A Comparison of Three Obstacle Avoidance Methods for a Mobile Robot

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ABSTRACT

Obstacle avoidance is one of the most critical factors in the design of autonomous vehicles such as mobile robots. The purpose of this paper is to compare and contrast three different methods for obstacle detection and avoidance. These include fixed mounting of sonar sensors, a rotating sonar sensor and a laser scanner. The three systems have been installed on the BEARCAT mobile robot. Current work is on going and was tested in June 2001 at the International Ground Robotics Competition. This test bed system provides experimental evaluation of the tradeoffs among the systems in terms of resolution, range and computation speed as well as mounting arrangements. The significance of this work is in the increased understanding of obstacle avoidance for robot control and the applications of autonomous guided vehicle technology for industry, defense and medicine.

Keywords: obstacle avoidance, range detection, ultrasonic transducers, laser scanner.

1. INTRODUCTION

One of the major challenges in designing intelligent vehicles capable of autonomous travel on highways is reliable obstacle avoidance. Obstacle avoidance may be divided into two parts, obstacle detection and avoidance control.

There has been a great amount of research devoted to the obstacle avoidance problem for mobile robot platforms and intelligent vehicles. Any mobile robot that must reliably operate in an unknown or dynamic environment must be able to perform obstacle avoidance. As road following and off road systems have become more capable, more attention has been focused on obstacle detection problem.

Several sensors are capable of obstacle detection. Two considered in this paper are: sonar and laser scanning. Sonar systems in various mounting arrangements have been used for many years for obstacle detection for mobile robots. Sonar systems are an excellent low cost obstacle detection solution. Laser scanners are more recent but have also been used for many years for obstacle detection and are found to be reliable and provide accurate results. They operate by sweeping a laser beam across a scene and at each angle, measuring the range and returned intensity.

The Center for Robotics Research at the University of Cincinnati has built an unmanned, autonomous guided vehicle (AGV), named Bearcat III for the International Ground Robotics Competition conducted each year by the Association for Unmanned Vehicle Systems (AUVS). We were using ultrasonic transducers last year on Bearcat II to detect and avoid unexpected obstacles, which did not provide us with accurate data. This year there is an enhancement in obstacle avoidance system using a laser scanner. The vehicle senses its location and orientation using the integrated vision system and a high-performance laser scanner is used for obstacle detection system of Bearcat III. It provides fast single- line laser scans and is used to map the location and size of possible obstacles. With these inputs the fuzzy logic controls the steering speed and steering decisions of the robot on an obstacle course 10 feet wide bounded by white/yellow/dashed lines.

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Several promising methods have been developed for obstacle detection.

The payoff to obstacle detection research may be in safer automobiles as pointed out in the survey conducted by Florida International University[1].

One approach developed at the University of Florida[2] noted that the obstacle avoidance problem could be divided into two sub-areas, i.e. obstacle detection and mapping, followed by vehicle control to avoid the detected obstacles.

Various methods including neural networks have been used on the Navlab project at CMU[3].

The paper describes the three methods used on the Bearcat and it compares them, stating the advantages and disadvantages of each method. The stationary sonar detection system is described in Section 2. The rotating sonar system is described in Section 3. The laser scanner system is described in Section 4. Finally, conclusions and recommendations are stated in Section 5.

2. STATIONARY SONAR SYSTEM

2.1 Sonar Theory & System

The first obstacle avoidance system consists of multiple ultrasonic transducers mounted in fixed locations. The two major components of an ultrasonic ranging system are the transducer and the drive electronics. The drive electronics has two major categories - digital and analog. The digital electronics generate the ultrasonic frequency. The system requires an isolated power supply: 10-30 VDC, 0.5 amps. A drive frequency of 16 pluses at 52 kHz is used in this application.

