A Study of Ultrasonic Sensor Capability in Human Following Robot System

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Abstract – Human following robot is very common in this technology era. Human following is a technique used by robot and autonomous vehicles to follow a human within a specific range. In this case, communication between the human and the robot is the most significant factor where sensor is needed to ensure its successfulness. This paper discussed a human following robot system that utilized ultrasonic sensor. Ultrasonic sensor is preferred for human following robot due to its wide detection area, less light dependency, the ability to detect glass and shining wall, smaller in size, lightweight, use a very low memory, cheaper than Laser Range Finder (LRF) or camera and lower power consumption. However, being a specular type of sensor and not narrowly focused, this can cause wrong estimation and recognition of human, especially at the legs. Therefore, necessary accompanying algorithms should be developed to encounter this issue. Here, three pieces 40 kHz ultrasonic sensors are mounted on the four-wheeled mobile robot platform. Ultrasonic sensors used to detect the human’s leg, and the data collected from the sensors were used upon the design of sensor platform. In order to detect human’s leg, the sensor platform was tested repeatedly to obtain optimum data. The data which have been collected from the ultrasonic sensor will then be interfaced with Arduino software. Thus, this paper outlines a set of benchmarks for human following and briefly evaluates its performances. The human following robot was tested in a real laboratory environment. The results were good, where the implementation of this algorithm is able to produce an accurate decision.

1. Introduction
In this high technology era, the rise of robotics plays an important role for human beings. Robots proved us to be always a very helpful thing as a more intelligent robot are able to cooperate with human for supporting the human. In order to support the human’s works, a robot must be able to detect and follow the human [1]. A robot that able to detect and follow human is called human following robot. A human following robot needs interaction between itself and human in order to give aid / assistance. For example, an intelligent cargo transportation robot helps by carrying luggage in an airport [2-6]. The development of mobile cleaning robot to detect and track the sound source by using three microphones [7]. Besides, one of the domestic applications for a following robot is that it can carry stuffs along with human in shopping malls, home, office or golf courses.
There are a variety of advantages of this robot for human beings as it can also be used in civil application and industrial area. However, the robot itself cannot track and detect an object. So, the robot needs a mechanism which can make decision for it to take action accordingly so that the task can be performed correctly [8]. The involved mechanism is sensor that can detect obstacles or object around the robot itself. A lot of sensors can be utilized like laser, radio frequency, cameras and others, that able to follow the human in a constant distance with the mobile robot itself. In this project, ultrasonic sensor is used. Ultrasonic sensor is a device that able to measure the distance to an obstacle by using sound waves. The sound wave is travelled out at a specific frequency and returned when its sense a thing to measure distance in real time. It has its faults and this could be an issue for the sensor to recognize an object because the sensor works based on specular basis which mean it is not a narrow range scanning angle. Hence, a precision and accuracy work need to be implemented in order to track an object.

The ultrasonic sensor is low cost device that able to operate in any environment with low visibility where vision or laser systems are not really efficient [9-19]. The ultrasonic sensor is able to measure distance from itself to the certain object by using pulse-echo in real time. Unlike other sensors, ultrasonic sensor provides data about object existence in front of the sensor. Only few researches used ultrasonic sensor in human following system even though it is a very superior sensor in maneuvering and scanning application in various fields and environment conditions [20]. Here, the system utilizes ultrasonic sensor for legs recognition. The position and number of sensor was designed to recognize both human’s leg at the same time and follow the human. Three sensors were used to detect both human’s left and right leg and their interception is used to differentiate left leg and right leg. Each ultrasonic data is evaluated by using probability and the algorithm that can detect and track human legs is developed. From here, the robot able to follow as it could recognize both human’s leg. The performance of human following robot was then analyzed.

The paper is organized as follows – Section 2 explains the method of sensor validation and the proposed human following procedures. In Section 3, the results of the proposed human following algorithm are presented. Finally, the work is concluded in Section 4.

