Distance Estimation and Direction Determination of the Person-Following Robot

M. Latif
Mechatronics Department, Faculty of Engineering, University of Trunojoyo Madura
Jl. Telang Raya PO BOX 2 Kamal, Bangkalan, Jawa Timur, Indonesia

***Abstract*— Person-following robot is a robot that has the ability to follow the movement of a person or a target and keeping of a specified distance. Distance estimation and direction determination is one important part of the person-following robot after detecting a target. Distance and angle information is used as input to control the position of the robot towards the target. Distance measurements in this research use stereo geometry and angle measurements based on the relationship of the camera view angle and position of the target in the image. Measurement sensor using two cameras arranged in a stereo. Testing distance estimation was conducted from 60 cm to 280 cm. While, angle measurement tests carried out in the range-20o to 20o with a distance of 200 cm between the robot and the target. The test results of distance estimation in the range 60cm to 180cm, the maximum measurement error is 3.52%. In the distance range of 200 cm to 280 cm, the maximum measurement error reaches 6.78%. Average of distance measurement errors that occurs is 3%. The test results of angle estimation showing high accuracy. Average of angle measurement error that occurs is 0.32%.**

I. INTRODUCTION

Person-following robot is a robot that has the ability to follow the movement of a person or a target and keeping of a specified distance [1]. Person-following robot system has some very complex problems. These include the detection of the target, distance estimation, direction determination, tracking, trajectory, and movement control of the robot [2]. Distance estimation and direction determination is one important part of the person-following robot after detecting a target [3]. Distance measurement performed to determine the distance information between the robots and the target. The information is used as input control to keep the distance between them.

In previous research, there are several methods to estimate the distance. Research conducted by Kwon H. et.al [4], the measurement is done by stating the modification of the law of sinus. Another approach to distance estimation suggested by Stefan Florczyk [5]. In the estimation requires a surface feature. The approach uses several markers on the target. These estimate, using the fact that an object closer to the camera will appear larger in the image. Determining the size of the object in the image using an approach based on a point attached to objects. The distance between the markers point in the image are used to calculate the size of the object. Weakness of this approach depends on the angle and position of the image capture. If the camera takes an image of a skewed perspective of the object, the distance measurement will be inaccurate.

In this research, take measurements the distance and determine the robot direction toward the target. Methods for measuring distance using stereo geometry. The angle estimate based on the relationship of camera view angle and position of the target in the image. In the distance and angle measurement, system of person-following robot equipped with vision sensors. The vision sensor is composed of two cameras arranged in a stereo.

II. DESIGN OF VISION SYSTEM

Vision system serves to identify the target and measure the distance and angle to determine the direction of the robot toward the target. Distance is used to control the position and velocity. While, the angles used to determine the orientation of the robot toward the target. Both of These parameters obtained through stereo cameras mounted on the robot. Both of these parameters are used as input the control system that has been designed. The stereo camera connected to a laptop that serves as a data processor and generating a control signal to be given to the robot. Both cameras focal length is 2.8 mm, and the view angle is 50 degrees. Cameras arranged horizontally with a baseline is 85 mm. Physical form of the stereo cameras is shown in Figure 1 with a black circle marks. The vision system is a major part before the control system in person-following robot.

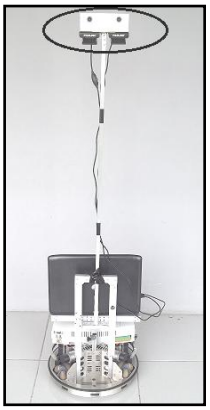

Figure 1. Physical form of the stereo cameras

III. DISTANCE IDENTIFICATION

Distance measurements in this research use stereo geometry. Measurements using two cameras that works as a stereo camera. Left and right cameras will produce two images. The catch of both cameras is shown in Figure 2.

Figure 2. The catch of both cameras

Based on both the image can be obtained disparity value. In Figure 3 shows a schematic of stereo geometry, the same target is viewed from two different positions [5][6]. Based on Figure 3, we can estimate the distance using Equation 1.