In the sonar ranging system[4] a short acoustic pulse is first emitted from a transducer. The transducer then switches to the receiver mode when it waits for a specified amount of time before switching off. If a return echo is detected, the range R, can be found by multiplying the speed of sound by one half the time measured. The time is halved since the time measured includes the time taken to strike the object, and then return to the receiver, where c is the speed of sound and t is the time in seconds.

$$R = \frac{ct}{2}$$

The speed of sound, c, can be found by treating air as an ideal gas and using the equation, where n = 1.4, R_1 = 287 m2/(s2K), and the temperature T, is in Kelvin.

$$c=\sqrt{nR_1T} \text{ m/s}$$

Substituting in the values, the equation reduces to:

$$c = 20\sqrt{T} \text{ m/s}$$

Which is valid for 1% for most conditions. The speed of sound is thus proportional to the temperature. At room temperature (20° C, 68° F) the values are:

$$c_m = 343.3 \text{ m/s}, c_f = 1126.3 \text{ f/s}$$

An Intel 80C196 microprocessor and a circuit were used to process the distance calculations. The distance value was returned through a RS232 port to the control computer. A pulse of electronically generated sound was transmitted toward the target and the resulting echo was detected. The system converted the elapsed time into a distance value. The digital electronics generated the ultrasonic frequency and all the digital functions were generated by the Intel microprocessor. Operating parameters such as transmit frequency; pulse width, blanking time and the amplifier gain were controlled by software supplied by Polaroid[5].

2.2 Methodology

The sonar sensing devices are mounted in front of the robot at a height where they don't detect the ground as an object. The devices are configured as shown in *Figure 1*.

The sonar detects objects in a 30^o cone. The sensing device has a range of 12 feet, but the area of interest is restricted to 7'3" radius so as to eliminate noise due to obstacles that are out of the robot path. A fuzzy logic approach is used to avoid the obstacles[6].

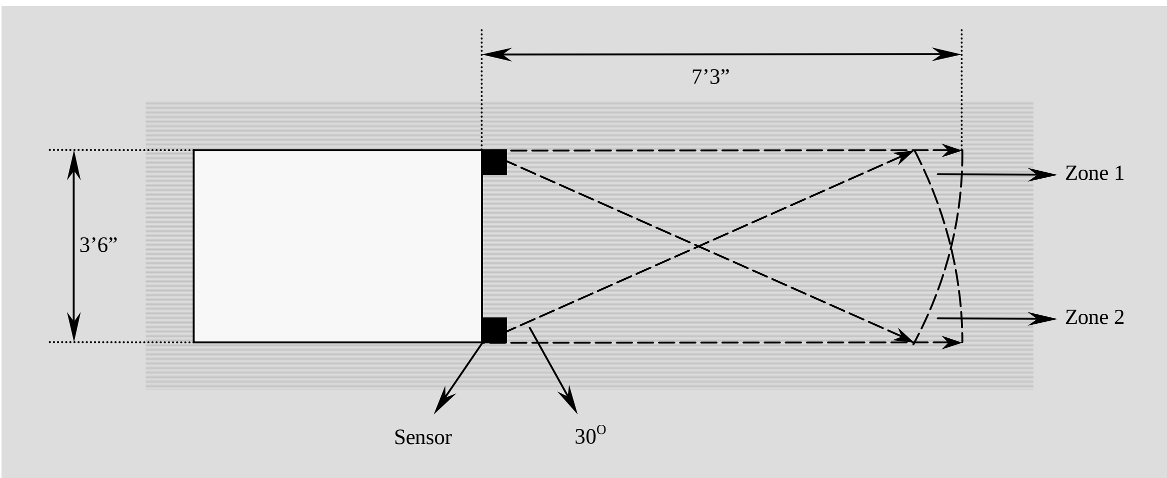

Figure 1: Robot with the stationary sonars.

As the robot moves, the obstacle fall first into zone 1 or zone 2 or both the zones simultaneously. The moment the obstacle is detected in either zone, the robot is steered in the opposite direction till that obstacle is out of way; meanwhile the robot maps its position with respect to the target. The control program always tries to steer the robot towards the target. In the other case when both the sensors sense the obstacles simultaneously this indicates that the obstacle is either a flat object or two separate obstacles parallel to the transverse axis of the robot. In this case the steering decision is taken based on the robot's relative position to the target and its previous motion. Thus the robot avoids obstacles and reaches the target.

This method was used on Bearcat I. The advantages and limitations of this method are discussed in the following sections.

