Chapter 20
Object-Tracking Robot Using Data Combination of Ultrasonic Sensor and Servo Motor

Seung-Ik Hwang, Beom-Seok Seo and Jang-Myung Lee

Abstract In this paper, distance values of ultrasonic distance sensor and the rotation angle values of the servo motor are used as a way of tracking the moving object. Depending on the environment, it is needed to track the accurate path or the shortest distance by predicting them. So, to prove that the proposed tracking method which using ultrasonic distance sensor and servo motor as the input element is more accurate and affordable than tracking method using vision and LRF and multiple ultrasonic sensors as the input element, it is experimented to compare two tracking methods. Furthermore it is proved that tracking is more accurate by applying Intermediate filter.

Keywords Object-tracking robot • Ultrasonic sensor • Servo motor • Rotation angle • Mobile robot

20.1 Introduction

Worldwide, according to industrial development and improvement of standard of living, research on robots for convenience has actively been done. There are some examples cleaning robots, service robots, and industrial robots. They show robots ties closely with people for a variety of purposes in real life or industrial. Basically, in order to drive the robot, the input element and the output element

S.-I. Hwang · B.-S. Seo · J.-M. Lee (✉)
Department of Electrical Engineering, Pusan National University, Busan, South Korea
e-mail: jmlee@pusan.ac.kr

S.-I. Hwang
e-mail: seungik7379@pusan.ac.kr

B.-S. Seo
e-mail: beomseok7379@pusan.ac.kr

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should be present. Several sensors can be examples of input elements. There are several kinds of sensors, distance measurement sensors, location-aware sensors, vision, pressure sensors, microphones, etc. Robot can be driven by calculating or by analyzing input data received from these sensors. Also driving element means the output element. The output element is electric device such as motor or hydraulic devices, monitors, speakers. Along with the development of the intelligent robot technology, many methods have been proposed for the interaction of people and robots. Mobile robot moving along the target is one of the ways in interaction of humans and robots. Also applying robot to the real world is becoming more important. In order to implement tracking object, calculate rotate error and straightness error between robot and objects by combining ultrasonic distance sensor to servo motor and by using the distance data measured by ultrasonic distance sensor and the angle of the servo motor data. Thus, by using the calculated error and by controlling two DC motors Installed on the robot, let robot track moving object in maintaining a certain distance. In addition to the ultrasonic distance sensor, there are vision and laser finder it is mainly used at a tracking robot. Although vision through image processing is more accurate than other sensors to achieve environment information, it needs a High specification of the system to process large data. As a result, it costs high. Also laser finder is affected by many obstacles surrounding environment, that's why it is difficult to obtain reliable data. Also its uncertainty is so enlarged that tracking is likely to fail. In contrast, ultrasonic distance sensor is less impacted on the surrounding environment and has advantage of high accuracy of the data at low cost comparing with vision and laser finder [1].

There are various methods of tracking object through using ultrasonic distance sensor, but among them, frequently used method is to pace number of ultrasonic distance sensors in different angles to tract direction in the sensor of being recognized. However, there are disadvantage of low accuracy. As direction of object is changed, ultrasonic angle of reflection is changed or sound wave from each sensor can be input to different sensor. This phenomenon shows inaccurate value is recognized [2].

To complement previously mentioned method and to track object in maintaining a certain distance from the robot to objects, straightness errors and rotation error generated by distance value of ultrasonic distance sensor, the value of the angle of the servo motor are calculated. Also the speed of the robot is controlled by using proportional control. Finally two experiments are discussed by comparing one inserting a filter in the middle of the ultrasonic distance sensor with the other not inserting. The filed this method is used is auto golf cart [3] or multiple robots moving in the formation at a constant distance [4]. In this paper, it proposes input elements which are ultrasonic distance sensor, description for the features, performance of servo motor and how to take advantage of servo motor in Sect 20.2. Also Wheel-drive robot and control techniques for moving object tracking using rotate are described in Sect. 20.3 and performance it is suggested by experiment of moving object tracking by using graph is described in Sect. 20.4. Finally it concludes this paper in Sect. 20.5.

