Obstacle Detection and Object Size Measurement for Autonomous Mobile Robot using Sensor

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ABSTRACT
Different types of sensors are often fused to acquire information which cannot be acquired by a single sensor. Sensor fusion is particularly applicable for mobile robots for object detection and navigation. The techniques that have been developed so far for detecting an obstacle are costly. Hence, a new technique is proposed which can detect an obstacle, judge its distance and measure the size of the obstacle using one camera and one ultrasonic sensor. The technique is cheap in terms of sensor cost and in terms of computational cost.

General Terms
Robotics, robot navigation.

Keywords
Sensor fusion, autonomous mobile robot, obstacle detection, navigation.

1. INTRODUCTION
Fusion of different sensors such as sound sensor, vision sensor, temperature sensor etc. allows the extraction of information which cannot be acquired by a single sensor. Different type of sensors work differently and they have their strengths and weaknesses. One sensor cannot provide all the necessary information. Sensor fusion combines the strength of different sensor to overcome the drawbacks of the other. [1, 2].

For an autonomous mobile robot, sensor fusion is important to perceive its environment. Without knowing the surroundings it is not possible for it to navigate around. An autonomous robot moves unsupervised. It obtains information of surrounding environments using its sensors and decides its course of action according to its programming without any external help. If the information provided is inaccurate or incomplete, it becomes hard for the robot to decide its next action. Sensor fusion allows a robot to perceive its surroundings like human beings. Human beings use their sense of vision, sound, smell, touch and taste to understand their surroundings. Information from one sensor alone is not enough to give accurate information. A food may look good but without the sense of smell and taste it cannot be determined whether the food is still edible or not. So our task is to fuse some sensors for the purpose of object detection and size measurement which is cost effective.

Robotics is a leading branch of engineering which demands knowledge of hardware, sensors, actuators and programming. The result is a system which can be made to do a lot of different things. However, to develop such a system is expensive and difficult. So, we have come up with a plan to build an autonomous mobile robot which is less expensive. A robot has three main different parts – preceptors, processors and actuators. The perceptors are the sensors which provide information about the surrounding environment to the robot. There are many works had done for object detection. Those robots are efficient in the purpose of accuracy. But they are very costly. So we move in a direction where we can have a robot that is cost effective and good enough in its accuracy.

1.1 Robot Navigation and Sensor Fusion
Robot navigation algorithms are classified as global or local, depending on surrounding environment. In global navigation, the environment surrounding the robot is known and the path which avoids the obstacle is selected. In local navigation, the environment surrounding the robot is unknown, and sensors are used to detect the obstacles and avoid collision. [3]

For global navigation, INS (Inertial Navigation System) or odometric system can be used [4]. INS uses the velocity, orientation, and direction of the robot to calculate the location of the robot relative to a starting position. In global environment, where the starting position, the goal and the obstacles are known, INS can lead a robot to its goal. But a major problem of INS is that it suffers from integration drift: small errors in the measurements accumulate to larger error in position. It is like letting a blindfolded man to navigate from point X to point Y in a known environment. He knows the way but he cannot see. He has to guess his location and decide the direction to move. With every guess, every error he makes is cumulated. By the time he thinks he has reached Y, his actual position may be quite a drift from Y.

In local environment, the robot does not know about the surrounding environment aside from its sensor readings. It has to relay on it sensor for information about its location. Since a single sensor is not capable of doing the task, sensor fusion rises in importance. Information from different sensors are obtained and combined to find the location of the robot, detect obstacle and avoid it.

There are many different types of sensors available such as, infra-red sensors, ultrasonic sonar sensors, LIDAR (Light

Detecting and Ranging) [5,6], RADAR (radio detection and ranging)[7-9], vision sensor etc. For obstacle detection and avoidance many of the above sensors can be fused to generate a map of the local environment. Obstacle detection can be classified into two types:

- Ranged-based obstacle detection.
- Appearance-based obstacle detection.