2.3 Advantages

This cost-effective method has a simple implementation. The algorithm for obstacle avoidance using this method is simple as it has minimal data handling which results in ease of computations and faster processing.

2.4 Limitations

Common to all sonar ranging systems is the problem of sonar reflection. With light waves, our eye can see objects because most objects reflect the incident light energy, which means that some energy will reach our eye, despite the angle of the object to us or to the light source. This scattering occurs because the roughness of an object's surface is large compared to the wavelength of light (0.550 nm). Only with very smooth surfaces (such as a mirror) does the reflectivity become highly directional for light rays.

Ultrasonic energy has wavelengths much larger (0.25 in) in comparison. Hence, ultrasonic waves find almost all large flat surfaces reflective in nature. The amount of energy returned is strongly dependent on the incident angle of sound energy. The *Figure 2* shows a case where a large object is not detected because the energy is reflected away from the receiver.

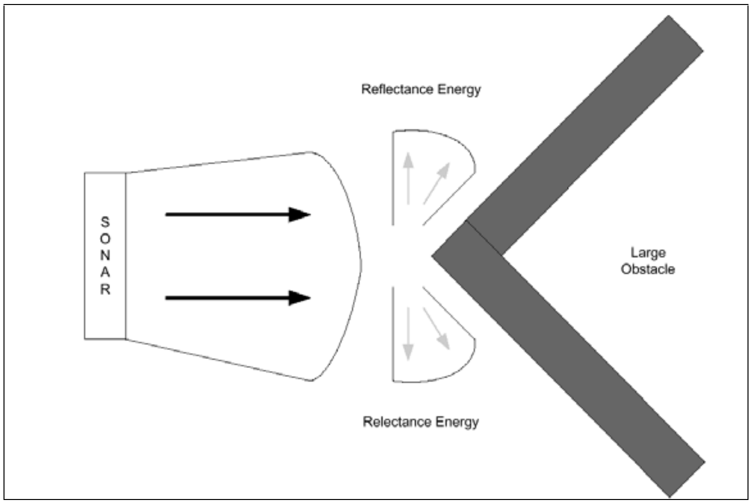

Figure 2: Undetected large object due to reflection.

Although the basic range formula is accurate, there are several factors when considering the accuracy of the result. Since the speed of sound relies on the temperature, a 10° temperature difference may cause the range to be in error by 1%. Geometry also affects range. When the object is at an angle to the receiver, the range computed will be to the closest point on the object, not the range from the centerline of the beam as shown in *Figure 3*.

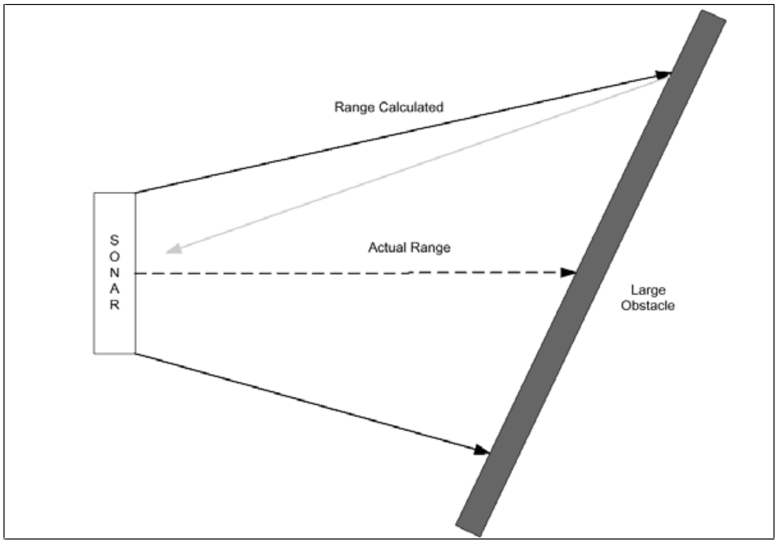

Figure 3: Range errors due to angle between object and sonar.