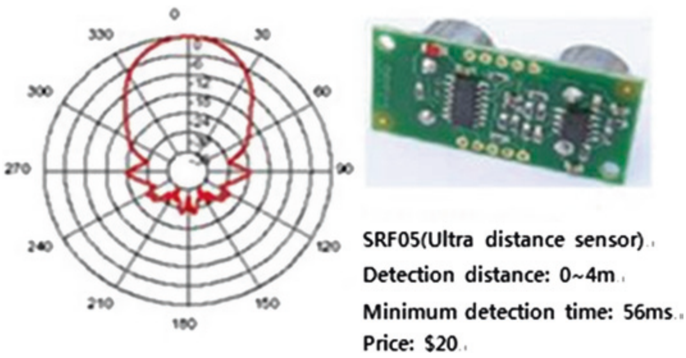

Fig. 20.1 Performance of ultrasonic sensors were used in the experiment

20.2 Explanation and Using Method of Distance Sensor Servo Motor

20.2.1 Ultrasonic Distance Sensor

Ultrasonic distance sensor is device using a frequency band of sound waves humans can't hear and it forms a one set of transmitter and receiver. There are two type of sensor. One is the reflective type that Transmitter and receiver lean towards each other in the same direction the other is the opposite type that the transmitter and receiver face each other. In this paper, reflective type is used. More performance is shown in Fig. 20.1.

The operation Method of the sensor like as shown in the Fig. 20.1. Distance can be calculated by the round-trip time from ultrasonic sensor to obstacle. The ultrasonic distance sensor varies in performance but low-cost sensors were used. Its measurement error is +5 cm, output range is 0–4 m, measuring angles is up to 25° and the minimum detection time is 56 ms.

20.2.2 Servo Motor

Basically servo motor is driven by receiving a PWM signal input, as shown in Fig. 20.2. Motor can indicate the direction continuously depending on the input pulse width. Servo motor used in the experiment can move up to 120° and its input voltage is 4.8–6 V. The round-trip time in motor is from minimum 0.64 s to maximum 0.84 s.

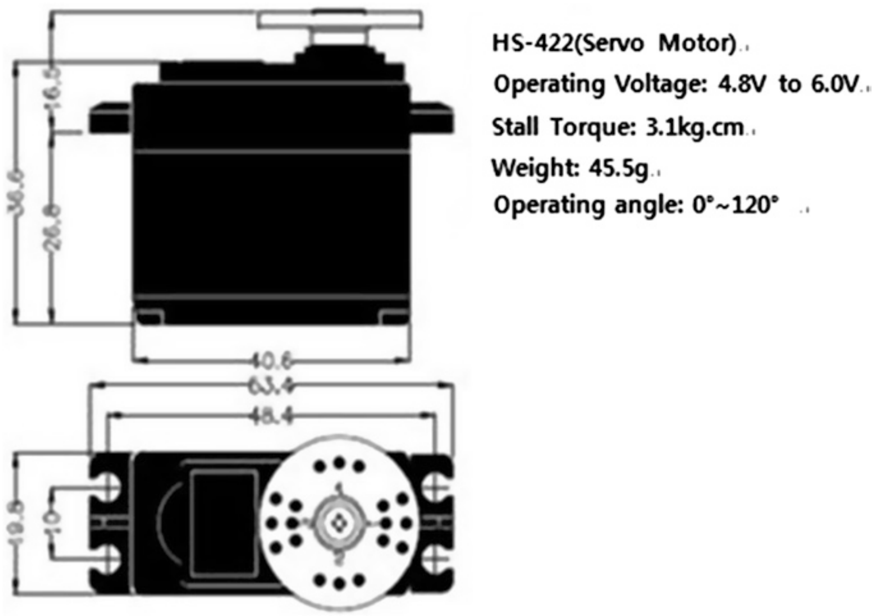

Fig. 20.2 Performance of servo motor were used in the experiment

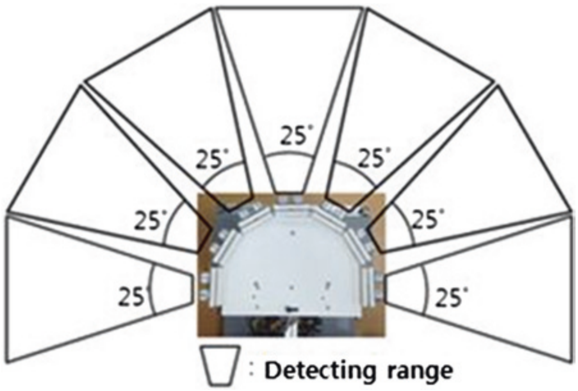

Fig. 20.3 Range and deployment method using a plurality of ultrasonic distance sensor