2. Methodology

2.1. Design and Development of Sensor Platform

Three pieces of ultrasonic sensors were used to perform tracking on the both human’s legs. The concept is that the sensors are arranged horizontally with a specific distance, where this distance will be the average width of human legs when the human is walking normally. Figure 2.1 shows the basic concept of the arrangement of ultrasonic sensor where the human legs are being sensed within the area of interception. There are two situations in the sensors placement, the first is when there is an intercept signal between sensor 1 and sensor 2, the systems inform the robot that is sense the human’s left leg, while when there is an intercept signal between sensor 2 and sensor 3, the system is sensing the right leg.

The dimension of the platform has been determined and the process of cutting Perspex is then carried on. Then, the combination of all cut Perspex is carried on according to the design as Figure 2.2 and connected using screw and nut. One sensor is located in the middle of the platform where another two are located at the right and left of the middle sensor. The purpose of using screw and nut is to aid the users in adjusting the angle while performing calibration on three sensors that used to track human’s left and right leg. By adjusting the angle, calibration on an algorithm would be easier to develop.
2.2. Calibration of Sensor Platform
The calibration of sensor platform involved the angle between both sides. After setting the sensor platform, both the right and left of the platform was adjusted to a specific angle of $0^\circ$, $10^\circ$, $20^\circ$ and $30^\circ$ to obtain the intercepted areas. For each angle being set, the areas of detection of combination of all sensors were visualized using 3D drawing. Flowchart in Figure 2.3 shows the steps of calibrating the sensor platform. Figure 2.4 and Figure 2.5 showed each adjusted angle of the sensor platform in order to test and calibrate the platform.

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**Figure 2.1.** Concept of Sensors Works

**Figure 2.2.** Design of Sensor Platform

**Figure 2.3.** Flowchart of Calibration of Sensor Platform
Adjustments of sensor platform were done as follows:

a) Angle of $0^\circ$ and Angle of $10^\circ$

![Figure 2.4. Angle of $0^\circ$ and Angle of $10^\circ$](image)

b) Angle of $20^\circ$ and Angle of $30^\circ$

![Figure 2.5. Angle of $20^\circ$ and Angle of $30^\circ$](image)

2.3. Position Validation of Sensor Platform

A cylindrical PVC pipe with a diameter of approximately same as human’s leg was used. The PVC pipe is placed within an area of one position, where there are three positions to be tested. Each position was randomly tested for 30 times to obtain average results. For 1st position, the tested area is the detection area of sensor 1 and sensor 2, while for 2nd position; the tested area is the detection area of sensor 2 and sensor 3. Last, the 3rd position was tested for both area of detection of 1st and 2nd position.

Besides, the sensor platform also tested with human’s leg as shown in Figures 2.6 – 2.8. Left leg of human was placed and tested in the area of 1st position, right leg of human was placed and tested in the area of 2nd position and 3rd position was used to test both legs in position. The testing of sensor platform take place in indoor lab environment and the human being tested was wearing long pants. The calibration of sensor platform involved;
a) 1st position: Left leg, 1st sensor & 2nd sensor detected, yellow LED lights up, robot in standby mode.

Figure 2.6. Position validations for the 1st position

b) 2nd position: Right leg, 2nd sensor & 3rd sensor detected, yellow LED lights up, robot in standby mode.

Figure 2.7. Position validations for the 2nd position

c) 3rd position: Left & Right legs. All sensors detected, Red LED lights up, robot in stop mode.

Figure 2.8. Position validations for the 3rd position

2.4. Testing the Ultrasonic Sensor on a Human Following Robot

The human following algorithm is tested and integrated with four different conditions in order to follow the human’s legs in a straight line. Robot has to check the human’s legs in front of it, then first is for the forward action, second is for stop action, third is the standby mode and last is backward action. Beneath are the algorithms of all condition:

a) Forward: IF (S1 & S2 & S3)>=60
b) Stop: IF \((25>S1>40) \& (25>S2>40) \& (25>S3>40)\)
c) Standby: IF \(((S1>50) \& (25>S3>40)) \text{ or } ((S3>50) \& (25>S1>40))\)
d) Backward: IF \((S1 \text{ or } S2 \text{ or } S3) \leq 25\)

3. Results & Discussion

3.1. Results of Calibration of Sensor Platform

The calibrations of sensor platform were done for the angles of \(0^\circ\), \(10^\circ\), \(20^\circ\) and \(30^\circ\). Figures 3.1 and 3.2 visualized the area of detection between sensors for these angles which were done in 3D to illustrate the area of detection between sensors.

