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Smart Obstacle Tracking System with Time of Collision Estimation

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***Abstract*:- With rapid advancements in the field of autonomous driving, there is a growing need to create new systems and also improve existing systems for obstacle detection. In this paper, we propose a smart obstacle detection system with navigation capabilities to avoid the obstacles and time of collision estimation. The system uses an X band Doppler RADAR to detect any moving object. A Doppler radar is basically a specialized radar that produces velocity data about obstacles or objects at a distance by using the principles of Doppler effect. It bounces microwave signals off a desired target and analyzes how the object's motion alters the frequency of the returned signal. The system also uses the signal processing technique embedded into ATMEGA328p microcontroller to estimate the frequency of the Doppler shift, hence the velocity of the target is measured. We also use a laser-distance-meter to precisely get the locational data of the obstacle. Based on the velocity and distance measurement, the time of collision is also computed to control the navigation of the system via PID controllers.**

Keywords: X-Band Doppler Radar, Laser-Distance-Meter, Atmega Microcontroller, PID

1. INTRODUCTION

Most of the automobile industries nowadays are focusing on self-navigation. The main area of concern is obstacle detection. Preciseness in this area is the major interest in most of the companies involving in this field.

This system has end number of possible applications:

- In parking lots, it would help a person to call his/her vehicle from a distant location.
- It can be used in unmanned aerial which can be used for evacuation and other military applications.
- It can be used in automatic irrigation, which would reduce the manual labor need.
- It would be of great use to physically impaired people as it would reduce the need of manual influence.
- It can even be used by delivery vendors who can send unmanned vehicles to houses for product deliveries.

The system which is to be developed should have the following desired features:

- High Accuracy and Precision: The distance and the position of the obstacle should be measured with utmost accuracy **[1]**. Any error during measurement may lead to severe outcomes which could be fatal.
- High Speed Measurement: Since obstacles can arrive at any moment, the sensors should be able to send data at as high speed as possible without any delay. The processor should be able to calculate the results without any processing delay. Reducing the delay as much as possible is as important as high accuracy.
- Greater Range: The range till which the sensor can detect the obstacles should be kept as high as possible [2],[3],[4]. Higher the distance till which the sensor can detect, greater the time the system gets for processing it and taking necessary actions for avoidance.
- Low cost: The system being developed should be economic as it is targeted to all kinds of people who may not be able to afford high costing devices. Also, it would be easier for companies to implement it.
- Real Time Work: The system should be able to detect both distant ranged and close ranged objects. The processing rate should be fast enough for the latter. The sensor should work continuously all the time the system is on for real time measurement.

Various systems have been developed which can be used to achieve these desired features [5][6][7]. There are systems of image based obstacle detection which are quite accurate but the image processing technique increases the response time which is not desired. Some system like detection of the obstacle via ultrasonic sensor has also been developed, which is fast enough but lacks in accuracy and range as sound waves are difficult to focus. Hence to overcome the difficulties faced by the above systems, a Doppler Radar based system has been developed which is described in the next sections.

2. THEORY OF OPERATION

The system has been divided into various parts and is subsequently developed into a real time embedded system which shows the process and principles of obstacle detection.

2.1 Sensor- Doppler Radar

We use an X-Band Bi-Static Doppler transceiver module HB100 which is a miniature microwave motion sensor. It uses the Doppler Effect to produce velocity data about objects at a distance. It does this by bouncing microwave signals off a desired target and analysing how the object's motion alters the frequency of the returned signal. This variation gives a direct and highly accurate measurements of the radial component of a target's velocity relative to the radar.

Fig 1: HB100 Doppler Sensor Module

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Doppler Effect can be defined as the difference between the observed frequency and the emitted frequency of a wave for an observer moving relative to the source of the waves.