20.2.3 Taking Advantage of the Ultrasonic Distance Sensor and Servo Motor

In order to track object, it is needed to determine the direction and distance of an object. Mobile robot can move using only one ultrasonic sensor but there are one data of distance not both information of direction and distance. The direction of the object can be known by Multiple Ultrasonic distance sensors installed in several directions as shown in Fig. 20.3. Seven sensors of detection angle of

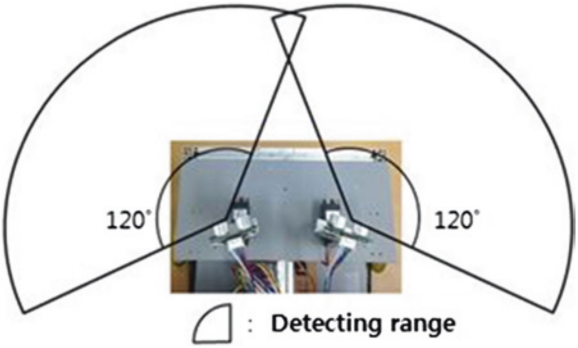

Fig. 20.4 Placement method and range that combines ultrasonic distance sensor and servo motor

25° are installed to detect the direction of more than 180°. Also, information of distance and direction can be known by combining ultrasonic distance sensor with servo motor that can designate direction through method suggested in this paper. Ultrasonic distance sensor can detect 120° range and two sensors are installed in robot as shown in Fig. 20.4.

20.3 Tracking Control of Mobile Robot

20.3.1 Configuration and the Equations of Motion for Mobile Robot

Configuration of mobile robot inputs is consisted of two sensors combined ultrasonic distance sensor with servo motor set up on the top of mobile robots using a fixed device as shown in Fig. 20.5. The detection range of 120° is respectively servo motor's reference value. Then, it is possible to minimize the Straightness errors when object is detected by two sensors. The reason why two combined sensors set up is that the detection of the round-trip time can be reduced half by using two servo motors instead of one. In addition, this configuration has the advantage of detecting wide area better than fixed ultrasonic sensor for navigate the specified direction. So, it has the same efficiency using multiple ultrasonic sensors.

Likewise, output element is two dc motor as wheel drive. Figure 20.6 shows the position of the robot according to the movement of wheel-drive mobile robot.

Position can be represented by Eq. (20.1).

$$P(t) = [x(t), y(t), \theta(t)] \tag{20.1}$$

$x(t)$, $y(t)$ are coordinates of the position about robot over time respectively and $\theta(t)$ is the angle between the X-axis and the front of the robot. Straight speed $V_S(t)$ of the robot and the rotational speed $V_R(t)$ are shown in Eq. (20.2). r is the radius of

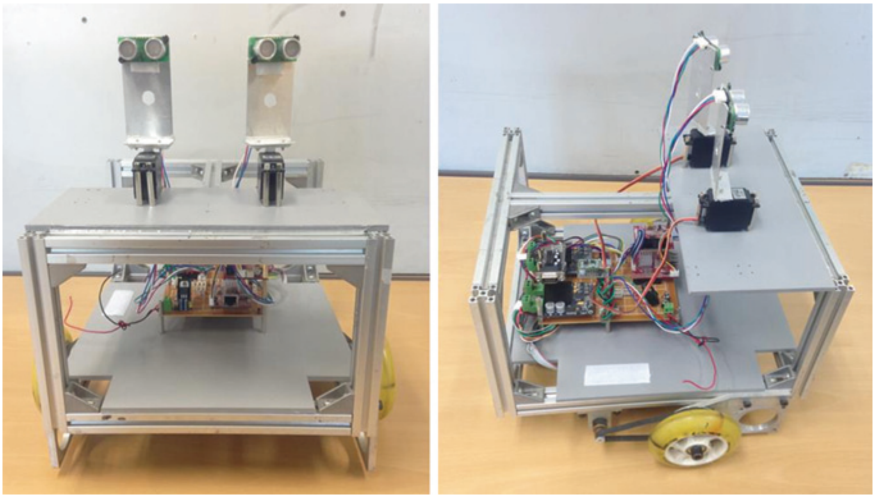

Fig. 20.5 Configuration of a mobile robot equipped with ultrasonic sensors and servo motor

