Implementation of Distance-Measuring System Using Ultrasonic to be used in an Autonomous Human-Following Luggage Robot

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Abstract: In this research, ultrasonic sensors are implemented to measure distances for an autonomous human-following luggage robot. The system consists of the luggage robot and the wireless transmitter device which is held by the person acting as a target. The robot is equipped with two ultrasonic sensors mounted on the top of it, acting only as receivers, two DC motors to drive the robot, and an Arduino board acting as microcontroller. Meanwhile, the transmitter device has one ultrasonic sensor. The luggage robot is designed to follow the person by following the signals sent by the transmitter device. In order to determine the direction of the target, a microcontroller is used to measure time difference of the signals received by the receivers mounted on the top of the luggage. A program is developed to compute the direction and distance to where the robot should move according to the transmitter device. The microcontroller then controls the motors through the H Bridge to make speed adjustment on both motors according to the direction of movement.

Keywords: autonomous human-following robot, ultrasonic sensor, Arduino microcontroller

1. Introduction

Today, people’s activities require them to stay mobile all the time with all the things that they have to carry such as books, papers, food and drink and bags. With all that in their hands, they will have hard time opening doors, taking calls and even greeting people. It will be helpful if they have luggage which, like no ordinary luggage, follows them around without dragging their luggage all the time.

The main idea of this research project is to develop a luggage robot that follow the owner around and stops at a distant when the owner stops walking. With this robot, they can pack our things in it and do not have to worry about occupying their hands by dragging the luggage here and there.

The whole processes are first the Arduino mega on the transmitter side will tell the ultrasonic sensor to send signals to the direction of the robot. The signals then received by the ultrasonic sensor receivers placed on the right and left edge of the robot. The time difference between the receivers is then

![Figure 1. System Overview](image-url)
to be calculated using the Arduino on the robot side to determine the direction of the robot needs to move and also the speed of each motor which will be controlled by the motor driver.

2. Luggage Robot Design

2.1. Mechanical Design

The luggage body is made entirely with ply wood. Wood is chosen because it gives adequate rigidity with a lot cheaper cost than metal sheet. The luggage body consists of several parts; the back side, the right and the left side, the top side and the bottom side as seen in figure 2.

![Figure 2. Mechanical Design of Luggage Robot](image)

The free wheel leg needs to be deployed for the luggage robot to move around. The leg keeps the luggage robot balanced and prevents the robot from toppling over to the front or to the back side.

2.2. Mechanical Calculation of Luggage Robot

This research project uses two DC motors to drive the luggage robot. Based on its specifications, the motor is suitable for this research project. Since the luggage robot uses three wheels, each wheel carries a third the weight of the total load. The loads that each wheel carries are approximately 3 kg and able to move and follow human’s normal walking speed which is 2 km/h or equal to 0.56m/s. The radius of the luggage robot wheel is 62.5 mm. The rolling friction coefficient is assumed to be 0.1 then we can calculate the force of the motor needed to produce the amount of torque.

![Figure 3. Illustration of Newton’s Second Law](image)

\[ \sum \vec{F} = m \times \vec{a} \]  \hspace{1cm} (1)
Assume gravitational force is 9.81 m/s² and the acceleration is 0.3 m/s² which is found by the maximum velocity 0.6 m/s within 2 seconds we got the motor force needed is 11.53N, then we can find the torque.

\[ \tau = F_{motor} \times r \]  

(2)

The torque needed for each motor to be able to carry the load of the luggage, with r = radius of the wheel and sf = safety factor of 1.5 is 11.02 kg.cm.

In order to find out whether the motor can catch up with human’s walking speed, linear velocity can be found using the formula below,

\[ v = r \times \omega \]  

(3)

From the calculation, with 100 RPM and 62.5 mm wheel radius the linear velocity is found to be 0.66 m/s which means it is enough to catch up with human’s walking speed which is 0.56 m/s. The torque needed is 11.02 kg.cm and the motors used have 16 kg.cm torques which is more than enough.

2.3. **Differential Drive Kinematics Modelling**

The wheel movement is on 2D plane (x,y) and the wheel is free to rotate about its axis, and it is directly proportional by the angular velocity of the wheel, and given by:

\[ \dot{x} = r \dot{\phi} \]  

(4)

![Figure 4. Illustration of Differential Drive Motion](image)

Figure 6 shows the point of Centre of Curvature (CoC), in which the luggage robot rotates around it. It also avoids slippage and has a pure rolling motion. The CoC lies on the common axis of the two riding wheels. In case of differential drive, the changing velocities \( V_l \) and \( V_r \) of the two left and right wheels. The luggage robot will move and follow any different trajectories with the same angular speed for both left and right wheels.

The right and left wheels linear velocities in terms of mobile angular speed can be seen as follow:

\[ V_l = \omega_{lin} \left( R + \frac{L}{2} \right) \]  

(5)

\[ V_r = \omega_{lin} \left( R - \frac{L}{2} \right) \]  

(6)

where R is the distance from CoC to the midpoint P. The distance, R between the two wheels can be found as:

\[ R = \frac{V_r + V_l}{V_r - V_l} \times \frac{L}{2} \]  

(7)
and because the vectors for linear speed of wheels $V_l$ and $V_r$ are orthogonal on the common axis of the driven wheels, we can determine the equation to represent the angular velocity of the luggage robot:

$$\omega = \frac{V_r - V_l}{L} = \frac{r}{L} \left( \frac{\omega_r - \omega_l}{L} \right)$$  \hspace{1cm} (8)

The instantaneous linear velocity of the luggage robot $V_{lin}$ is defined relatively to the point P. It is a result of linear velocity of the left driven wheel, $V_l$ and respectively the right driven wheel $V_r$. This two drive velocities, $V_r$ and $V_l$ are permanently two parallel vectors and perpendicular on the common mechanical axis of the two driven wheels.

$$V_{lin} = r \left( \frac{\omega_r + \omega_l}{2} \right)$$  \hspace{1cm} (9)

The movement of the luggage robot will follow these rules:

- When $V_r = V_l$, then the radius, R is infinite, the luggage robot moves in a straight line
- When $V_r \neq V_l$, the CoC point located at a distance R from the robot center point P, the luggage robot follows a trajectory round, either moving to the left or to the right.