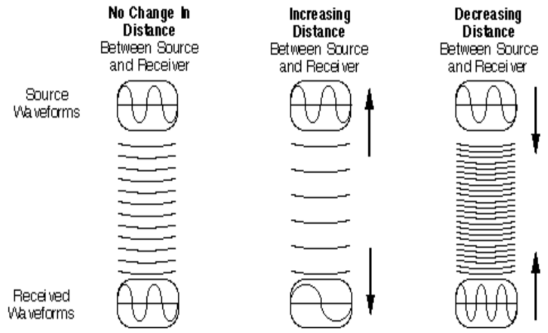

Fig 2: Illustration of Doppler Effect

If the frequency of the received signal is greater than that of the transmitted signal, it can be said that the relative motion of the obstacle is towards the radar and if it is lesser, than the relative motion is away from the radar.

The variation of received frequency also depends on the direction the wave source is moving with respect to the observer. It is maximum when the source is moving directly toward or away from the observer and diminishes with increasing angle between the direction of motion and the direction of the waves, until when the source is moving at right angles to the observer, there is no shift.

The Doppler Effect derived with *c* as the speed of light and *v* as the target velocity gives the shifted frequency (f_T) as a function of the original frequency (f_t):

$$f_r = f_t \left(\frac{1 + v/c}{1 - v/c} \right)$$

It gives us the velocity of the objects around it. It can give us velocity data about obstacles as far as 15 meters from the radar.

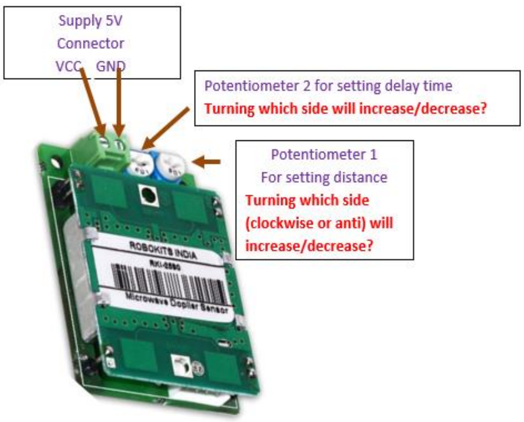

Fig 3: Description of Radar Parts

After providing power supply of 5V, the radar module will turn on and relay will make a sound. We need to set the distance and delay time by varying potentiometer 1 and potentiometer 2. The sensor module can detect motion up to 15 meters distance away and provide an output low signal. In relay board when distance is detected, led will turn high and based upon the delay which is set by us led will turn off at a particular delay time.

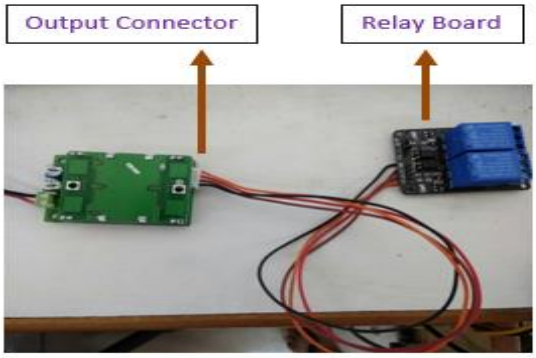

Fig 4: Connecting Radar with Relay Board

Features of HB100 sensor:

- ➢ Consumes low current (typical 30 mA) and works at between 4.75V and 5.25V
- ➢ Pulse Operation and Flat Profile
- ➢ Very long detection range (20 m in ideal cases)
- ➢ Works at X-Band frequency: 10.525 GHz
- ➢ High level of accuracy

2.2 Sensor- Laser Distance Meter (LiDAR)

Here we would use TF03 LiDAR [8] long range distance sensor. A Laser Distance Meter sends out a finely focussed pulse of light to the target and detects the reflection from the target. The meter measures the time taken between these two events, and converts this to a distance data. It uses the basic formula, i.e. Distance = 1/2 (Speed x Time).

Fig 5: TF03 LiDAR

An Ultrasonic Distance Meter works on a similar principle as this, but instead of light it uses sound of high pitch inaudible to the human ear.

Then why prefer laser over ultrasonic distance meter?