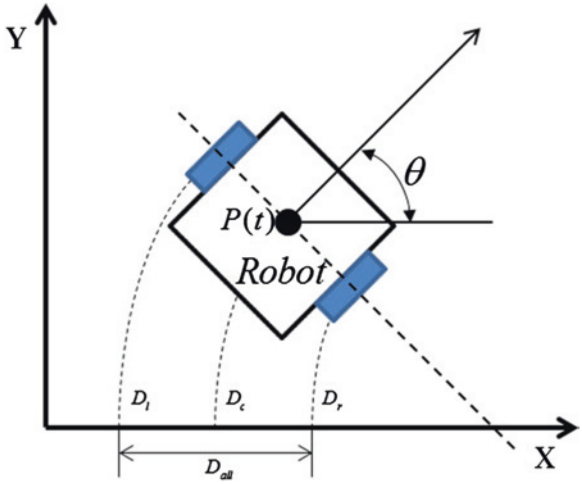

Fig. 20.6 Movement and position of the wheel-drive mobile robot

the wheel, ω_l is the angular velocity of the left wheel and ω_r is the angular velocity of the right wheel.

$$\begin{aligned} V_S &= \frac{r}{2}(\omega_l + \omega_r) \\ V_R &= \frac{r}{2}(\omega_l - \omega_r) \end{aligned} \tag{20.2}$$

Position and change of direction according to the movement for mobile robot are separated by two cases. One case is robot moves in no rotation, the other case is robot moves in rotation. The former case can be represented by Eq. (20.3), the latter case can be represented by Eq. (20.4).

- In case of not having rotational motion.

$$\begin{aligned} \Delta x &= V_S \Delta t \, \cos\theta(t) \\ \Delta y &= V_S \Delta t \, \sin\theta(t) \\ \Delta\theta &= 0 \end{aligned} \tag{20.3}$$

- In case of having rotational motion.

$$\begin{aligned} \Delta x &= \tfrac{V_S}{V_R}\{\sin[\theta(t) + \Delta\theta] - \sin\theta(t)\} \\ \Delta y &= -\tfrac{V_S}{V_R}\{\cos[\theta(t) + \Delta\theta] - \cos\theta(t)\} \\ \Delta\theta &= V_R \Delta t \end{aligned} \tag{20.4}$$

Therefore, consecutive location and position of the mobile robot in an absolute coordinate system can be represented by Eq. (20.5).

$$\begin{aligned} x(t+1) &= x(t) + \Delta x \\ y(t+1) &= y(t) + \Delta y \\ z(t+1) &= z(t) + \Delta z \end{aligned} \tag{20.5}$$

20.3.2 Tracking Control of Robot for Moving Objects

The configuration of mobile robot for moving object is as follows. In here, it assumed that object exists only or closer than other objects in experimental environment. Then, mobile robot is driven to maintain a certain distance with target for tracking. Direction angle of servo motor ϕ_d, distance of the target value S_d are given information. Distance value S_d can be found by using ultrasonic distance sensor and each direction angle ϕ_d can be found in real-time by using the angle of rotation of the servo motor. Figure 20.7 shows the state for the actual moving object tracking and then, represented by a symbol. The moving speed and the rotational speed are necessary for mobile robot to drive. So, two speeds should be found. Using the distance and direction obtained from the sensor, velocity it can make S converge to S_d and ϕ converge to ϕ_d should be found. Such expression is represented by Eq. (20.6).

$$l = s \cdot \sin(\phi - \omega) \qquad \therefore \frac{l}{s} = \sin(\phi - \omega) \tag{20.6}$$

Therefore, ω can be represented by the Eq. (20.7).

$$\omega = \phi - \sin^{-1}\left(\frac{l}{s}\right) \tag{20.7}$$

l_t can be derived like as Eq. (20.8) in Fig. 20.7.