For the angle set to \(0^\circ\), the area of detection between two sensors are small where this could make the robot hard to make decision in order to detect the human leg. While, for the angle set to \(10^\circ\), a larger area of detection between the sensors shows that it is able to detect human leg within the area.

![Figure 3.1. Results of Area of Detection for 0\(^\circ\) & 10\(^\circ\)](image)

Meanwhile, for the angle set to \(20^\circ\), the area of detection was visualized to be slightly larger than the angle at\(10^\circ\). It could make the robot unable to recognize legs when distance between legs and robot increases. Thus, accuracy could be decreases. The area of detection of angle \(30^\circ\) is too complicated where it could confuse on decision making where accuracy will extremely decreases. Overall, the angle of \(10^\circ\) is said to be the suitable angle for the sensor platform.

![Figure 3.2. Results of Area of Detection for 20\(^\circ\) & 30\(^\circ\)](image)
3.2. Results of Position Validation

Table 3.1 shows the results of position validation of sensor platform. Since the result from calibration of sensor platform illustrated that the sensor platform is suitable to work with the angle of 10°, position validation were also conducted at the same angle. For the 1st position, the results show that sensor 1 and sensor 2 able to detect the object which located on the left side of sensor platform. For the 2nd position, the results show that sensor 2 and sensor 3 able to detect the object which located on the right side of sensor platform while sensors 1, 2 and 3 able to detect the object which located on the left and right side of sensor platform. All of the 30 readings for each position were successfully recorded and it can be concluded that the sensor platform is able to detect human left and right legs within the area of detection.

| No. | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 |
|-----|----|----|----|----|----|----|----|----|----|
| 1   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 2   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 3   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 4   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 5   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 6   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 7   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 8   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 9   | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 10  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 11  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 12  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 13  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 14  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 15  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 16  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 17  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 18  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 19  | /  | /  | -  | -  | /  | /  | /  | /  | /  |
| 20  | /  | /  | -  | -  | /  | /  | /  | /  | /  |

3.3. Results of Ability Test

The ability test was conducted to clarify the performance of the human following robot. The results were obtained in the indoor lab environment. Figures 3.3 – 3.4 show the results of the human following robot that has successfully followed the targeted human for a distance of 360cm.

Figure 3.3: Ability Test for 60cm, 120cm & 180cm
Figure 3.4. Ability Test for 240cm, 300cm & 360cm

Table 3.2 shows the results being recorded when the ability tests were constructed. The total movement of robot for 300cm has been verified by tested for every 60cm.

| No. | Human Walking Distance (cm) | Robot Following Distance (cm) | Success (✓) | Fail (✗) |
|-----|-----------------------------|-----------------------------|-------------|----------|
| 1   | 60                          | 0                           | /           |          |
| 2   | 120                         | 60                          | /           |          |
| 3   | 180                         | 120                         | /           |          |
| 4   | 240                         | 180                         | /           |          |
| 5   | 300                         | 240                         | /           |          |
| 6   | 360                         | 300                         | /           |          |

4. Conclusions

A solution to human following robot has been presented in this paper. Three ultrasonic sensors have been integrated with the sensor platform with an objective of following a human. A study on the suitable number of ultrasonic sensor has been carried out. Besides that, a methodology of verification on the ultrasonic sensor is constructed. Ideally, the ultrasonic sensor has a specification of angle of view with ±30°, while the data obtained in the verification of the sensor is ±60°. The collected data are simply different to the ideal result due to multi-curved surface, tested in indoor environment and single sensor tested at one time. It has been proven that the ultrasonic sensor has a wide angle detection area which visualized like a bell shape. The design of sensor platform has been constructed along with the robot. The sensor platform was constructed to test the performance of human following robot. The human following algorithm was tested repeatedly in order to obtain the best result. The human following robot was tested in a real laboratory environment. The results were good, where the implementation of this algorithm is able to produce an accurate decision. Finally, comparison of different sensor shows that ultrasonic sensor is capable in a human following robot.

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