decision maker. Particularly, the Fuzzy Logic technique has obtained this sensor fusion system. Fig. 1 shows a soccer robot system as an application for propose system.

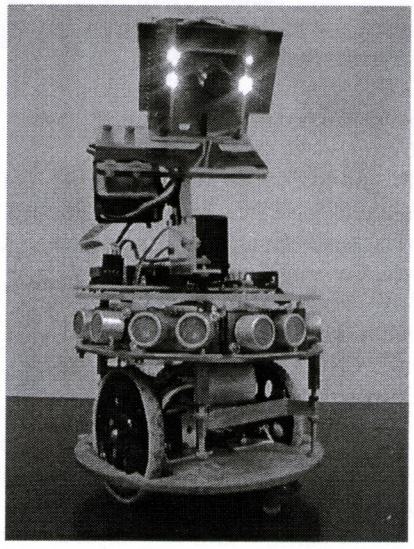

Figure 1. A Sensor fusion system applied on soccer robot named I'MROBOT3

Soccer robot is a kind of autonomous robot that moves are made like a football player, so the need for artificial intelligence implanted in the brain (the processor). Soccer robots made for the purposes of research, entertainment, and industry. Basic design of a robot soccer intelligence can also

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be adopted from a mobile robot with some modifications. Designing and applying artificial intelligence to the mobile robot is not easy, but with the development of technology, many methods that can be used to support the manufacture of artificial intelligence. This type of control is also very diverse, depending on the object to be created[7].

Our soccer robot named I'MROBOT 3 is a two-wheeled vehicle with two independently driven called differential drive robot, and a free caster at the rear side. Two encoders are attached to the two differential wheels which coupled with two continues servo motors, provide information for position estimation. The robot is equipped also with two different perception sensor systems. Five SRF ultrasonic transducers are positioned around the vehicle circumference, and used for detect the presence of an obstacle. A CCD camera with special purpose embedded signal processing mounted on a tracking system module which consist of two standart servo motor, and work as a 2 DOF manipulator for tracking some object such like ball target. The task is to reach targets (pursue the ball) in and avoid obstacles (obstacle avoidance). Fuzzy logic decision maker is used in order to control the motion of robot, by processing two feature-data which obtained from the camera and five SRF ultrasonic.

II. LITERATURE REVIEW

A. Fuzzy Logic

Fuzzy logic algorithm requires three basic processes, namely fuzzification, rule evaluation, and defuzzification, showed on Fig.2.

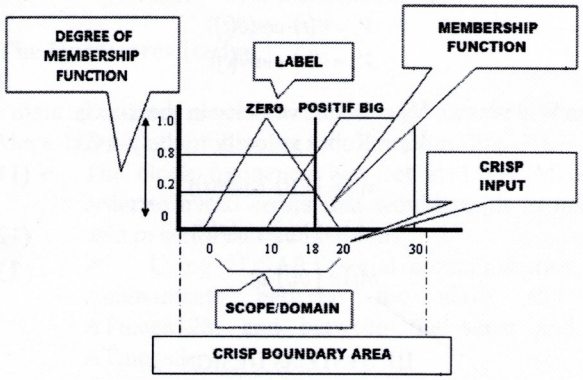

Figure 2. The basic concepts of fuzzy logic

- The degree of membership are : the degree to which crisp values corresponding with the membership function (from 0 to 1), also referred to as the level of membership, the truth value, or input fuzzy.
- Label is the descriptive name which is used to identify a membership function.
- The membership function is to define the fuzzyset by mapping crisp inputs into degrees of membership from its domain.
- Crisp inputs are the inputs which particular firm and specifics.
- Scope / Domain is the width of membership function Range of functions (usually a number) where the membership function are mapped.
- Crisp is a range of areas throughout the limits of possible values can be applied to the system variables.

Fig 3. Shows an fuzzification process, where the input of invalid data is commonly called Crisp Input, will be processed as the fuzzy input.