In ranged-based obstacle detection, sensors scan the area and detect any obstacle within the range and the sensors also try and calculate the range between the robot and the obstacle. In appearance based obstacle detection, the physical appearance of the obstacle is detected from the environment, usually by image processing [10]. In this paper we propose the combination of both ranged-based and appearance-based obstacle detection technique to measure obstacle size and distance from the autonomous robot. The next section contains the relevant works done in this area. In section III, the proposed system and in section IV, the implementation details are discussed.

2. RELATED WORKS

Using sensor fusion detecting and avoiding obstacle are the key words for developing Unmanned Ground Vehicles (UGV) program. This project is developed for US military. The goal of this program is to drive High Mobility Multipurpose Wheeled Vehicle autonomously on the road. The abilities of this program are to drive autonomously with 10mph, detect obstacles on the road and avoid them, overall data collection for the goal. For this program three types of sensors are used. The sensors are LADAR (Light Detecting and Ranging), Global positioning system sensor and Inertial Navigation system sensor. Here detecting obstacle is done by the LADAR sensor. To avoid obstacle is the algorithmic part. The autonomous vehicle using these sensors is named NIST HMMWV. This project is very expensive and uses costly sensors to detect obstacles [11].

In another research obstacle detection is done by a new Infrared Sensor. This sensor is suitable for distance estimation and map building. Amplitude response as a function of distance and angle of incidence is easily formulated using a model that needs only one parameter: the IR reflection coefficient of the target surface. Once an object has been identified and modeled, its distance from the IR sensor can be obtained in successive readings, within 2ms (typical response time). Distance measurements with this sensor can vary from a few centimeters to1m, with uncertainties ranging from 0.1mm for near objects to 10 cm for distant objects, being typically 1.2 cm objects placed at 50 cm. However, with IR sensors the reading from the sensor is not always linear with the distance, also the reading varies with the surface of the obstacle. [12]

Another research uses stereo camera and radar to accurately estimate the location, size, pose, and motion information of a threat vehicle with respect to a host vehicle. The goal is to detect and avoid potential collision. To do that first fit the contour of a threat vehicle from stereo depth information and find the closest point on the contour from the vision sensor. Then, the fused closest point is obtained by fusing radar observations and the vision closest point. Next, by translating the fitted contour to the fused closest point, the fused contour is obtained. Finally, the fused contour is tracked by using rigid body constraints to estimate the location, size, pose, and motion of the threat vehicle. The stereo camera can give a three dimensional perspective, thus a distance measurement but it is costly, computationally and economically and not quite suitable for autonomous mobile robots [13].

3. PROPOSED SYSTEM

We propose a sensor fusion technique which is less costly both in terms of economically and computationally, that will allow an autonomous robot to detect an obstacle, find the distance and also measure the size of the obstacle. Our system uses a camera and an ultrasonic transceiver device to achieve this. We use the range data collected by the ultrasonic sensor with the image captured by the camera for object detection and object size measurement. Figure 1 below is the block diagram of the proposed system.

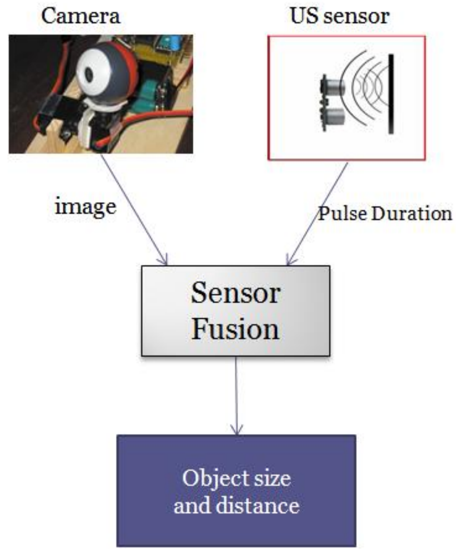

Figure 1: Schematic diagram of the proposed system

Human eye have a fixed angle of vision i.e. the lateral range of area, covered by the eye is limited to a fixed angle. The same is true for the camera. The field of view for a camera is also fixed. Everything the camera sees is squeezed into the image. Although the image has a fixed resolution, the size of an object in the image varies with respect to distance from the camera as well as with respect to the size of the object itself in real life. If the object is placed at two different distances from the camera in two different images, the appearance of the object in the image, where the distance between the object and the camera is less, is larger. If there are two objects of different sizes at the same distance, in the image it would appear that the larger object seems larger in the image. This geometric similarity is used to find the size of an object.

