PID Controller-based Object Tracking and Speed Control System for Wheeled Soccer Robot

Preprint · July 2017

DOI: 10.31227/osf.io/xqu9a

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***Abstract*—This paper discussed about the detection system of ball objects and speed control system of wheeled robot football using PID controller. The object detection system uses behavior-based control methods based on the orientation of the robot position against the object position. The position of the robot is controlled to keep it perpendicular to the ball. When the position of the robot is perpendicular to the ball, the robot will move with a certain speed that is controlled by the PID controller based on the distance between the robot and the ball. Test results in static conditions (static balls) show the robot can detect the object of the ball, either when the position of the object perpendicular, to the right, or left of the robot. In testing the dynamic state (moving ball) with random directions, the robot can also move dynamically as the ball position changes.**

Keywords—object tracking; position control; speed control; PID controller; wheeled soccer robot

I. INTRODUCTION (*HEADING 1*)

One of the abilities that must be owned by a wheeled soccer robot is to find the ball position, move towards the ball position, then hold the ball to further dribble and kick the ball into the opposing goal. To complete this task, the robot must be equipped with a camera sensor and ball position detection algorithm as well as setting the speed of movement to the ball position. The position of the ball in a wheeled soccer wheeled game is dynamic, meaning the ball moves and the position of the ball can move. For object detection, camera position is controlled to follow moving objects automatically by using PID controller. The camera must be controlled with the correct movement speed in order to produce the best detection results. If camera movement is too slow, the camera will lose the object to be captured, whereas if it is too fast, the captured image will be damaged [1].

The environment around the wheeled soccer robot is dynamic, where the position of the opposing robot and the ball position constantly changing. Therefore it is necessary to apply a control system on robots that have the ability to read these dynamic environmental conditions. One of them is using behavior-based control and fuzzy logic controller on football robot navigation system. The robot is designed to have the ability to find the target (ball), avoid obstacles and kick the ball into the opposing goal [2]. In order for the wheeled soccer robot to move as freely as possible in anticipating dynamic environmental conditions, the movement of the robot must be designed in such a way, including the use of omni-directional drive system. With this drive system the position of the robot can be controlled with algorithms such as fuzzy logic, so that the movement of the robot can be more free and flexible. This greatly helps the robot in tracking down and avoiding all obstacles. [3].

Based on the conditions described earlier, this paper discusses the detection system of ball objects and speed control systems on wheeled soccer robots. Object detection systems use behavior-based control methods, while speed control systems use PID controllers.

II. SYSTEM DESIGN

A. Mechanical Design

This wheeled soccer robot is designed with length of 51cm, width of 43cm and height of 40cm. The robot body is made with the main material of a square aluminum pipe with a size of 10mm×20mm and 3mm and 5mm thick acrylic sheets. Robotic mechanics are made into 2 levels: first level for battery and wheel drive motor, second level for sensors, electronic circuit, and gripper. The mechanical design of the robot is shown in Fig. 1. The wheel of a soccer robot uses three omnidirectional wheels for the robot to move in any direction, the principle of robotic movement shown in Figure 2.

B. The block diagram of the system

The system consists of a camera (CMUCam5) used as a ball detection sensor, an ultrasonic sensor to measure the distance of the robot to the ball, the Arduino Mega2560 as the system controller, and the DC motor and its driver to drive the robot wheel. The control system block diagram of the wheeled soccer robot is shown in Figure 3.

