Range Detection for AGV Using a Rotating Sonar Sensor

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ABSTRACT

A single rotating sonar element is used with a restricted angle of sweep to obtain readings to develop a range map for the unobstructed path of an autonomous guided vehicle (AGV). A Polaroid ultrasound transducer element is mounted on a micromotor with an encoder feedback. The motion of this motor is controlled using a Galil DMC 1000 motion control board. The encoder is interfaced with the DMC 1000 board using an intermediate IMC 1100 break-out board. By adjusting the parameters of the Polaroid element, it is possible to obtain range readings at known angles with respect to the center of the robot. The readings are mapped to obtain a range map of the unobstructed path in front of the robot. The idea can be extended to a 360 degree mapping by changing the assembly level programming on the Galil Motion control board. Such a system would be compact and reliable over a range of environments and AGV applications.

Keywords: sonar sensing, motion control, obstacle avoidance, mobile robots

1. Introduction

The design of a mobile system is a challenging task. The specific challenge of designing an intelligent controller is in determining the requirements, what information is needed to satisfy the requirements, how to measure it and how to use this information in a manner that will satisfy the performance specifications of the machine. The overall design specifications were to build a robot, which follows a course marked by solid or dashed lines of various colors, avoids obstacles, and adapts to variations in terrain elevation [1-2]. This implied the design of separate subsystems with discrete design objectives integrated in an upper level control logic that enables the robot to function as an integral system meeting all the performance requirements.

At the subsystem level, the primary design considerations included the selection of equipment with the desired functional and operational features as well as reliability, commercial availability and affordability. Equally important was the compatibility of the software that controlled these units and their interfaces. Also all the subsystem components have been chosen to be modular in design and independent in terms of configuration so as to increase adaptability and flexibility. This, in fact is a unique feature of the design since it enables replacement of existing components with more sophisticated or suitable ones, as they become available. To ensure desired performance of the individual sub-systems, several unique approaches were tried. These include, the implementation of a fuzzy logic controller for obstacle avoidance and a novel three-dimensional vision algorithm for line following [3]. In the design and development phase of the of the different systems various analytical, experimental and computational methods were utilized

The main attractions of sonar ranging systems include their low cost, ease of implementation, and inherent safety. The disadvantages are specular reflection, slow processing speeds, and wide beam pattern, all of which contribute to potentially large errors [4-5]. Sonar ranging is based upon measuring the time it takes for a burst of continuous wave ultrasound to be returned to the sensors. The reflected echo strength depends on the size, shape, texture, and orientation of the reflecting surface. Large surfaces reflect more and increase the chances of an echo being detected. Depending on its shape, a reflecting surface may cause dispersion or a focusing of the reflected beam.

The previous work we have done using a static sonar system which worked well in the outdoor environment [1]. However, the static sonar system usually provide a minimum information. The extension of the old system is expensive and inflexible. On the other hand, the rotating sonar is cheap. If we define a smaller angle of sweep to obtain reading, we can have more detail information for the decision of obstacle avoidance. The only drawback is that the smaller sweep angle is more time consuming and the overall system performance will slow down.

In this paper we discuss a single rotating sonar implementation and the basic mathematical and geometrical relationship between the robot and obstacles. An overall system design and development is presented in the next section. The hardware for the rotating sonar is discussed in Section 3. In Section 4 the range detection and geometrical relationship is related. Conclusion is presented in Section 5.

2. System Design and Development

An autonomous mobile robot is a sophisticated, computer controlled, intelligent system. The adaptive capabilities of a mobile robot depend on the fundamental analytical and architectural designs of the sensor systems used. The mobile robot provides an excellent test bed for investigations into generic vision guided robot control since it is similar to an automobile and is a multi-input, multi-output system [6-9]. The major components of the robot are: vision guidance system, steering control system, obstacle avoidance system, speed control, safety and braking system, power unit and the supervisor control PC.
Following is a brief description on the design and development of the main subsystems of the mobile robot.

A block diagram of the system is shown in Figure 1.