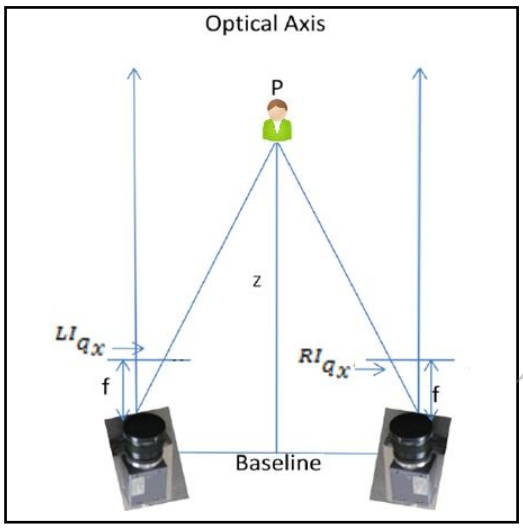

Figure 3 A schematic of stereo geometry

$$z = \frac{fa}{RI_{q_x} - LI_{q_x}} \quad (1)$$

Where, z is the distance (in pixels), a is the baseline and f is the focal length of the camera. LI_{q_x} is distance from image center to the target on the left camera, while RI_{q_x} is distance from image center to target on the right camera. Result of the equation is distance in pixels [7].

Based on Equation 1 then, performed a calibration to determine the relationship of the real distance and the distance in pixels. Both of these relationships are shown in Table 1.

Table 1. Relationship of the real distance and the distance in pixels

Distance	
Real (mm)	Pixel (mm/px)
600	11.9
800	17
1000	23.8
1200	29.75
1400	39.667
1600	52.889
1800	59.5
2000	95.2
2200	95.2
2400	119
2600	238
2800	476

IV. ANGLE IDENTIFICATION

Angle Identification conducted to determine how much the angle between the direction of the robot and the target. It is used to determine the direction of the robot in motion toward the target. Estimated angle obtained by camera view angle and position of target in image. Specifications camera view angle according to the information vendors is 71°. However, based on measurements taken, the camera view angle is 50°. The measurements were made by putting an object in a position up to meet the camera frame. Then, draw a straight line from both sides of the object to the center camera. View angle of the camera used in this research according to the results of measurement that is 50°. Then, the angle is divided into two sections with the center point at 25°. Distribution the area is -25° on the left and 25° on the right of the camera center point. The image size of camera captured is 320x240 pixels with the center point at 160 in x axis. Center point the image is considered 0, so it has a width of -160 pixels on the left side and 160 pixels on the right side. Distribution camera view angle and image size is shown in Figure 4.

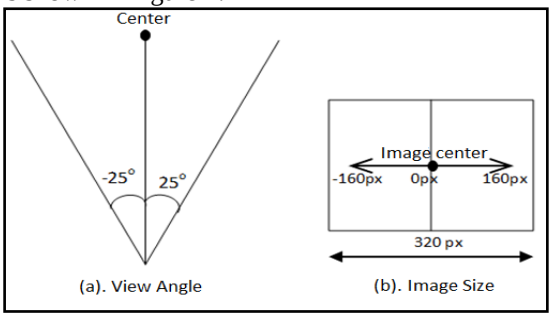

Figure 4. Distribution of view angle and image size

Based on correlation between camera view angle and width of the image, then the angle of the robot toward targets can be found using linear regression. Both of these relationships are presented in data form as shown in Table 2. Linear regression will generate formula to calculate the angle. The formula is shown in Equation 2.

$$Angle = 0.1563x \quad (2)$$

Where, x is the position of targets in the image.

Tabel 2. Relationship of the camera view angle and width of the image

Pixel Width	Angle (deg)
-160	-25
-120	-18.75
-80	-12.5
-60	-9.375
-40	-6.25
-20	-3.125
0	0
20	3.125
40	6.25
60	9.375
80	12.5
120	18.75
160	25

The process mentioned above just find the angle of each camera. To find the angle between robot directions and the target done by adding up both camera angles and then divided by two. The result of these calculations is the angle of physical robot direction toward the target.