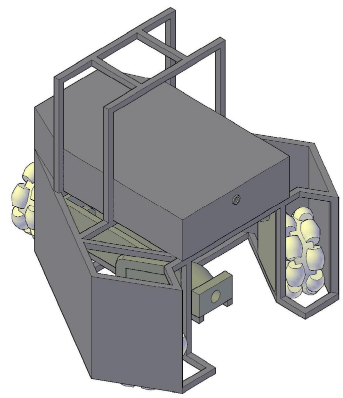

Fig. 1. Mechanical design of robot

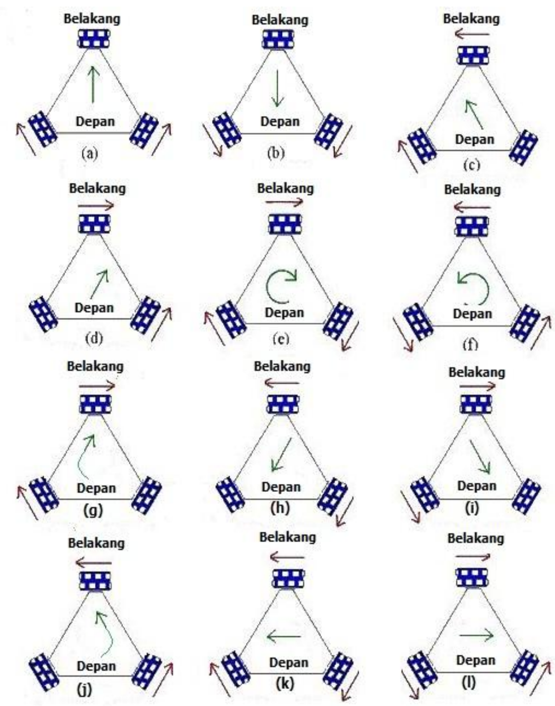

Fig. 2. The concept of robot movement with omnidirectional drive system

C. The principle of ball detection

When the robot is activated, the CMUcam5 camera sensor will be active and look for a ball that is placed arbitrarily. CMUcam5 has a reading angle range of 75° (θ_1). If the robot does not find the ball, the robot will rotate to the right to find the ball. If the robot detects the ball, the robot will move to the right or left by θ_2 to make the robot camera's point of view perpendicular to the ball. The concept of ball detection by the robot is shown in Figure 4. Once the ball is detected and centered, the ultrasonic sensor will measure the distance between the robot and the ball (path c). If the distance of the robot with the ball is smaller or equal to 5cm, the motor gripper will immediately move to hold the ball, while if the ball is more than 5cm, the robot will move towards the ball. Robot movement speed towards the ball will be maximum (PWM wheel motor value = 255) when the distance of the robot with the ball more than 50cm. The speed of the robot will be reduced when the distance of the robot to the ball is equal to 50cm, until finally the robot will stop when the distance of the robot with the ball is equal to 5cm. The speed of wheel motors based on the distance between the robot and the sphere is set by using the PID controller.

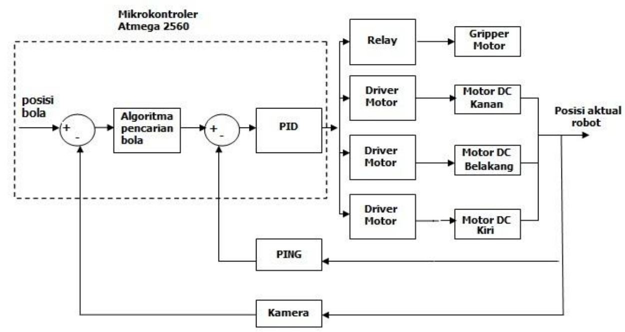

Fig. 3. The block diagram of a wheeled soccer robot controls

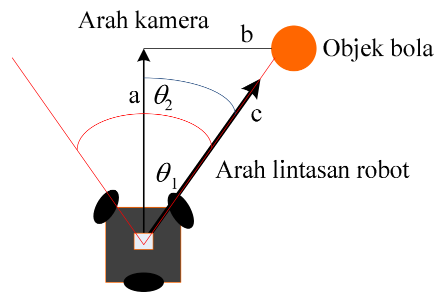

Fig. 4. The concept of object detection

D. Speed Control System use PID Controller

Then the ultrasonic sensor will measure the distance between the robot with the ball (path c in Figure 4). If the distance of the robot with the ball is smaller or equal to 5 cm, the motor gripper will immediately move to hold the ball. If not, if the robot's distance with the ball is more than 5 cm, the robot will move towards the ball. The speed of movement of the robot to the ball will be maximum (PWM value for motor driver is 255) when the distance of the robot with the ball more than 50 cm. The speed of robot movement will decrease when the distance of the robot to the ball is equal to 50 cm, and continue to decrease in proportion to the reduced distance of the robot with the ball. The robot will stop when the distance of the robot with the ball is 5 cm. This speed control is done based on the distance of the robot with the ball, using the PID controller.