3. Obstacle Avoidance System

3.1 The Polaroid Ultrasonic Ranging System

The obstacle avoidance system consists of multiple ultrasonic transducers. A Polaroid ultrasonic ranging system is used for the purpose of calibrating the ultrasonic transducers. An Intel 80C196 microprocessor and a circuit board with a liquid crystal display are used for processing the distance calculations. The distance value is returned through a RS232 port to the control computer. The system requires an isolated power supply: 10-30 VDC, 0.5 amps. The two major components of an ultrasonic ranging system are the transducer and the drive electronics. In the operation of the system, a pulse of electronically generated sound is transmitted toward the target and the resulting echo is detected. The elapsed time between the start of the transit pulse and the reception of the echo pulse is measured. Knowing the speed of sound in air, the system can convert the elapsed time into a distance measurement [10].

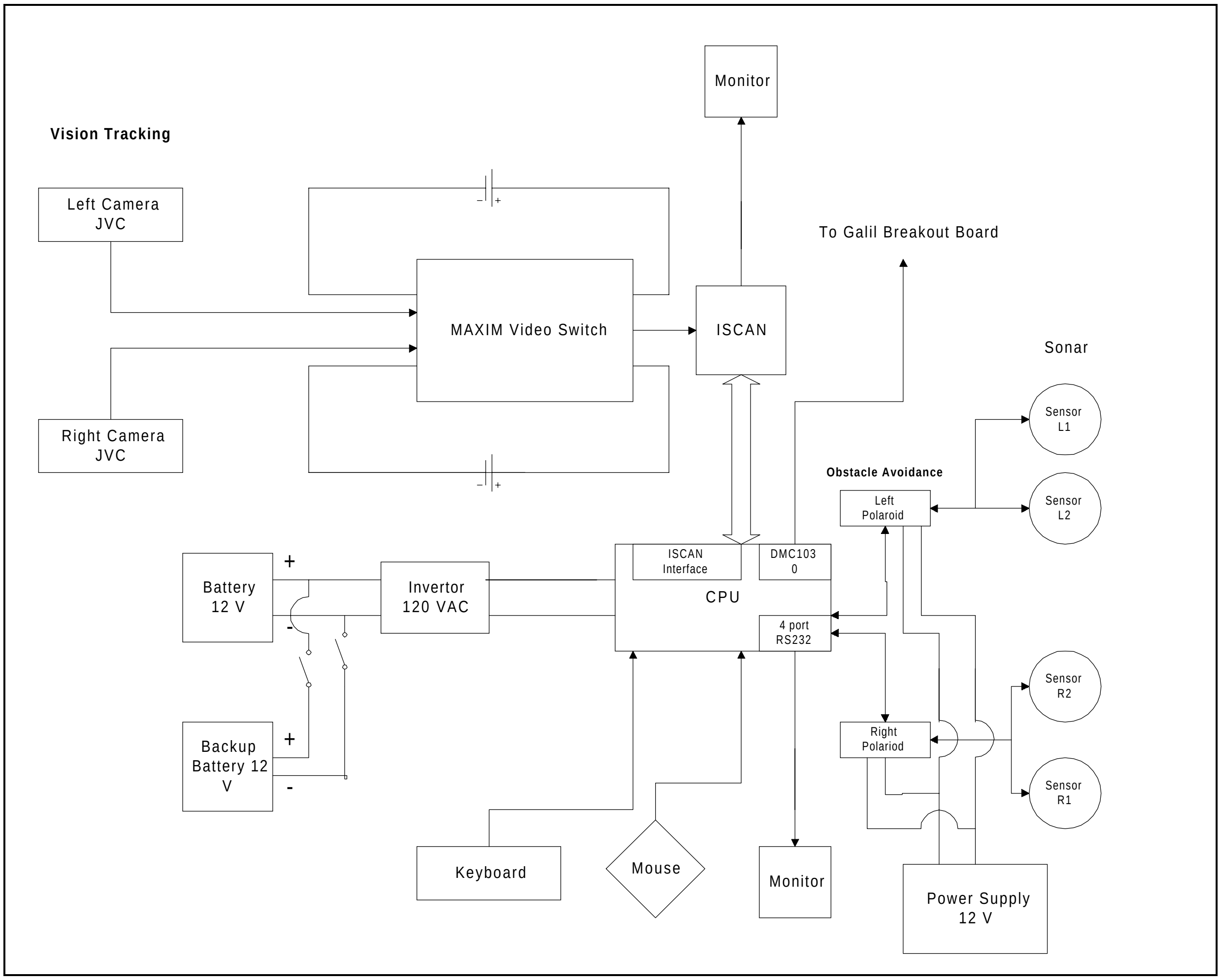

Figure 1. System block diagram

The drive electronics has two major categories - digital and analog. The digital electronics generate the ultrasonic frequency. A drive frequency of 16 pluses at 52 kHz is used in this application. All the digital functions are generated by the Intel microprocessor. The analog functionality is provided by the Polaroid integrated circuit. The operating parameters such as the transmit frequency, pulse width, blanking time and the amplifier gain are controlled by a developers software provided by Polaroid.

3.2 Motor Control

Using a closed loop DC motor arrangement, the transducer is made to sweep angle depending on the horizon (this is about 64 degree for a range of 8’ and about 53.130 for a range of 10’ 10” horizon). The loop is closed by an encoder feedback from a Micro-MO brushless with encoder.