$$l_t = s \cdot \cos(\phi - \omega) - s_d \cdot \cos\phi_d \tag{20.8}$$

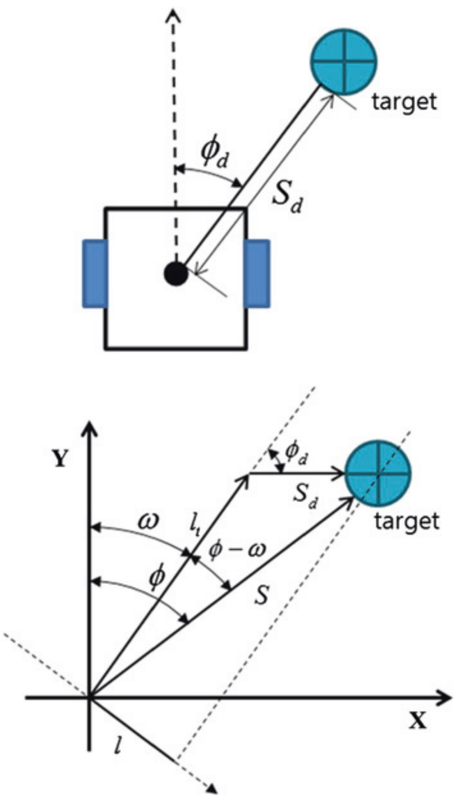

Fig. 20.7 Movement and position of the moving object tracking

Based on the calculated expression, PWM of DC motor it is equipped in both sides of the mobile robot was controlled proportionally to converge it because l_t and ω are zero.

20.4 Experiment and Comparison

20.4.1 Experimental Methods

Experiment was done by producing comparison of target to prove method suggested was effective. Comparison of target is mobile robot with multiple ultrasonic distance sensor, which uses 7 same ultrasonic distance sensor and it has Probe range of 180°. The experimental conditions include different input elements but same equipment and same place. Similarly configuration of robot's body, velocity about straight error and rotation error are same experimental conditions. Experiment and comparison are done through 90° curve driving and S-shaped driving. As the result, it can be represented from the sensor information. Also two cases are compared with applying intermediate filter to Ultrasonic distance sensor and not applying it.

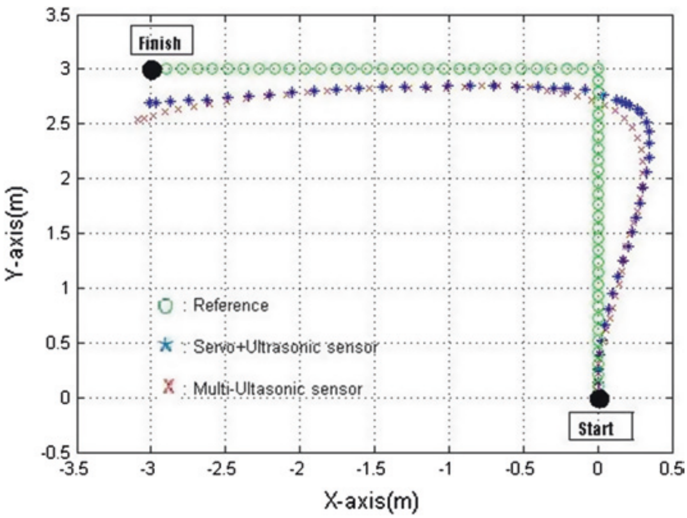

Fig. 20.8 90° traveling of the robot movement trajectory graph (not applying filter)

Table 20.1 Experimental error of 90° traveling (not applying filter)

	Servo motor		Multiple sensors	
	X-axis	Y-axis	X-axis	Y-axis
Average error (cm)	16.5	13.3	17.5	14.8
Maximum error (cm)	32.1		42.3	

20.4.2 The Experiment Not Applying the Intermediate Filters

- Case 1: 90° traveling
- Case 2: S-shaped traveling

From Figs. 20.8, 20.9, 20.10 and 20.11 for each of the symbols, O shape of the green is a reference, * shape of the blue is trajectory of the robot using an ultrasonic distance sensor and two servo motors. And X shape of the red is trajectory of a mobile robot using multiple ultrasonic distance sensors. These three elements Integrate into one graph to compare them. Experimental result for first 90° driving is shown in Fig. 20.8 and Table 20.1. And there was no significant difference when comparing the overall path. Overall, the average error was about 1 cm and the maximum error was about 10 cm. Second S-curve driving was differences in movement. At the first starting point, mobile robot with multi-ultrasonic sensor move across the inside of the curve without following the reference. On the other hand, mobile robot combined servo motor and ultrasonic sensor moves outside slightly beyond the reference. The reason why this migration path was shown in graph is that multi-ultrasonic sensor detects several directions but servo ultrasonic sensor can't detect interval during rotation. It causes rotation time error in using