The structure of pid controller used is a parallel structure, show in Figure 5. r(t) is the set point of distance between the robot and the ball, c(t) is the actual distance between the robot and the ball, that measured use ultrasonic sensor, and u(t) is the PWM signal of the PID controller, to control the motor speed of the robot wheel drive. Kp, Ki and Kd are the parameter of PID controller.

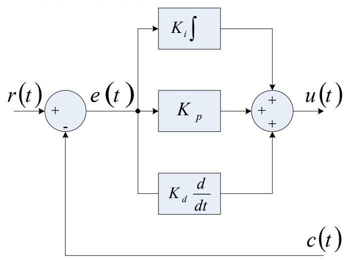

Fig. 5. The block diagram of Parallel PID Controller

The control signal of the PID controller is expressed by the following equation :

$$u(t) = K_p.e(t) + K_i\int e(t)dt + K_d\frac{de(t)}{dt} \tag{1}$$

In its field implementation for wheeled soccer robots, the concept of ball detection is shown in Figure 6

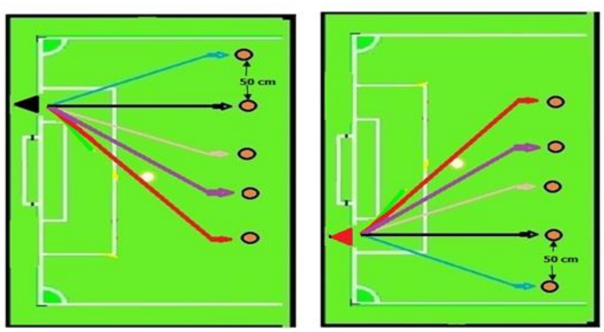

Fig. 6. The concept of detecting a ball object

The concept of search and the detection of ball objects in implementation on the match field for wheeled soccer robots is shown in Figure 5. The wheeled football robot is placed on the right or left side of the goal in a straight position against the ball and then the robot moves to the specified ball position, for example the spacing between position-1 and position-2 is 50 cm.

E. Electronics Systems

The electronic control system on the robot uses Arduino Mega2560 board with clock of 16 MHz. Detection of objects using CMUCam5 camera. CMUCam5 detects the centroid of the object, in this case is an orange ball. The output of the camera is used in the Arduino program to determine if the robot has found the ball or not. The microcontroller system circuit also receives input from the ultrasonic sensor to detect the distance between the robot and the ball. The ultrasonic sensor detection results and data from the camera sensors are used as a reference for the robot position. The output of the microcontroller system is connected to the motor driver circuit. The design of electronics control systems in robots is shown in Figures 7, 8, and 9.