2.4. Program Design

There are three (3), main algorithms for the program design, firstly the Distance Measurement Algorithm, secondly the Ping Sequence and the last is the Motor Update Algorithm. The flowcharts can be seen on figure 5a, figures 5b and figure 5c.

![Figure 5a. Distance Measurement Flowchart](image)

![Figure 5b. Ping Sequence Flowchart](image)

![Figure 5c. Motor Update Flowchart](image)

The initial distance measurement is used to decide whether the luggage robot will start to move once it is turned on. It works by receiving the signal transmitted from the transmitter device and calculate the distance which is done by the ultrasonic sensor receiver on the robot side.
The ping sequence is started once the initial distance measurement indicates that the distance from the luggage robot to the target transmitter is more than 60 cm. The sequence start by listening ping signal from the transmitter unit and wait for either ping1 or ping2 to receive the signal first. Once one of the ping receives a signal, record and save the data set point for that ping. Once the data set point is saved, wait for the other Ping to receive the signal and record the data set point. After two data set points from each of the Ping is present, calculate the data to find difference between the Ping and distance. This calculation results in deciding where the target transmitter is present, either left side or right side of the luggage robot.

The motor update program starts when data from the ping sequence program is present. The program is taking the result data from the ping sequence and drive the motor towards the direction. The motor update program works by continuously given data from the ping sequence program about the direction where the luggage robot needs to move. Once the direction is decided, the program write digitals and analogs signal through the Arduino board to control the motor. In order to make a turn one motor needs to rotate faster than the other wheel while the other wheel is only half of the speed.

3. Testing, Result and Discussion

3.1. Movement Testing and Result

The movement test was conducted to analyze the performance of the luggage robot regarding its movement capability. The test was divided into two parts, to test the straight movement of the luggage robot and its capability in making turns, right and left turn. The test was done by attaching marker to the free wheel leg so the actual path of the luggage robot can be seen.

For the straight path testing, the path of the robot is not exactly straight due to the attempt of the luggage robot to keep the guidance point, which is the transmitter device, in the middle of its receivers, thus overshoot from the calculation could happen making the robot turn more than expected.

In case of turning right and left testing, the test was done by making the robot turn in smaller radius thus the experiment was done in a room to simulate tight operating area. Figure 6b and figure 6c show the tests were successfully achieved.

3.2. Weight Testing

The test was conducted to compare the time needed to travel a distance while carrying load and with no load. This test shows how weight will affect the speed of the motor.

| Table 1 Comparison Speed Testing under load and no load |
|----------------|-------------------|-------------------|
| No | No Load | Velocity (m/s) | With Load | Velocity (m/s) |
| 1 | 8.97 | 0.49 | 13.1 | 0.39 |
| 2 | 7.98 | 0.55 | 9.54 | 0.41 |
| 3 | 7.98 | 0.5 | 10.87 | 0.37 |
| 4 | 8.12 | 0.49 | 9.82 | 0.41 |
| 5 | 7.99 | 0.51 | 11.93 | 0.36 |
| Avg. | 7.97 s | 0.5 m/s | 10.47 s | 0.39 m/s |
Table 1 shows the difference of the time needed for the luggage robot while carrying 5 kg load and without carrying any load. The average of the data was calculated and the difference is found. The time difference is 2.5 seconds while the average speed difference is 0.11 m/s, indicating each 5 kg of weight added will affect the speed by 0.11 m/s until the weight is too much for the motor to handle causing stall.

3.3. Reliability Testing According to Human Walking Speed

This test was conducted to see the reliability of the luggage robot as illustrated in figure 15, regarding its capability to follow the owner in various walking speed, simulating a practical use of the luggage robot where the walking speed of the owner may be varied. The test consists of several experiments varied by the owner walking speed, slow, moderate, and fast. Other variables such as time and distance travelled before loss of signal is also considered. The experiments were done in a straight path.

Table 2 Result of Reliability Testing

<table>
<thead>
<tr>
<th>Walking Speed</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow (0.3 m/s)</td>
<td>100%</td>
</tr>
<tr>
<td>Normal (0.6 m/s)</td>
<td>70%</td>
</tr>
<tr>
<td>Fast (0.8 m/s)</td>
<td>0%</td>
</tr>
</tbody>
</table>

Figure 7. Reliability Test Configuration

Table 2 shows the result of the three tests conducted in slow, normal and fast walking speed. The results of the test can be concluded that the robot is able to follow the owner with 100% success rate if the owner walks at slow speed, 70% success rate if the owner walks at normal speed and 0% success rate if the owner walks too fast or running. The data indicates the luggage robot is not capable in following human who walks at fast speed. This is again due to the distance between the luggage robot and the human are greater than 2 meters, out of range of the ultrasonic sensor capability.

4. Conclusion

In conclusion, the design and development of the Autonomous Human-Following Luggage Robot has been accomplished and the research’s objectives have been achieved. Implementing ultrasonic sensors were proven to be able for distance-measuring and obtaining directional sense for the robot and to develop a program for the luggage robot based on actuators and sensor’s feedback. The luggage robot is able to follow human holding the transmitter and the differential drive kinematics concept is proven to be able to drive the robot to the direction according to the transmitter device.

References


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