The drive hardware comprises two interconnect modules, the Galil ICB930 and the 4-axis ICM1100. The ICM 1100 communicates with the main motion control board, the DMC 1030 through an RS232 interface. The transducer sweep is achieved by programming the Galil [11]. By adjusting the Polaroid system parameters and synchronizing them with the motion of the motor, distance values at known angles with respect to the centroid of the robot are maintained.

4. Range Detection

In this section we discuss the basic mathematical and geometrical relationships between the robot and obstacles. Before the system makes any decision, we would like to know the distance, width, and the shape of the obstacle. Then, the robot will make a decision to turn left, or right, or go straight. The optimal angle of sweep per reading is also discussed to make sure the robot can safely avoid an obstacle without slowing down the overall system performance.

4.1 The distance of the obstacle

We use one simple model to explain the geometrical relationship between the robot and obstacle (rectangle) as shown in Fig. 2. Our sonar may detect the object more than one point. In Fig. 2 we discuss the center point of the obstacle. However, the distance from center point may not the safety point to take into consideration. The detail discussion is given in the 4.3.

From the figure 2. we know

$$d\cos\theta = L\cos\theta' \tag{1}$$

Solving for L, we get

$$L = d\cos\theta / \cos\theta' \tag{2}$$

and

$$d\sin\theta + \overline{PO} = L\sin\theta' \tag{3}$$

We get

$$L = (d\sin\theta + \overline{PO}) / \sin\theta' \tag{4}$$

We find that Eq. (2) equal Eq. (4)

$$d\cos\theta / \cos\theta' = (d\sin\theta + \overline{PO}) / \sin\theta' \tag{5}$$

$$\tan\theta' = (d\sin\theta + \overline{PO}) / d\cos\theta \tag{6}$$

$$\theta' = \arctan[(d\sin\theta + \overline{PO}) / d\cos\theta] \tag{7}$$

(6) Substituting (2) or (4) to get L

4.2 The width of the obstacle (rectangle shape)

Knowing the width of the obstacle is an important parameter for finding the path of the robot to avoid the obstacle.