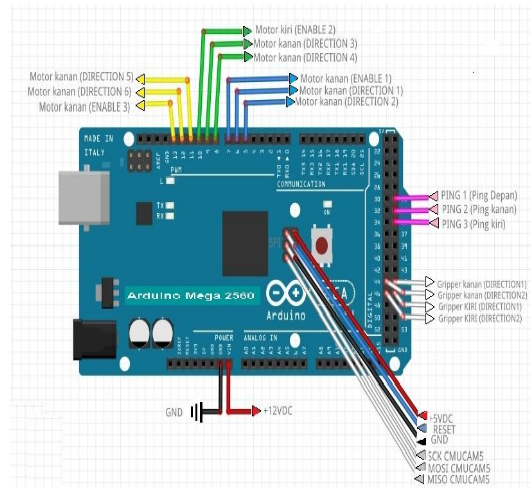

Fig. 7. Design of electronics control system with Arduiono Mega2560

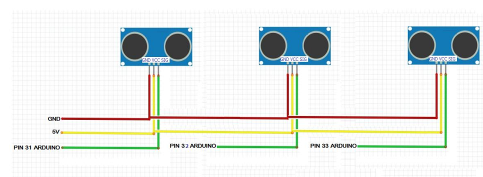

Fig. 8. Wiring diagram of ultrasonic sensor

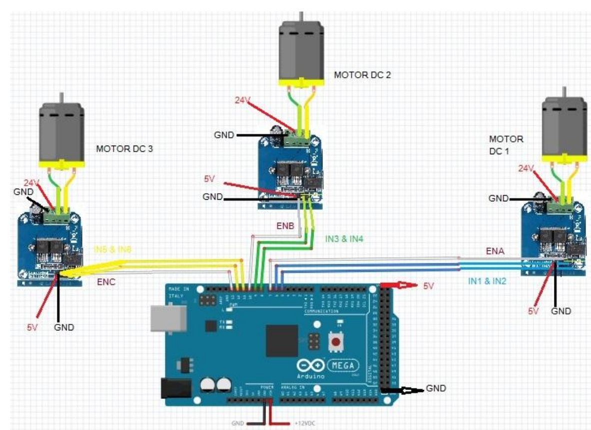

Fig. 9. Wiring diagram of driver motor

III. TESTING SET-UP

Tests conducted to determine the robot's performance in detecting ball objects in both static and moving conditions (dynamic). In testing on static conditions, testing is done to determine whether the ball object successfully detected by the robot so that the coordinates of the object position is known. The test is done by arranging the object straight in front of the robot camera, the object on the left side of the robot, and the object on the right side of the robot, the detection distance is 40cm, 80cm, 120cm, 160cm and 200cm. Data retrieval is done by displaying x and y coordinate data, and height and weight using serial monitoring from arduino IDE software and PixyMon software. Illustrations of the target marker positioning sensor testing can be seen in Fig. 10.

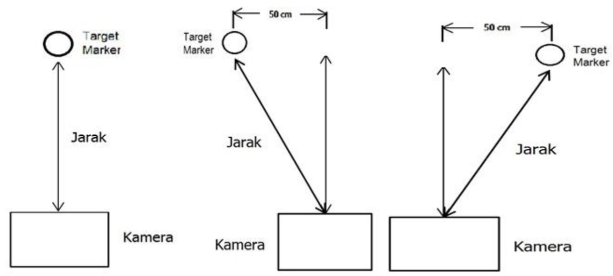

Fig. 10. Sensor testing with target marker: directly in front, offset to the left, and offset to the right

IV. Results and Discussion

A. *Testing for the position of the object straight in front of the camera (centered)*

Testing is done by placing the object (target marker) at various distances: 40cm, 80cm, 120cm, 160cm and 200cm. Target marker is placed at the center position of the camera sensor. The result of the camera test when the target marker is in the center of the sensor is shown in Figure 11 and Table 1.

Table 1 shows the results of CMUcam5 camera sensor testing related to position, width, and target marker height. For the value of x it is seen that the value ranges from 171-178, this is due to non-precise left-right position at the time of target shift. The value of y changes from 162 to 115 because the greater the distance of the sensor with the target marker the target marker's position will be higher, so the y value is smaller. Results of sensor readings with a value of x ranging from 170 ± 10 can be interpreted that the target is in the center.

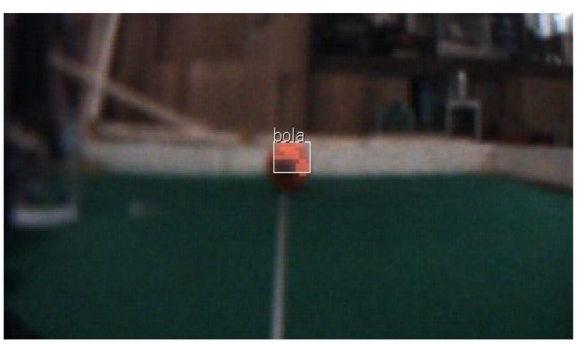

Fig. 11. The result of object detection with the position centered against the robot at a distance of 200 cm