3.1 Object Detection: Using Ultrasonic Sensor

Using an ultrasonic sensor we can easily detect of presence of an object. Our robot will follow the technique of bat to detect obstacle in its path. The ultrasonic sensor will always release ultrasonic wave. If the wave collides with an obstacle in front of the robot, the wave will bounce back to the sensor. If the receiver receives this reflected wave then we can be sure that there is an obstacle in front of the robot. The time difference between the transmission of the ultrasonic wave and the reception of the reflected wave is calculated. Since we know the speed of the sound wave we can calculate the distance of the obstacle.

Distance = speed x time … … … (1)

3.2 Object size measurement

This is done in two parts. The first part consists of taking visual information of the object. We are using a camera to take images and we would use various image processing techniques to extract the object from the image. The second part consists of taking the range information of the object. We are using an ultrasonic sensor for this job.

For a fixed field of view in figure 2, the horizontal and vertical distance the camera can see is constant at a particular distance. If the angle of vision is known, then we can find the area if we know the distance.

x = distance between camera and object.
h = horizontal viewing length on a 2D plane perpendicular to *x*.
Θ = horizontal field of view

$$h = 2x\tan(\frac{\theta}{2}) \quad \dots\dots\dots (2)$$

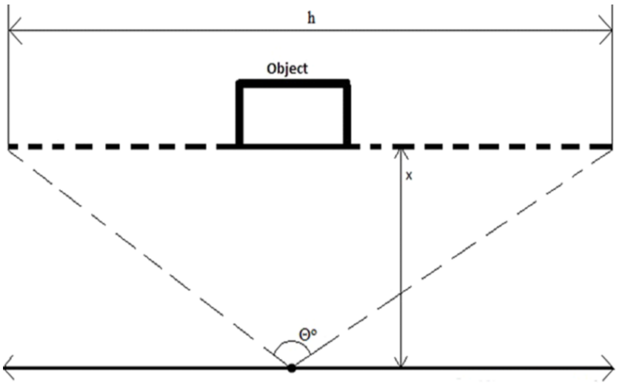

Figure 2: Field of view

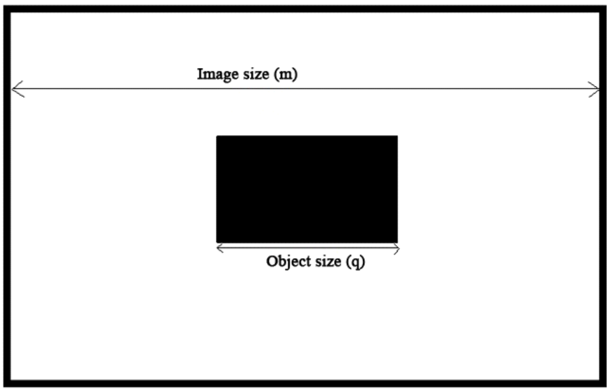

Figure 3: The image captured by the camera

This distance h is squeezed into the image. If the image is m x n pixels in size, m is the horizontal pixels and n is the vertical pixels. The camera can horizontally see as far h in reality. In the image h is represented as m as shown in figure 3.

If an object is present at distance x, and the horizontal length of the object is p in real life, in the image it takes up q pixels. As because, there exist a geometric similarity between the image and the real life scene, the ratio of object length in the image is equivalent to image length. Since we can calculate the values of q, m, h we can also calculate the value of p. If,

q = object length in image
m = image length
p = is the object length in real life, and
h = is the horizontal distance

then, $\frac{q}{m} = \frac{p}{h}$ hence, $p = \frac{hq}{m}$

For vertical measurements, we use the same procedure with different values; the angle of vision becomes (alpha, α). The equation for vertical distance is:

$$v = 2x\tan(\frac{\alpha}{2}) \quad \dots\dots\dots (3)$$

The similarity equation becomes:

$$\frac{s}{n} = \frac{t}{v} \quad \dots\dots\dots (4)$$

Where s is the vertical height of the object image in terms of pixel and t is the vertical length of the object in real life.