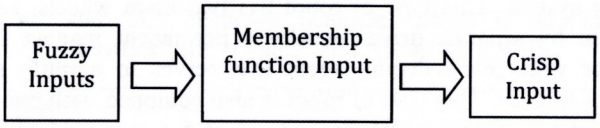

Figure 3. Block diagram of fuzzification

After fuzzification on process is complete, will continue with the evaluation rule. The rule evaluation procedure are showed on Fig.4. The rule will be created, depending on the experience of the system designer, the more experience, the better results will be obtained. Here is the language commonly used in the evaluation stage of the fuzzy rule:

- Label/linguistic values: low, medium, high
- Combiner Operators: AND,OR, NOT
- Condition: good, moderate, bad

The use of rules in the application:

- If the U.S. left :no obstacle (high) and U.S. right: no obstacle (high), then forward (good)
- If the U.S. left: there are obstacles (medium) and U.S. right: no obstacle (high), then turn right (moderate)
- If the U.S. left: no obstacle (high)and U.S. right: there are obstacles (high), then turn right (good)
- If the U.S. left: there are obstacles (high) and U.S. right: there are obstacles (high), then go back (good)

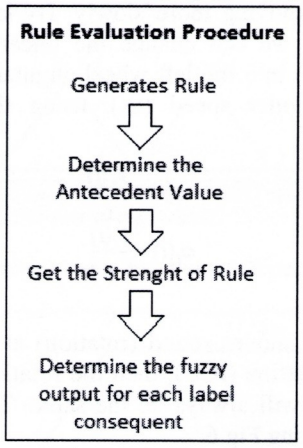

Figure 4. The evaluation rule procedure

The final step is defuzzification, which takes the output of each fuzzy label, to be a crisp output. Using the method defuzzification COG, the output value of the single tone

combined using weighted averages. COG formula, for calculation of reduction of the single tone is:

$$CrispOutput(y) = \frac{\sum(FuzzyOutput[i]) \times (SingletonPosition[i])}{\sum(FuzzyOutput[i])} \quad (1)$$

B. ***Differential Drive***

One kind of mobile robots are commonly used in the room are: a mobile robot with differential steering or differential drive system. This type of robot has two main wheels, each driven by separate drive (usually a permanent magnet DC motor with gear-reducing agent that serves to amplify the motor torque). This type of robot is also equipped with one or two castor wheels which are placed at the rear side of the robot and used as a counterweight (balance).

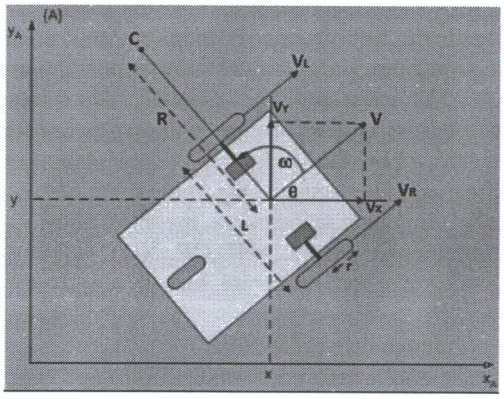

Figure 5. The position and orientation of mobile robots in cartesian coordinate system

Fig. 5. shows the architecture of the robot viewed from the top: If the two wheels of the robot is rotating with the same speed then the robot will move with a straight direction, whereas if the speed of one wheel more slowly then the trajectory of the robot motion-shaped curve with the direction toward one of the wheels are moving more slowly. By knowing the wheel radius (r), then we can change the linear velocity of each wheel (V_r & V_l) into the left wheel angular velocity (ω_l) and right wheel angular speed (ω_r), using the following two formulas:

$$\omega_r(t) = \frac{V_r(t)}{r} \quad (2)$$

$$\omega_l(t) = \frac{V_l(t)}{r} \quad (3)$$

When the robot moves round (rotation) at a certain point of the center of rotation (ICC), then the rotational speed at each point the robot will always be the same. The illustrations as shown in following Fig.6.

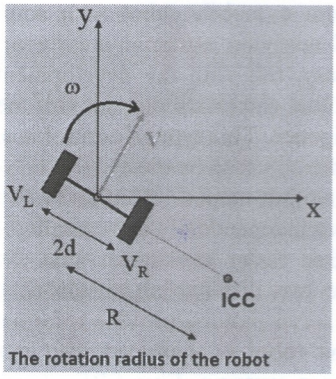

Figure 6. Robot trajectory based on a particular center point of rotation

Thus, the equation used to calculate the rotational speed of the robot are as follows:

$$V_r = \omega \cdot (R+d) \quad (4)$$

$$V_l = \omega \cdot (R-d) \quad (5)$$

then,

$$\omega = \frac{(V_r - V_l)}{2 \cdot d}$$

$$R = \frac{d \cdot (V_r + V_l)}{(V_r - V_l)} \quad (6)$$

(7)

so the speed of robot:

$$V = \omega \cdot R = \frac{(V_r + V_l)}{2} \quad (8)$$

To get the speed of the robot are:

$$V_x = V(t) \cdot \cos(\theta(t)) \quad (9)$$

$$V_y = V(t) \cdot \sin(\theta(t)) \quad (10)$$

Whereas : V_x = Robot velocity in the x-axis
V_y = Robot velocity in the y-axis

$$x(t) = \int V(t) \cdot \cos(\theta(t)) \quad (11)$$

$$y(t) = \int V(t) \cdot \sin(\theta(t)) \quad (12)$$

$$\theta(t) = \int \theta(t) \cdot dt \quad (13)$$

III. SYSTEMS DESIGN

In this paper, the systems design are divided into three units, they are mechanical design, hardware design and software design.

A. **Control Systems Design**

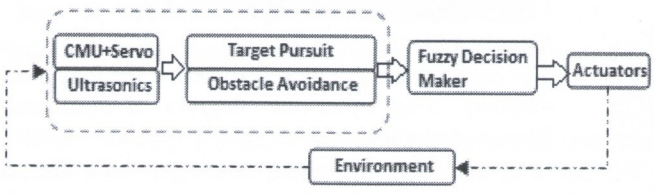

Figure 7. Block diagram of system

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Fig. 7., shows that an embedded camera (CMUCam) is used to obtain feature of target position by extracting the color of target (color tracking). While the ultrasonic sensors (SRF04) are used to obtain the range or the distance of obstacles which may exist around robot. Thus both feature-data were obtained then processed as inputs by fuzzy logic decision maker to determine the appropriate action or the motion should be done by robots.

B. **The Mechanics Design**

The mechanic design of robot system was based on the compact and efficient consideration. Therefore, the dimensions of the robot was made in small enough size for consideration of the dimensions of environmental testing bed. The shape of the robot was also designed in a cylindrical, so that it is easier to install the ultrasonic sensors, also in order to have flexible maneuver. Acrylic and aluminium materials are chosen as a robots frame and casing, since it is not too heavy, strong, but still easy to set up. The following Fig. 8., shows the technical drawings of robot.

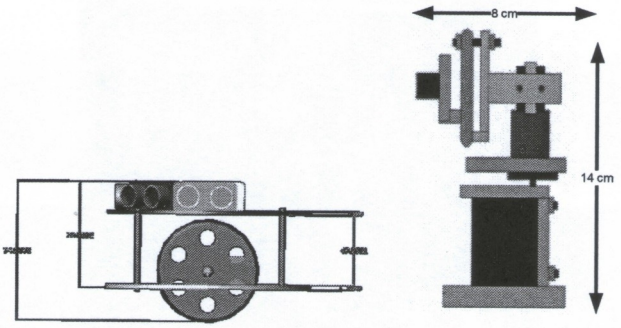

Figure 8. The mechanics design

C. **The Hardwares Design**

The main or master processor that is used on the system is ATMega 128 with the following configuration (Fig. 9.).

- The clock frequency was set at11.0592MHz, in order to avoid errors that would result in loss of data in serial communication.
- Using 2USART serial communication, for communicate between the slave and the ATmega128, and between the slave and the ATmega8 .

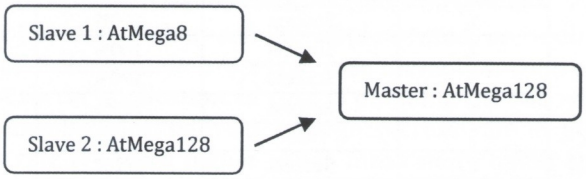

Figure 9. Block diagram of electronics system

D. **Softwares Design**

Software parts are built using the C programming language, a compiler codevision AVR, because it has a wizard to generate the required configuration. While to support the design of fuzzy systems, The Fuzzy Generator software is used such like MathLab Toolbox. The Fuzzy has four crisp inputs, consist of: a target position, target distance, the position and distance of obstacle. Here are details of the membership function input:

- The position of the target named as input variable "TarPos" are: 'TBigRight', 'TRight', 'TFront', 'TLeft', and 'TBigLeft' (Fig. 9a).
- Target distance namely as input variable "TarDist" are: 'TNear' and 'TFar' (Fig. 9b).
- The direction of the obstacles named as "ObsPos"are: 'OBigRight', 'ORight', 'OFront', 'OLeft', and 'OBigLeft' (Fig. 9.c).
- and The obstacles distance, which is named as "ObsDis" are: 'ONear' and 'OFar' (Fig. 9.d).