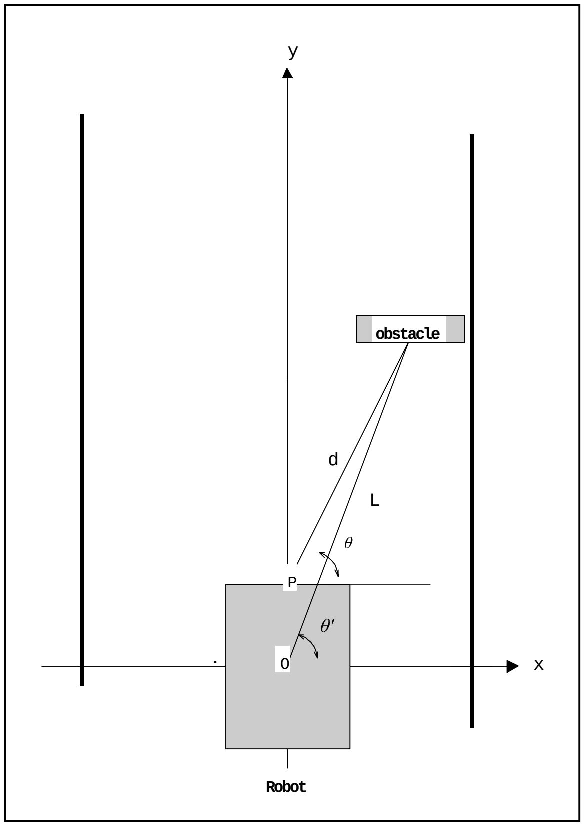

Figure 2. The distance from the robot to the obstacle

First we define the symbol as following:

D_F : is the distance of the sonar first contact the obstacle.
D_2 : is the distance of the sonar second contact the obstacle.
D_N : is the distance of the sonar n-th contact the obstacle.
D_L : is the distance of the sonar last contact the obstacle.
D_{F-1} : is the distance of the sonar before contact the obstacle.
D_{L+1}: is the distance of the sonar after contact the obstacle.
θ_F : is the angle of the sonar first contact the obstacle.
θ_2 : is the angle of the sonar second contact the obstacle.
θ_N : is the angle of the sonar n-th contact the obstacle.
θ_L: is the angle of the sonar last contact the obstacle.
θ_{F-1} : is the angle of the sonar just before contact the obstacle.
θ_{L+1}: is the angle of the sonar just after contact the obstacle.