- ➢ The speed of sound is only ⅓ of a km per second, so the time measurement is easier, but it takes a lot of time against the speed of light which is 300,000 km per second. So the time required for detection is quite lesser in the latter which is an important advantage.
- ➢ Ultrasound is intrinsically less accurate as sound is far more difficult to focus than laser light. Accuracy is typically limited to several centimetres, compared with a few millimetres for laser.
- ➢ Ultrasound sensors needs fairly large, smooth, flat surface as the target, so this is a severe limitation. Also the waves spread out which makes detection of smaller objects difficult.

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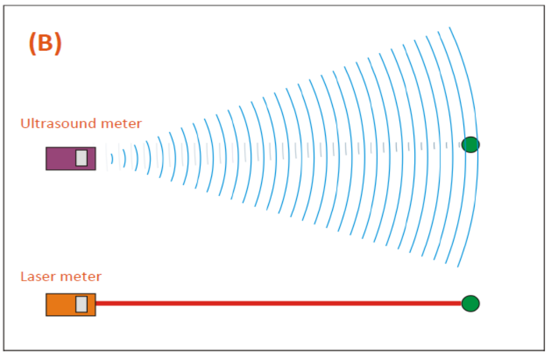

Fig 6: Laser Meter can accurately detect even smaller objects

- Range is limited to about 15m in ultrasound meters, whereas laser devices can measure up to 150m ideally.

Features of TF03 LiDAR:

- Small in volume and hence easy to be integrated.
- High-speed measuring up to 10 KHz.
- High repeated accuracy. Resolution 1mm.
- Wide range, as far as 100m.

2.3 System Architecture and design

The flow chart of the system is as given below.

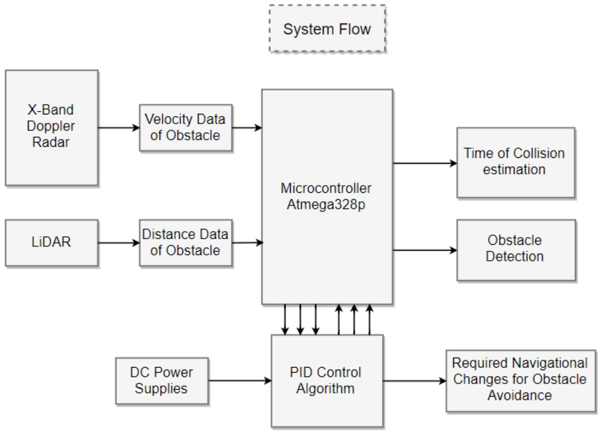

Fig 8: System Architecture Diagram

The development of the system is as follows:

- The Laser-distance-meter gives us the distance of the obstacle from the system device.
- We connect the Doppler radar sensor to a 5V power supply. We regulate the power supply of 12V using 7805 IC to get a 5V DC supply.

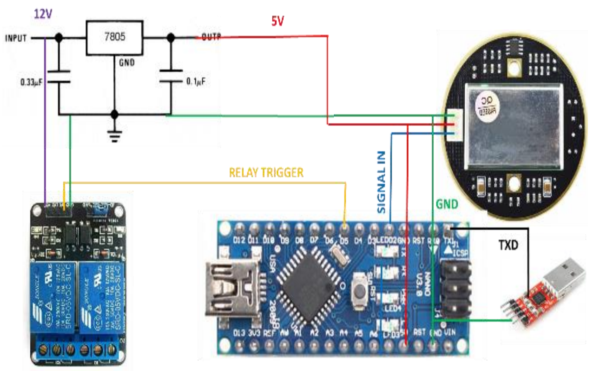

Fig 9: Connections made with Doppler radar

- Whenever an obstacle is detected by the radar sensor, it picks up the velocity of the object.
- Now there are two ways; either we can input the distance of the object manually for experimentation; or we use a LiDAR sensor to get the distance of the object automatically for practical use.
- We start getting velocity data of the obstacle continuously from the radar.
- The radar uses Doppler Shift property to get the velocity data of the obstacle.
- After the first detection of obstacle, we get the velocity at that instant. Hereafter, at every instant, we get the instantaneous velocity data (v_i) at every time instant (t_i).
- So, we know the starting distance (D) of the object, and the velocity and time intervals of the obstacle after that instant. So the distance covered (d) by the object can be calculated as follows:

$$d = \int_{t1}^{t2} vi * t \, dt$$

- Hence the final distance of the obstacle (D_f) from the system device can be calculated as follows:

$$D_f = D - d$$

- Whenever D_f goes below the set critically value, say d_c, the relay triggers a buzzer or a hooter to create an alarm for the user to make required navigational direction change.
- Also, at this instant, the PID controls come into action.
- If it's a motor driven vehicle, the alert of the obstacle nearing the vehicle causes the PID control to make required navigational changes.
- The control of the vehicle motion is open for future developments.

2.4 Further enhancement

The system we have designed contains only one sensor unit pointed in one direction and hence its field of vision is very limited. An illustration of a better option is given below.

Instead of wiring a single sensing module to the microcontroller [9],[10], we can wirelessly pair multiple sensing modules. These sensing modules can be places at different regions of the device which we need to protect from colliding as shown in the image below.

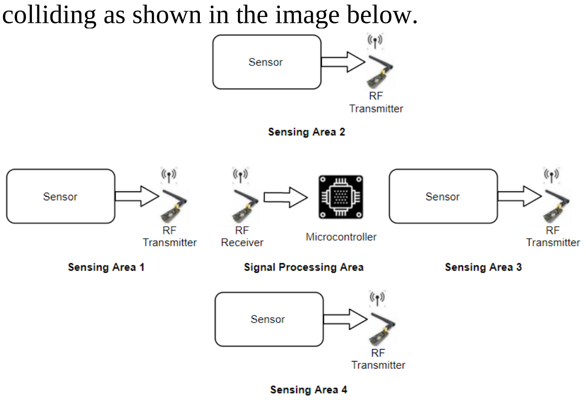

Fig 10: Illustration of the proposed method

These several sensing modules work independently and sense an obstacle. Whenever, any one of them detects an obstacle, it sends the data about the obstacle to the microcontroller via RF communication. Hence the

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microcontroller takes the necessary actions to avoid the obstacle.
Also further a PID controller logic was implemented to track an object with a fixed distance. This hi particularly useful in application where a fixed distance needs to be maintained between two objects in motion.

PID Controller
PID is the control algorithm that is used by most applications based on motion control. PID control uses a closed-loop control feedback system to keep the actual output of a process as close to the target or set point output as possible.

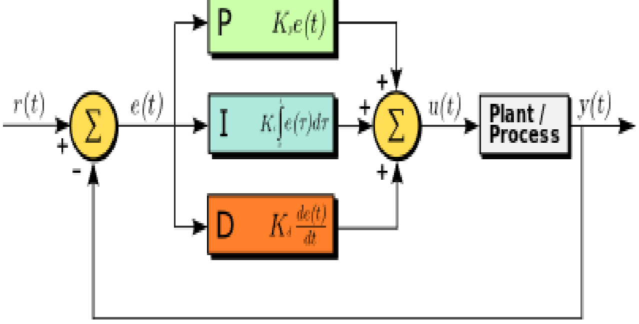

Fig 7: Block Diagram of PID control algorithm

We sum up the proportional, integral, and derivative to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is:

$$u(t) = \mathrm{MV}(t) = K_\mathrm{p} e(t) + K_\mathrm{i} \int_0^t e(\tau)\, d\tau + K_\mathrm{d} \frac{de(t)}{dt}$$

Where,
K_p is the proportional gain, a tuning parameter,
K_i is the integral gain, a tuning parameter,
K_d is the derivative gain, a tuning parameter,
e(t) = SP - PV(t) is the error (SP is the set point, and PV(*t*) is the process variable),
t is the time or instantaneous time.