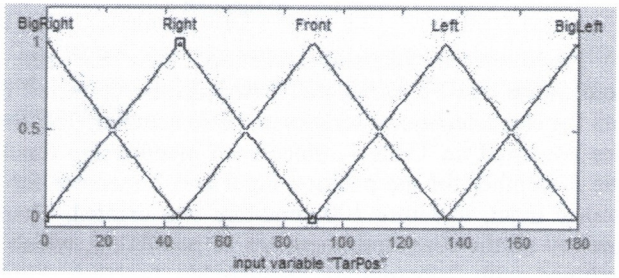

Figure 9.a The membership function of Target Position

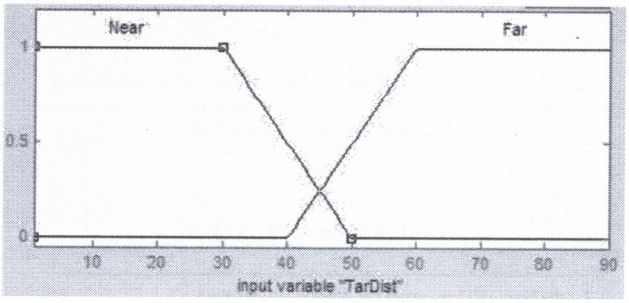

Figure 9.b The membership function of Target Distance

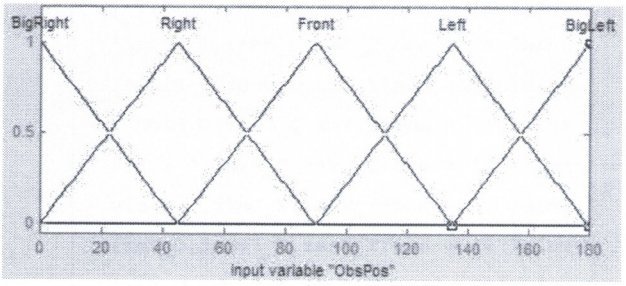

Figure 9.c The membership function of Obstacle Distance

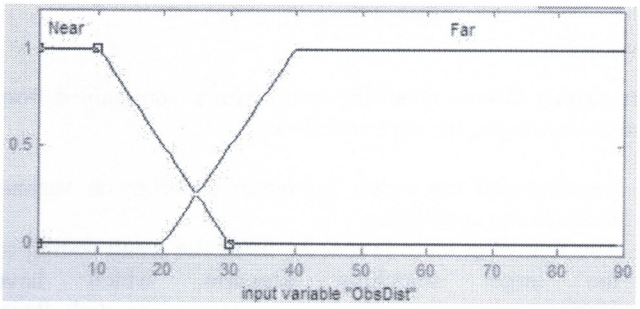

Figure 9.d The membership function of Obstacle Distance

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Futhermore the membership at the output are in the form of 4 single tone membership function which is shown on Fig. 10. as follows:

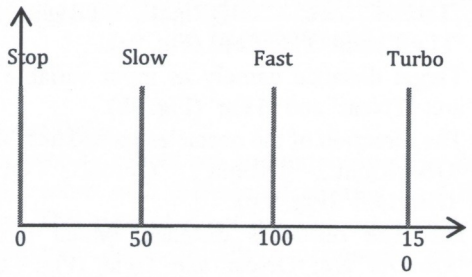

Figure 10. Membership function output

From the membership function, then the rule of fuzzification can be formulated based on the collected data from the characteristic of sensors and also actuator. The list of rules are listed on Table 1. Since each membership function have 5 member for the position input and 2 member for the distance input, therefore 100 condition was created. Then to represent all the condition, there are 16 possibility, which are combined with 7 output of membership function. Finally, equation 14 is used as a decision maker formula for the system.

$$Out = \frac{oStop.pStop + oSlow.pSlow + oFast.pFast + oTurbo.pTurbo}{oStop + oSlow + oFast + oTurbo} \quad (7)$$

Table 1. Rule of fuzzyfikasi

```
rule[ 1] = and(T_Near,O_Near);
rule[ 2] = and(T_Far,O_Near,O_BigL);
rule[ 3] = and(T_Far,T_Near,O_Left);
rule[ 4] = and(T_Far,O_Near,O_Front);
rule[ 5] = and(T_Far,O_Near,O_Right);
rule[ 6] = and(T_Far,O_Near,O_BigR);
rule[ 7] = and(T_Near,T_BigL,O_Far);
rule[ 8] = and(T_Near,T_Left,O_Far);
rule[ 9] = and(T_Near,T_Front,O_Far);
rule[10] = and(T_Near,T_Right,O_Far);
```