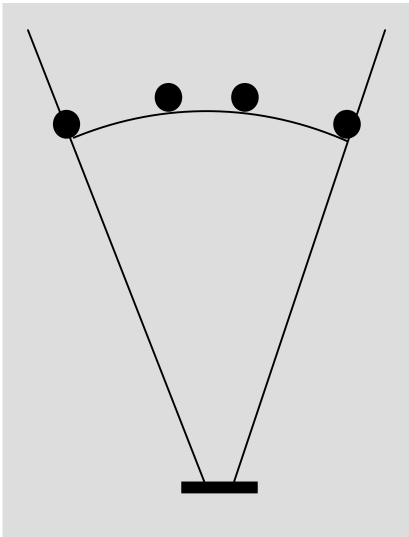

Figure 4: Equal responses

As seen in *Figure 4*, the sensor would give the same distance value if the object were present anywhere along the curve. Thus the sensor does not give the exact location of the object. In the case of ramps and dips, the sensor will detect the ground as an obstacle. Also as the system does not give the profile of the object, trivial objects such as grass, which are detected by the sonar, are also regarded as obstacles, which result in a redundant obstacle avoidance.

3. ROTATING SONAR SYSTEM

3.1 The System

Here, we talk about the obstacle avoidance system used on Bearcat II. For accurate path navigation, in addition to the proper functioning of the vision system, the obstacle avoidance system must also function to perfection. Obstacle avoidance system consists of a single rotating transducer[7].

This setup uses a single Polaroid ultrasonic ranging system and a drive system to rotate the transducer. The drive system for the transducer consists of a Galil DC motor and its control circuitry. With this arrangement the transducer is made to sweep and angle depending on the horizon (range between which we need detection). The loop is closed by an encoder feedback from an encoder. The drive hardware comprises of two interconnected modules, the Galil ICB930 and the 4-axis ICM 1100. The ICM 1100 communicates with the main motion control board the DMC 1030 through an RS232 interface. The required sweep is achieved by programming the Galil. Adjusting the Polaroid system parameters and synchronizing them with the motion of the motor maintain distance values at known angles with respect to the centroid of the robot.

3.2 Methodology

This section discusses the basic nature of relationships between the robot and the obstacle. Before the system takes any decision, it is important that we know the distance, width and shape of the obstacle. Depending upon these factors, the robot has to take a decision as to whether it will go straight, turn left or turn right. Also it has to decide upon the amount of turn depending on the nearness of the target to it.

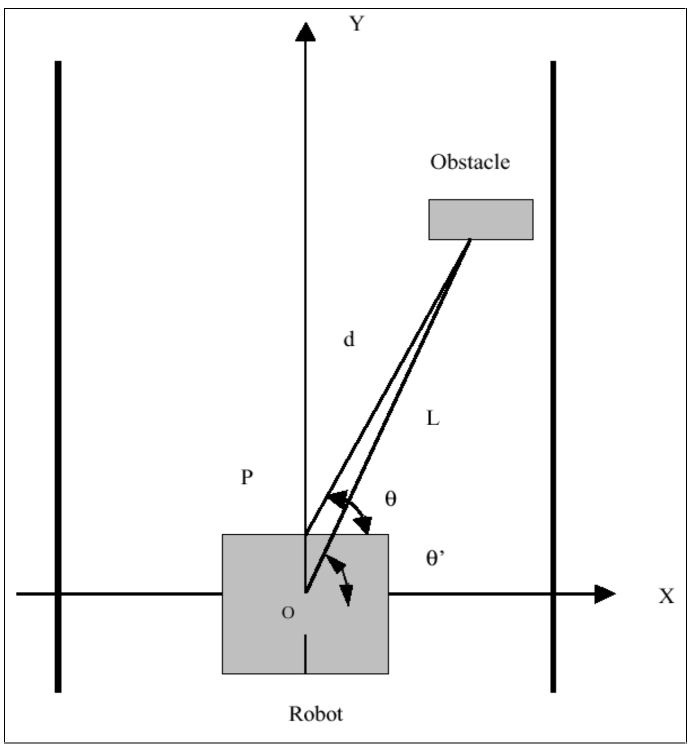

Figure 5: Robot with the rotating sonar

The optimal angle of sweep per reading should be obtained in such a way that it does not slow down the overall system performance. From *Figure 5*, we can obtain the value of the distance of the obstacle (L) from the robot center (O). Another important thing to be known is the width of the obstacle. Assuming that ‘θF’ is the angle of the first sonar contact with the obstacle, ‘θL’ is the angle of the last sonar contact with the obstacle, ‘θF-1’ is the angle just before the first contact with the obstacle, ‘θL+1’ is the angle just after the last contact with the obstacle, we can get the value for the width of the obstacle by the difference in the width of the two angles. The sonar uses the “Time of Flight” approach to detect these angles. Once the values of ‘θF’ and ‘θL’, we can estimate the direction of the obstacle with respect to the robot. Three possibilities arise:

- θL < 900 and θF < 900; this is an indication that the obstacle is to the right.
- θL > 900 and θF > 900; this implies that the obstacle is to the left.
- θL < 900 and θF > 900; this implies that the obstacle is straight ahead.

Depending on the cases above, the robot makes an effort to avoid the obstacle, while simultaneously making sure that it stays inside the track. This is an overview of the range detection method. For a detailed and complete discussion regarding range detection, it would be worth wile to refer to the paper by Chiang et al. [7]. The advantages and limitations of this system are discussed in the following section.

3.3 Advantages

Compared to the stationary sonar, the data received from this method can be used to estimate the size and direction of the object. It has an added advantage of using a single transducer.

3.4 Limitations

Apart from the limitations of the sonar system discussed in section 2.4, this has an added limitation of the drive motor synchronization and it is relatively costly due to additional equipment. The motor has to make a slow rotating motion so that the transducer has enough time to send and receive the acoustic pulses. As the time of flight varies with the distance of the object, only objects within a certain range can be detected successfully. Also the vibrations of the drive motor lead to noise in the data received. This method is complex in the sense the controller has to control the drive mechanism.

4. LASER RANGE SCANNER SYSTEM

4.1 The Laser Scanner Theory & System

Programming third-generation robot systems is very difficult because of the need to program sensor feedback data. A visualization of the sensor view [8] of a scene, especially the view of the laser scanner, helps human programmers to develop the software and verify action plan of a robot. A laser range scanner operates on a similar principle to conventional radar. Electromagnetic energy is beamed into the space to be observed and reflections are detected as return signals from the scene. The scene is scanned with a tightly focused beam of amplitude-modulated [4], infrared laser light (835 nm). As the laser beam passes over the surface of objects in the scene, some light is scattered back to a detector that measures both the brightness and the phase of the return signal. The brightness measurements are assembled into a conventional 2-D intensity image.

The Laser scanner has the advantage that it gives us a detailed description of the field of view. The laser scanner works by measuring the time of flight [9] of laser light pulses. It is a non-contact measurement device that scans its surroundings two dimensionally. The pulsed laser beam is deflected by an internal rotating mirror so that a fan shaped scan is made of the surrounding area and the shape of the object is determined by the sequence of impulses received. We can get a maximum scan angle of 180° with a resolution of 0.25°, 0.5°, 1°. Now with this resolution and scan angle we get a clear profile of the path in front of our robot. We get data such as at every angle scanned the distance of the point of reflection of laser beam from any object in the field of view with its coordinates can be determined. Giving these values in the algorithm used for tracking the robot can avoid obstacles easily. The main strength of the laser scanner is the data accuracy and resolution that is returned from the scanned field.

The Laser scanner on the robot communicates with the host computer using a serial interface. Any of the common interfaces either RS 422 or 232 could be used. The transfer rate varies from 9.6 K baud to 500 K baud, which can be set as desired. The data is transferred in binary format where a byte of data consists of 1 start bit, 8 data bits, a parity bit with even parity or without parity and 1 stop bit. The real time measurement data scanned by the device is given out in binary format via the RS-232/422 serial interface, which is available for further evaluation. We are using a RS-422 serial interface card with our scanner, which supports higher baud rates for faster communication.

The measurement data from the Laser scanner is used for object measurement and determining position. These measurement data correspond to the surrounding contour scanned by the device and are given out in binary format via the RS 422 interface. This data when seen in a GUI environment gives us the coordinates of every point in the field of view. We can see all the objects in the field of view, which reflect the laser beam so we can get the position and size of every object. In the binary format as the individual values are given in sequence, particular angular positions can be allocated on the basis of the values' positions in the data string.