After estimating the obstacle velocity and position, we can detect the obstacle position at a future time and use these data in the PID algorithm and make necessary navigational changes. Every time the controller gets a new data, the PID algorithm will take necessary actions.

Another feature that can be added to the system is that we can add a GSM module to our system. Whenever the obstacle is in close proximity, the GSM module can send an alert to the cloud and the user can get this data from the cloud to take necessary precautions.

3. EXPERIMENTAL RESULT

The actual system built can be seen in the figure given below.

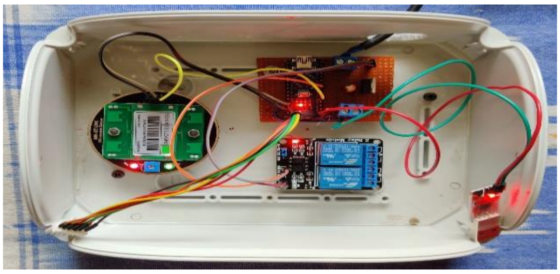
Fig 11: The Actual System Built

As it can be seen, the microwave Doppler radar sensor along with the other components have been placed inside a casing which allows microwave as well as RF frequencies to pass through.

3.1 Sample Input and Output

The system has been designed so as to use a computer as the user interface.

- Give power to the device.
  Output:
  "---:W E L C O M E:---CrLf"
- We place an obstacle 15m away and start moving it towards the device at a.
  Output:
  "---:OBSTACLE DETECTED:---CrLf"
  "Velocity=0.52m/s"
  "----:ENTER DISTANCE:----CrLf"
- In our developed device, the LiDAR was used to record the distance of the obstacle from the device.

- After getting the distance input from the user, the system displays the output.
  Output:
  "Estimated time of collision=28.85s CrLf"
- In the program we had set the warning distance to be 5m. We keep moving the object at a varying speed towards the device. When the object is approximately 5m away from the device, we get the Output:
  "ALERT ALERT ---- Obstacle Danger Close CrLf"

3.2 Experimental Errors Occurred

The most significant error that was faced was that we received the *"ALERT"* when the distance of the obstacle from the device was around 5.02m. Hence we see that there was an error of 0.02m. This might have occurred because we calculate the distance change as an integral value of instantaneous velocity and time. Since the instantaneous time of reading can't be truly continuous, this error cannot be completely removed. It can only be minimised if the velocity reading rate of the sensor can be increased. But as the error is very negligible, it is not much of a concern. The error might also have occurred because of manual reading of distances. If the reading of the initial obstacle distance is done using the proposed LiDAR, the error will be reduced.

We also checked the error in the velocity read by the sensor. In the figure given below, we have plotted the error against distance of the obstacle.

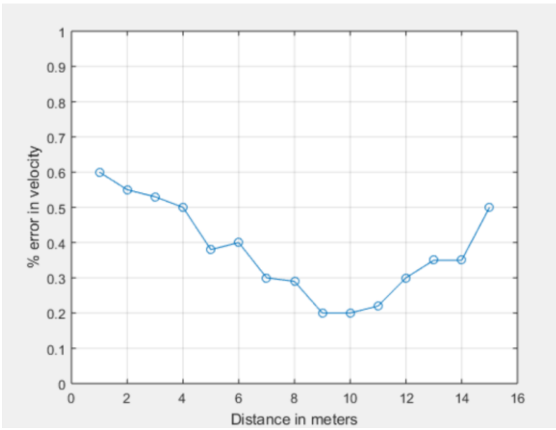

Fig 12: Percentage error in calculated velocity against distance of the obstacle from the radar

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4. CONCLUSION

This paper presents the development of a complete embedded system for obstacle detection and time of collision estimation which can be used for navigational purposes. It started with the choosing of appropriate sensors which provide us with accurate data. Then the paper gradually discusses how the complete system can be built and how the obstacle can be detected in real time. Then test results for a controlled experiment is given, which describes of how the output is generated. Also, the paper discusses about the errors that occur and how they may be reduced.

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