4. EXPERIMENT

4.1 The Camera

The camera can be a standard web cam of any resolution. However, it is preferred that the resolution is not too great, since a larger size of image would require more computation power.
In our experiment we have used a Canon 550D camera to take image and used MATLAB for processing of that image.
In MATLAB we have taken the image as input; we have converted the colour image to grayscale image for computational simplicity. Grayscale is an image in which the value of each pixel carries only intensity information. Images of this sort are composed exclusively of shades of gray, varying from black at the weakest intensity to white at the strongest [14]. After conversion to gray scale we have performed thresholding on the image to separate the object from the back ground. Thresholding is a simple method of segmentation. Thresholding can be used to convert grayscale images to binary images [15]. Following the thresholding, we perform opening and closing on the image to eliminate all noises from the image.
The term opening means to perform erosion followed by dilation on the image and closing is dilation performed before erosion. Opening removes small objects from the foreground of an image, placing them in the background, while closing removes small holes in the foreground. [16] After isolating the object in the image we measure the dimensions of the object in the image. The horizontal length of the object is found by the equation:

$$p = \frac{hq}{m} \quad \dots\dots\dots (5)$$

The vertical height of the object is found by the equation:

$$t = \frac{vs}{n} \quad \dots\dots\dots (6)$$

4.2 The Ultrasonic Sensor

The ultrasonic sensor has the following features:

- Supply Voltage – 5 VDC
- Supply Current – 30 mA typ; 35 mA max
- Range – 2 cm to 3 m (0.8 in to 3.3 yrds)
- Input Trigger – positive TTL pulse, 2 uS min, 5 μs typ.
- Echo Pulse – positive TTL pulse, 115 uS to 18.5 ms
- Echo Hold-off – 750 μs from fall of Trigger pulse
- Burst Frequency – 40 kHz for 200 μs
- Burst Indicator LED shows sensor activity

- Delay before next measurement – 200 µs
- Size – 22 mm H x 46 mm W x 16 mm D (0.84 in x 1.8 in x 0.6 in)

Figure 4: TS601-01 Ultrasonic sensor

The ultrasonic sensor detects objects by emitting a short ultrasonic burst and then "listening" for the echo. Under control of a host microcontroller (trigger pulse), the sensor emits a short 40 kHz (ultrasonic) burst. This burst travels through the air at about 1130 feet per second, hits an object and then bounces back to the sensor. The ultrasonic sensor provides an output pulse to the host that will terminate when the echo is detected; hence the width of this pulse corresponds to the distance to the target [17].

4.3 Result

When we run the fused sensors using Matlab, we figured out clusters of information about the object. Our system receives the information about how far the object is, object width, object, and object height. In each second the system receives six sets of reading about the object. We ran the program for 50 seconds for each experiment. We used objects of different dimensions for each experiment. We got 290 reading about the distance and size of the object. There were some rough values, which were outliers and we ignored them for better accuracy.

Table 1: Experiment results with different rectangular objects

Experiment no.	Real Width(cm)	Real Height(cm)	Average Obtained Width(cm)	Average Obtained Height(cm)	Error in Width(%)	Error in Height(%)
1	10.5	7.2	9.92	6.33	5.48	11.98
2	6.8	3.2	6.13	2.54	9.85	20.6
3	5.7	5.1	5.26	4.75	7.72	6.86
4	18	12	16.80	11.00	6.67	8.33
5	16	14	15.21	12.67	4.93	9.50
6	13.5	6.4	12.92	5.68	4.29	11.25
7	24	16	21.84	14.71	9.0	8.0
8	9.1	6.1	8.6	5.9	5.49	3.2