TABLE I. Target Detection Test Result On Center Position

Target marker distance (cm)	Sensor readings *(integer)*			
	Coordinates		*Width (pixels)*	*Height (pixels)*
	x	*y*		
40	178	162	105	74
80	177	131	17	39
120	175	125	41	23
160	173	117	20	17
200	171	115	22	16

B. *Testing with target marker offset to the left*

Testing is done by placing the object (target marker) to the left direction of the robot camera at a distance of 40cm, 80cm, 120cm, 160cm and 200cm. The test results are shown in Figure 12 and the data in Table 2.

Fig. 12. The results of object position detection test to the left of the robot with a distance of 200 cm

TABLE II. Target Detection Test Result On Left-offset Position

Target marker distance (cm)	Sensor reading *(integer)*			
	Coordinates		*Width (pixels)*	*Height (pixels) x*
	x	y		
40	3	149	6	9
80	22	126	40	35
120	55	120	31	26
160	73	115	22	17
200	98	112	17	12

Based on Table 2 it can be seen for x coordinates that the values are between 3 and 98, if the value of x less than 170 can mean that the target marker is to the left of the center. The value for y coordinates between 112-149 due to the greater the distance of the sensor with the target marker, then the target marker will look higher on the camera so that the y value also increases.

C. Testing with target marker offset to the right

Testing is done by placing the object (target marker) to the right direction of the robot camera at a distance of 40cm, 80cm, 120cm, 160cm and 200cm. The test results are shown in Figure 13 and the data in Table 3. Based on the data in Table 3, the value of x is in the range from 209 to 300. For the sensor readout value, if the value of x greater than 180 can be interpreted that the target marker is to the right of the midpoint. The value for y coordinates is in the range of 114 to 151, the greater the distance of the sensor with the target marker, the target marker will appear higher so that the y value also increases.

Fig. 13. The results of object position detection test to the right of the robot with a distance of 200 cm

TABLE III. TARGET DETECTION TEST RESULT ON RIGHT-OFFSET POSITION

***Target marker* distance (cm)**	**Sensor reading *(integer)***			
	Coordinates		***Width (pixels)***	***Height (pixels) x x***
	x	y		
40	300	151	42	45
80	270	131	34	35
120	254	120	32	30
160	230	118	26	22
200	209	114	21	19

D. Detection Test for Moving Ball (Dynamic) Conditions

The detection test for the ball in moving (dynamic) condition is done by means of a robot directed to the ball, then when the robot manages to detect the ball and moves towards the ball, the ball will be driven by a human (dribbled) with random directions. Test results show the robot can dynamically follow the direction of movement of the ball. Control system testing for robot movement speed is done by varying the distance of the ball to the robot and observing the response speed. Variations of distance tested were 5cm, 25cm, 50cm, 75cm, 100cm, 150cm, and 200cm. The test results show the speed of the robot can be controlled based on the distance between the robot with the ball. The shorter the robot's distance to the ball, the robot's speed will decrease.

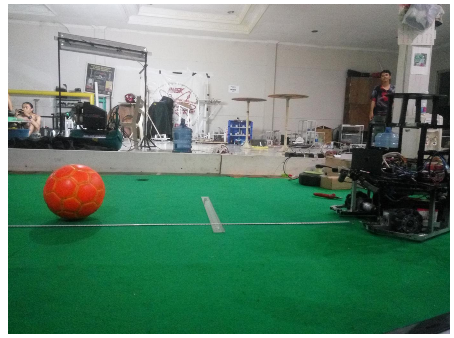

Fig. 14. Robot speed control test for dynamic ball position

V. CONCLUSION

Based on the results from the research that has been done, when the ball is static, the object detection system can work well. For dynamic ball conditions, although the robot is able to follow the movement of the ball position, the response is still slow but the speed of movement of the robot based on the distance conditions between the ball with the robot, speed control system can work as expected.

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