4.2 Methodology

Under the laser scanner, sensing becomes an active process; the robot decides at each step of its path what sensory information [10, 11] is required for generating its next step. The robot has to decide upon the amount of turn depending on the nearness of the target to it. The optimal angle of sweep per reading should be obtained in such a way that it does not slow down the overall system performance. The scanner is mounted such that the sweep is 10-12 inches above the ground level. The laser scanner gives us a field of view showing the complete 180° sweep made by the laser beam. The laser beam starts from the right and goes to left. So at every angle, depending on the resolution set, we can get the distance and position of the objects along the robot's path. With these values we know exactly at what angle is an obstacle present and what is it's size. This simplifies the problem we had earlier in our algorithm where we could not get the exact position and size of the obstacle. The data returned for every degree scanned allows us to generate a profile of the size, shape, distance and orientation of the obstacle in the scanned area. Thus for a scanner resolution of 0.5°, we get 361 values for the field of scan. The fuzzy logic can then decide the path the robot must follow, the angle it must turn to avoid the obstacle. In addition the scanners contour measurement data can be evaluated to determine the relative positions and sizes of objects. LMS 200 with 10mm resolution offer programmable monitored zones with corresponding switching outputs in stand-alone operation, i.e. without external evaluation. The functions and options required can be configured within the scanner itself.

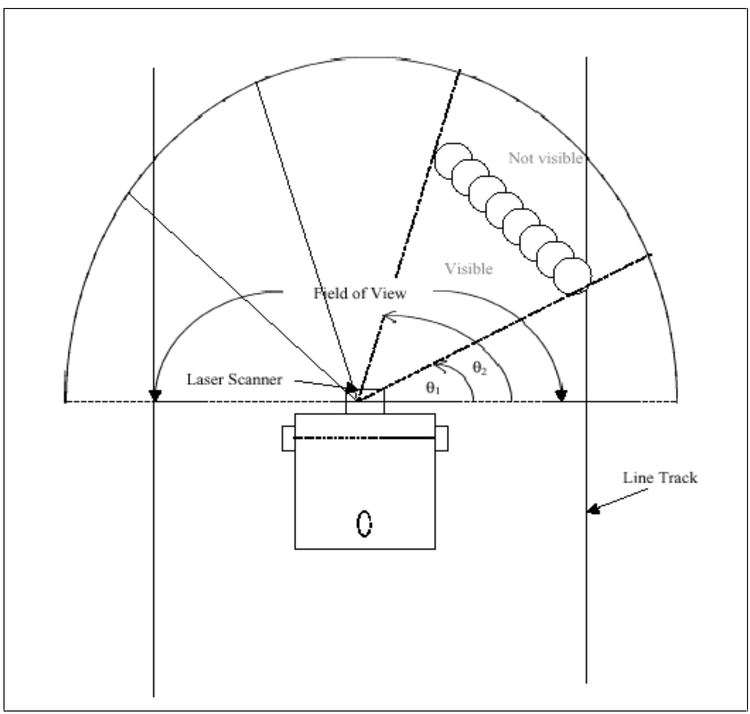

Figure 6: Scanner Range detection

4.3 Advantages

The laser scanner gives very high resolution and accuracy in terms of the distance measured. The environmental conditions such as the temperature do not effect the accuracy of the scanner. Real time transfer of measured data is possible and high scanning frequencies up to 75 Hz can be achieved. The laser scanner has a range of 8 meters against 12 feet for the sonar systems. It has multiple configuration options, which can be effectively used for elimination of stray and excess data. The object is detected irrespective of its size and its orientation.

4.4 Limitations

The method has higher cost as compared to the sonar system and interfacing of the system with the controller is complex. The algorithm for data filtering is complex and the large amount of data can cause the processing to be slower and requires higher processing power and memory.

5. CONCLUSION

Based on the comparisons above it can be said that the laser scanner is a better candidate for obstacle detection. The three systems have been implemented and tested on different versions of the Bearcat. Experimental results from the operation of the Bearcat show that obstacle avoidance is achieved better with the help of the laser scanner. We recommend the use of a laser scanner for obstacle avoidance.

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