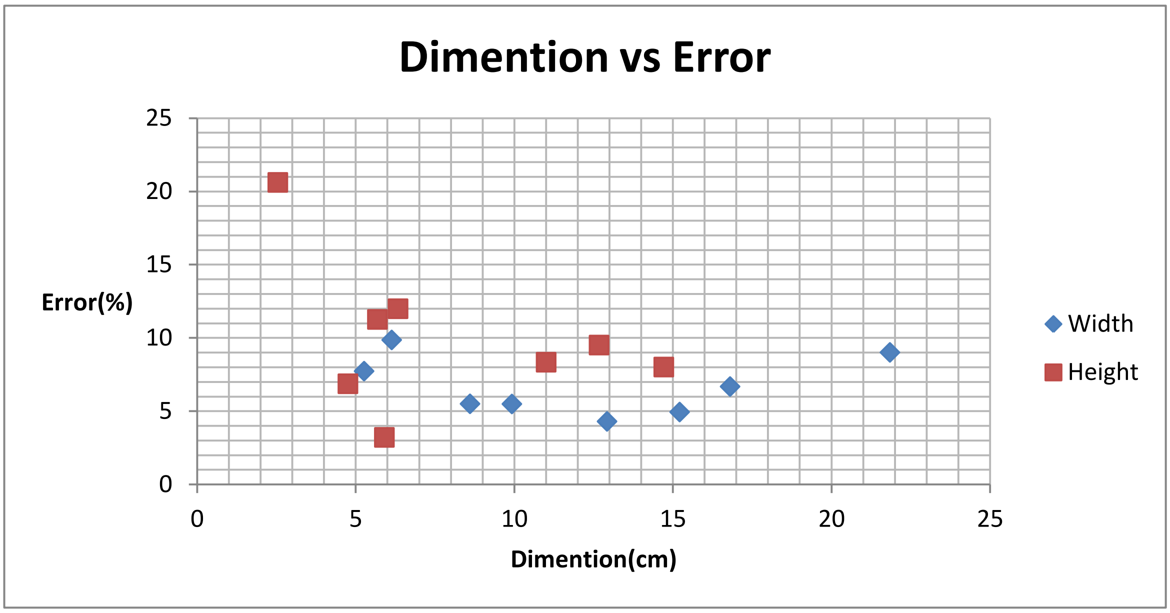

Figure 5: Percentage Error in Dimension

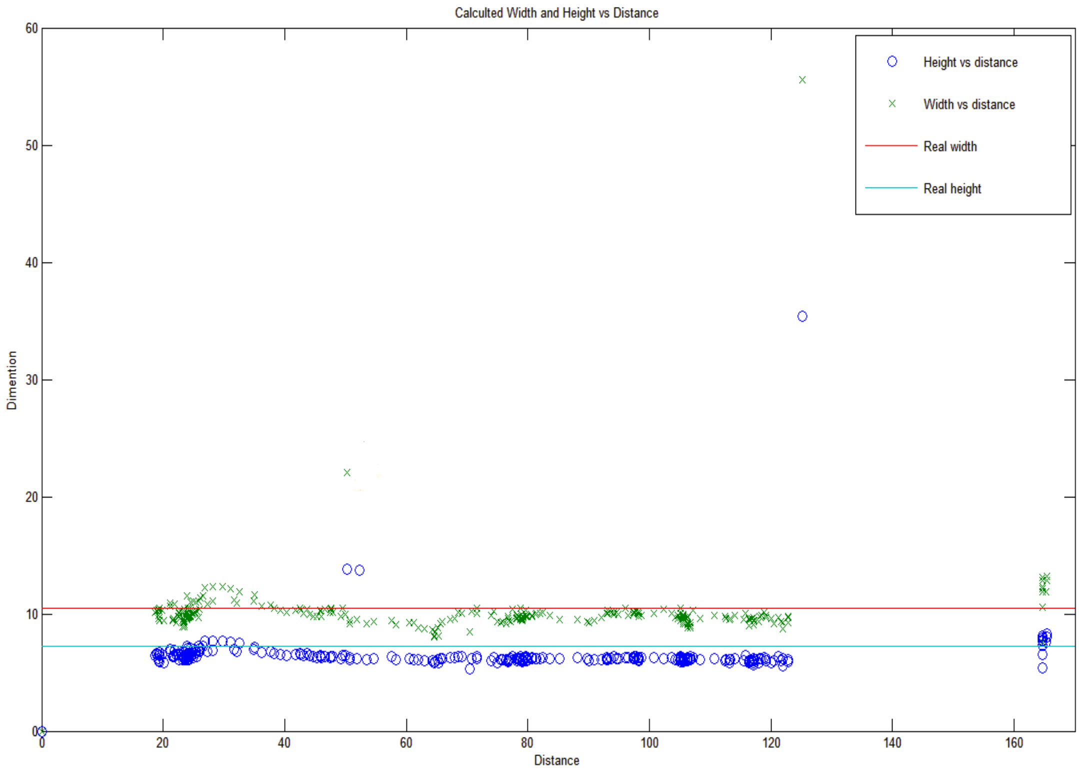

Figure 6: Distance vs. Dimensions graph for a single experiment

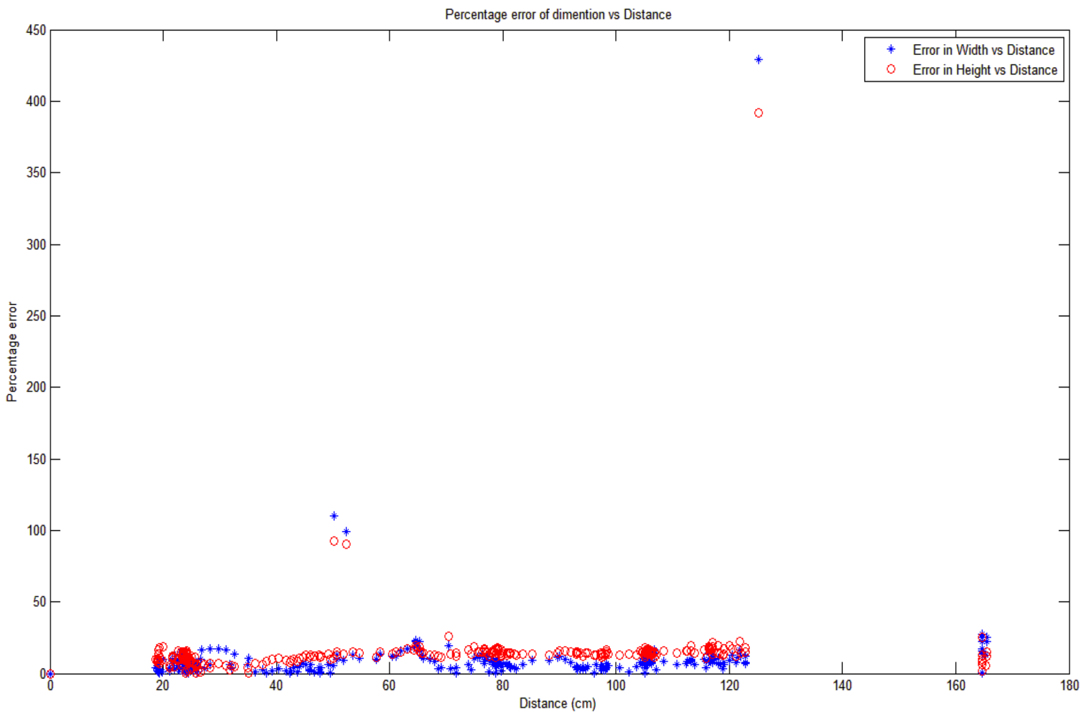

Figure 7: Percentage error in dimensions vs. distance for a single experiment

5. CONCLUSION AND FUTURE WORK

The error in length and width is the influence of several factors, the error in calculating the distance is a key factor, and also the distortion of the lens plays a key role in determining the size of the object. Some information about the object might have been lost when applying different image processing techniques. Regardless, the error percentage is small enough to be acceptable.

The future prospect of the project includes improving the accuracy of the system. We will use more efficient image processing techniques and algorithms to reduce the computational complexity and to detect and measure the size of an object more accurately. Different algorithms will allow us to work on colour image domain, we would be able detect, identify and track objects better.

We can introduce machine learning, so that the robot can learn by itself and navigate around without colliding with obstacles. The robot will learn to identify obstacles and objects.

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