V. EXPERIMENTS MEASUREMENT OF DISTANCE

Experiments measurement of distance performed in the range of 60 cm to 280 cm. Based on the test results, the greater the distance of the robot to the target then the error will be higher. Test results of the distance estimation from 60 cm to 180 cm the maximum measurement error is 3.52%. In the distance range of 200 cm to 280 cm, the maximum measurement error reaches 6.78%. The average of distance measurement error is 3%. The results of distance measurement are shown in Table 3. Comparison of real distance and distance measurement results and measurement error is shown in Figure 5.

Table 3. Results of distance estimation

Distance		
Real (mm)	Measurement (mm)	Error VI. (%)
600	595.60	0.73%
800	790.33	1.21%
1000	1010.62	1.06%
1200	1174.26	2.15%
1400	1401.15	0.08%
1600	1638.61	2.41%
1800	1736.72	3.52%
2000	2116.97	5.85%
2200	2116.97	3.77%
2400	2283.63	4.85%
2600	2710.40	4.25%
2800	2989.76	6.78%
Average		3%

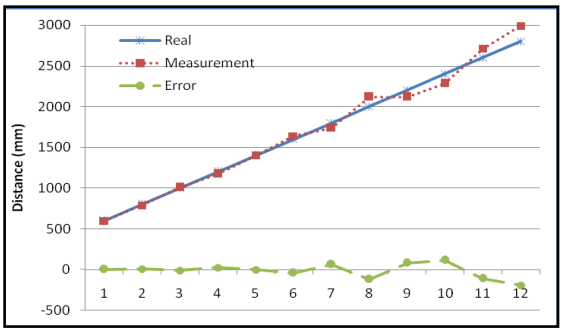

Figure 5. Comparison of real distance and distance estimation results and measurement error

VII. EXPERIMENTS MEASUREMENT OF ANGLE

View angle of the camera robot is limited, that is from -25° up to 25°. In the experiments, the maximum angle used is 20°, because the angle which can be reached by both cameras is 20°. Identification of distance measurements performed from 200 m with a target condition did not move. The results of measuring angle showing high accuracy. The average of angle measurement error is 0.32%. The results of angle measurement are shown in Table 4. Comparison of real angle and angle measurement results and measurement error is shown in Figure 6. In the graph, the real angle and angle estimation results appear as if coincide. This is because the difference in the value of both very small.

Table 4. Test results of angle estimation

Angle		
Real (deg)	Estimation (deg)	Error VIII. (%)
-20	-19.860	0.70%
-15	-14.993	0.05%
-10	-9.950	0.50%
-5	-4.990	0.20%
0	0.000	0.00%
5	4.990	0.20%
10	9.950	0.50%
15	14.993	0.05%
20	19.860	0.70%
Average		0.32%

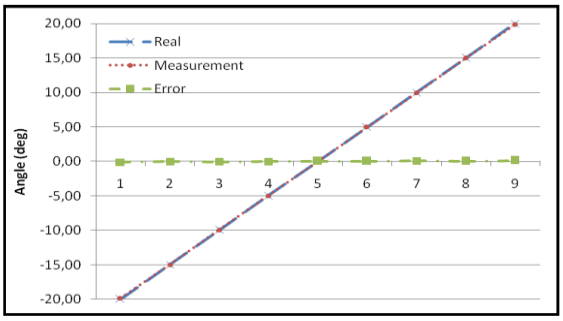

Figure 6. Comparison of real angle and angle estimation results and measurement error

IX. CONCLUSION

The results of the distance measurement from 60 cm to 180 cm the maximum measurement error is 3.52%. In the distance range from 200 cm to 280 cm, the maximum measurement error reaches 6.78%. The average of distance measurement error is 3%. Based on the experiment results, the greater the distance of the robot to the target then the error will be higher. The results of measuring angle showing high accuracy. The average of angle measurement error is 0.32%.

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