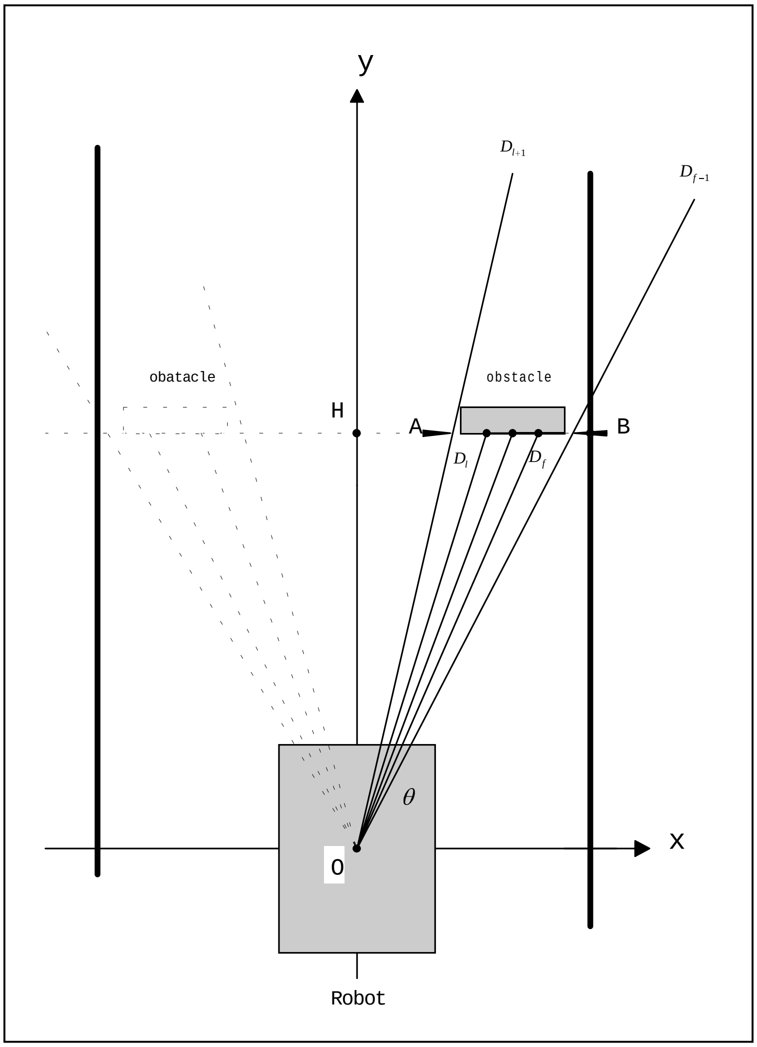

Figure 3. The width of the obstacle

For the safety reason, we measure the distance of A and B.

From the figure 3, we know

$$\overline{OB}\sin\theta_{F-1} = D_F \sin\theta_F \qquad (8)$$

Solving for $\overline{OB}$, we get

$$\overline{OB} = \frac{D_F \sin\theta_F}{\sin\theta_{F-1}} \qquad (9)$$

also

$$\overline{OA} = \frac{D_L \sin\theta_L}{\sin\theta_{L+1}} \qquad (10)$$

From the figure 3, we know the width of the obstacle

$$\begin{aligned}\overline{AB} &= \overline{OB}\cos\theta_{F-1} - \overline{OA}\cos\theta_{L+1} \\ &= D_F \sin\theta_F \cot\theta_{F-1} - D_L \sin\theta_L \cot\theta_{L+1} \qquad (11)\end{aligned}$$

4.3 The direction of robot to avoid obstacle

(1) $\theta_L < 90^o$ and $\theta_F < 90^o$, this means the obstacle in the right-hand side.

L_{Road}: The width of the road.

L_{Robot}: The width of the robot car.

From the figure 3, we know

$$\overline{OA}\sin\theta_{L+1} = D_F \sin\theta_F \qquad (12)$$

$$\overline{OA} = \frac{D_F \sin\theta_F}{\sin\theta_{L+1}} \qquad (13)$$

so

$$\begin{aligned}\overline{HA} &= \overline{OA}\cos\theta_{L+1} \\ &= D_L \sin\theta_L \cot\theta_{L+1} \qquad (14)\end{aligned}$$

If $\overline{HA} > \frac{L_{Robot}}{2}$ Then Robot go straight.

If $\overline{HA} \le \frac{L_{Robot}}{2}$ Then Robot turn left.

(2) $\theta_L > 90^o$ and $\theta_F > 90^o$, this means the obstacle in the left-hand side.

L_{Road}: The width of the road.
L_{Robot}: The width of the robot car.

$$\overline{OB} \sin\theta_{F-1} = D_F \sin\theta_F \qquad (15)$$

$$\overline{OB} = \frac{D_F \sin\theta_F}{\sin\theta_{F-1}} \qquad (16)$$

$$\begin{aligned} \overline{HB} &= \left|\overline{OB} \cos\theta_{F-1}\right| \\ &= \left|D_F \sin\theta_F \cot\theta_{F-1}\right| \qquad (17) \end{aligned}$$

If $\overline{HB} > \frac{L_{Robot}}{2}$ Then Robot go straight.
If $\overline{HB} \le \frac{L_{Robot}}{2}$ Then Robot turn right.

(3) $\theta_L > 90^o$ and $\theta_F < 90^o$, This means that the obstacle is in the front.

The same calculation can make decision that the robot should turn left or right or stop. However, the detail information should consider the obstacle course and the competition rules.

5. Conclusions and Recommendations

A stable test platform has been designed, constructed and tested. However, more sophisticated algorithms and advanced control techniques need to be investigated. Also the use of a more heuristic methodology in the obstacle avoidance should be investigated. For the system to be more efficient and able to go at faster speeds, interrupt handling is desirable. The program would then not have to constantly poll the obstacle avoidance or vision systems. Also, the motor control needs to have an interrupt to inform the control program when it has completed its move [12-14].

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