IV. EXPERIMENTAL RESULTS

This chapter discuss about the result which were gained from several test stages, they are as follows:

- Experimental test result for target pursuing on various illumination conditions.
  The following table (Tabel 2), listed the result testing of the target searching scenario, which have 100% success rate to find the target on the dark floor. And however it become on 80% on conditions when the illumination are more high. This is because the illumination of the floor has influence the data which are obtained from the camera (target position) have some error, caused by the reflected light. And Fig. 11 shows the conditions when the experiment were conducted.

Tabel 2. Experimental result of target pursuing

Number of trial	Illuminance of the floor	% Success rate
1	Most high	20%
2	Very high	60%
3	High	80%
4	Medium	80%
5	Low	40%
6	Totally dark	100%
7	Totally dark	100%
8	Totally dark	100%
9	Totally dark	100%
10	Totally dark	100%

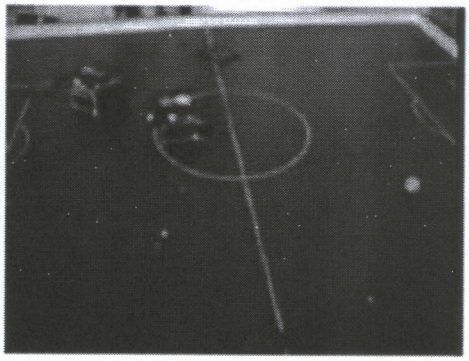

Figure 11. Setup testing for target pursuing

- The following table (Table 3) shows the experimental results which taken during the condition of the robot pursuing a moving target, while avoiding some stationary obstacles which was placed randomly. The results showed that the success rate reached 80%. from 10 times trial taken.

Table 3. Experimental result of obstacle avoindance

Number of test	Success rate	% Success rate
1	Success	100%
2	Success	100%
3	Success	100%
4	Success	100%
5	Failed	0%
6	Success	100%
7	Success	100%
8	Failed	0%
9	Success	100%
10	Success	100%
The average success rate		**80%**

- Experimental test result in case "of pursue while avoid" scenario. From the test results (table 4), it can be seen that the average success rate is 80% from 10 times taken trial. The

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testing data was performed on the conditions that the robot have to pursue a ball as a moving target while avoiding the opponent (as static obstacles). Fig. 12 shows some snapshoot picture taken during experimental test when robot in scenario of pursue the ball while pursue the ball

Table 4. Experimental result of target pursuing while obstacle avoiding

Number of	Success rate	% Success rate
1	Failed	0%
2	Success	100%
3	Failed	0%
4	Success	100%
5	Success	100%
6	Success	100%
7	Success	100%
8	Success	100%
9	Success	100%
10	Success	100%
The average success rate		80%

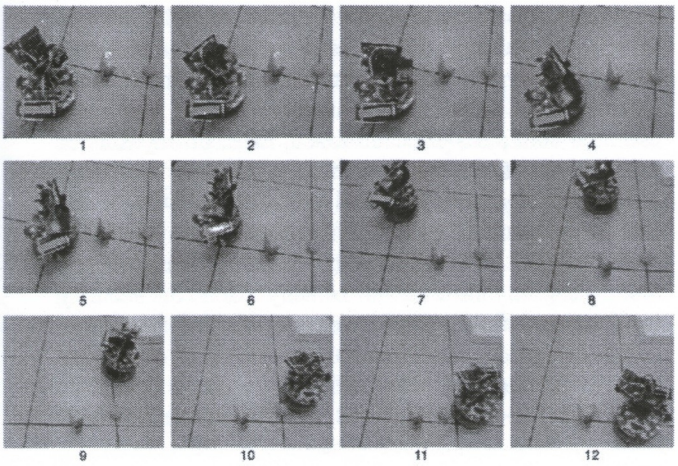

Figure 12. Snapshoot taken during "pursue and avoid" scenario test

V. CONCLUSION REMARK

From the results which are obtained from several experiment, showed that the method of Fuzz Logic Decision Maker can be implemented on indirect sensor fusion system process in case on motion control of robot soccer application, in case of pursuing the ball while avoidingobstacles, with an average success rate of 80%. Thus rate are more higher which mean more better than used on previous paper[1], which employ Virtual Force Field method as a decision maker on sensor fusion system.

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