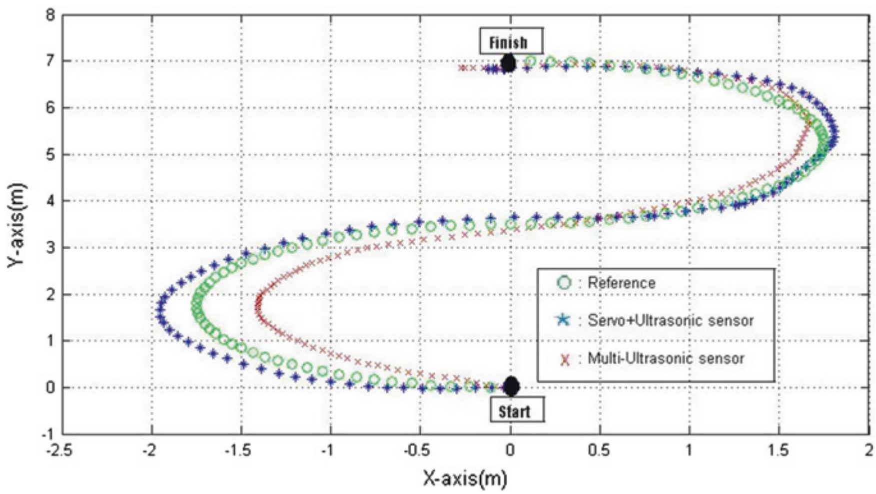

Fig. 20.9 S-shaped traveling of the robot movement trajectory traveling (not applying filter)

Table 20.2 Experimental error of the S-shaped traveling (not applying filter)

	Servo motor		Multiple sensors	
	X-axis	Y-axis	X-axis	Y-axis
Average error (cm)	13.8	17.2	20.7	16.9
Maximum error (cm)	23.5		33.9	

servo ultrasonic sensor. Also, errors in the two paths, servo motor's average error is smaller than multi-ultrasonic sensor's error about 7 cm to the X-axis but bigger than its error about 0.3 cm to the Y-axis. The maximum error is smaller than its error about 10 cm. Finally, the experiments are carried out by applying the intermediate filter to compensate for the path of movement (Table 20.2).

20.4.3 The Experiment Which is Applied the Intermediate Filters

- Case 1: 90° Traveling

Experimental result for the first 90° travelling applied in intermediate filter is shown in Fig. 20.10 and Table 20.3.

As compared with average error, servo motor's average error is smaller than multi-ultrasonic sensor's error about 3 cm to X-axis and bigger than its error about

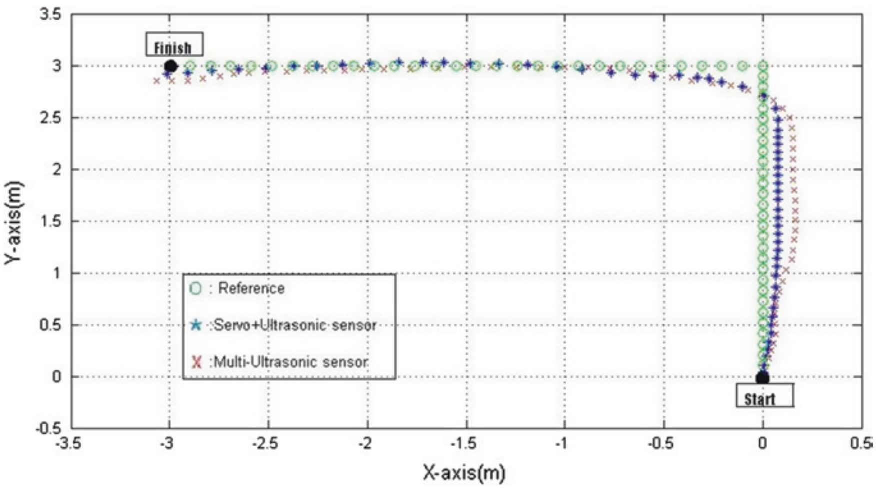

Fig. 20.10 90° traveling of the robot movement trajectory graph (applying filter)

Table 20.3 Experimental error of 90° traveling (applying filter)

	Servo motor		Multiple sensors	
	X-axis	Y-axis	X-axis	Y-axis
Average error (cm)	10.5	10.3	13.8	9.2
Maximum error (cm)	17.3		19.6	

1 cm to Y-axis. The maximum error is smaller than its error about 2.3 cm. Despite straight driving is not a high different, this result tells servo motor is more effective when mobile robot track the moving object at the point of total path.

- Case 2: S-shaped traveling

Experimental result for S-shaped travelling applied in intermediate filter is shown in the Fig. 20.11 and Table 20.4. Servo motor's average error is smaller than multi-ultrasonic sensor's error about 8 cm to X-axial and smaller than its error about 1 cm to Y-axial. The maximum error is notably smaller than its error about 16 cm. This results show method of tracking using servomotor depending on the ratio of the angle of rotation is more effective because it's maximum error is smaller than method of tracking using multi-sensor's maximum error about 16 cm. This shows that accurate tracking. Comparing filter applied mobile robot with filter not applied mobile robot, there is no significant difference in multi-ultrasonic sensor but servo ultrasonic sensor is significantly improved as filter apply mobile robot.

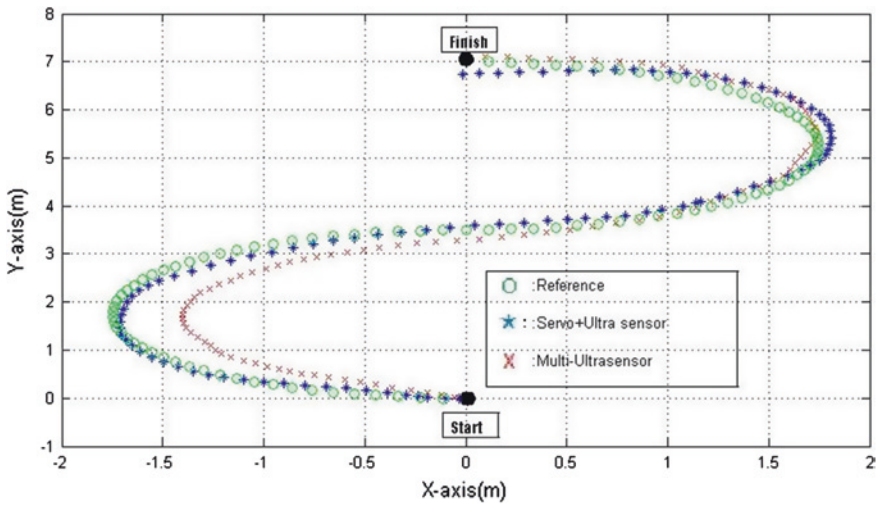

Fig. 20.11 S-shaped traveling of the robot movement trajectory traveling (applying filter)

Table 20.4 Experimental error of the S-shaped traveling (applying filter)

	Servo motor		Multiple sensors	
	X axial	Y axial	X axial	Y axial
Average error (cm)	10.3	13.8	18.5	14.5
Maximum error (cm)	18.6		34.7	

20.5 Conclusion

In this paper, moving object tracking method using ultrasonic distance sensor and servo motor is proposed. Features of the proposed method are as follows. Input element for tracking is ultrasonic distance sensor.

- Data size of ultrasonic distance sensor is smaller than camera or LRF sensor and process time is faster than them. Also, it suited to real-time target tracking.
- Ultrasonic distance sensor and servo motor are used to gather the data about distance and direction in tracking obstacle.
- Method in this paper is more efficient for tracking than using method of seven ultrasonic distance sensor.
- In case that the intermediate filter is applied, the performance of the proposed method is improved.

It is explained that the proposed mobile robot for tracking moving objects using a low-cost ultrasonic distance sensor and servo motor can track the moving objects efficiently. By placing a plurality of ultrasonic sensors, the interference of the ultrasonic sensor which having a disadvantage of tracking can be solved. In addition, it shows high-efficiency, accurate tracking at a low-cost.

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