Comparative analysis on the development of Hardware and Software for detection of obstacle and estimation of distance

[1] **J. Venu Gopala Krishnan** [2]**Dr. N. Manoharan**, [3]**Dr. B. Sheela Rani**,
[1] Research Scholar,
[2]Vice Chancellor,
[3]Professor & Head, Department of EIE,
Sathyabama University,
Chennai.

Abstract - This paper presents a system for real time obstacle detection and distance estimation. Computational stereo performance has progressed such that several commercial or open source implementations are available which operate at frame rate, but suffer from well known correspondence errors. The global segmentation step is based on a graph structure appropriate for collision detection, human vision inspired perceptual organization. Autonomous driving in off-road environments requires an exceptionally capable sensor system for an unstructured environment that does not provide many of the cues available in on-road environments. Our project is position detection using ultrasonic sensors. Briefly; measurement of distance for an object from an ultrasonic sensor and map its position in a pre-calculated area. It uses RF04 ultrasonic sensors for distance measurement and drive this sensor via PIC (Peripheral Interface Control) 16f877 microcontroller. After getting the necessary data from sensor which makes serial communication between PIC and PC and then mapping in PC using MATLAB. This paper presents an obstacle detection system with a non-contact type ultrasonic distance measuring device that includes a microcontroller for controlling operation of a transducer that functions as both transmitter and receiver. The system proposed detects the obstacle with a distance up to 3 meters and sends back the value to the user. The system aims at increasing the mobility of unmanned vehicle used in a war field by offering simple sensor devices. An algorithm is developed to have computer based estimation of distance with correct accuracy.

I. INTRODUCTION

The work presented in this paper is to determine the distance between the vehicle and obstacle [1]. The research focuses on obstacle detection in order to reduce difficulties in off-road environments [2],[3]. One key component of any autonomous system is its perception system: the vehicle [7] must first sense its surrounding environment before it can determine how to safely drive within the environment.

The system designed comprises of independent, battery a powered transmitter and receiver section that makes use of a pair of matched ultrasonic piezoceramic transducers. The Ultrasonic sensor circuit used senses the distance [4] and through the hardware circuit it indicates the distance [5,[6]]via an LCD Display connected in the module.

An algorithm is developed to display the distance in the computer so as to enable the user for easy identification. Here this algorithm determines the accurate distance than it displays in the LCD with decimal approximation. This cost-effective method has a simple implementation in Vehicle Navigation system.

The paper is organized as follows. In Section II a brief review of Vehicle Navigation System is presented with the basic explanation. Section III describes the development of Vehicle Navigation System. In Section IV development of software for Vehicle Navigation System using ultrasonic spread-spectrum distance measurement. Experimental results are presented in Section V. Concluding remarks are given in Section VI.

II. BRIEF REVIEW OF VEHICLE NAVIGATION SYSTEM

Robots require a wide range of sensors to obtain information about the world around them. These sensors detect position, velocity, acceleration, and range to objects in the robots workspace. There are many different sensors used to detect the range to an object. One of the most common rangefinders is the ultrasonic transducer. Vision systems are also used to greatly improve the robot's versatility, speed, and accuracy for its complex.

Moving through an unknown environment becomes a real challenge when it cannot rely on our own eyes. Dynamic obstacles usually produce noise while moving, but the unstructured off-road environment confounds basic environment perception. The common way for distance measurement is by using any mechanical device to detect static obstacles on the ground, uneven surfaces, holes and steps via simple sensing mechanism. This device is portable, but range is limited to its own size and it is not usable for dynamic obstacle detection algorithm.

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There are three important characteristics in ultrasonic echoes [10]: (1) Similarity - The echoes from different locations are very similar. (2) Correlation - As to the same equipment, the ultrasonic echoes vary with detection distances only in amplitude not in shape, i.e., the echoes are very correlative. (3) Narrow-band - The echo's power spectrum converge around the center frequency of the ultrasonic transducer and the frequency band of the echo is very narrow.

From the above three characteristics of ultrasonic echoes with received signal can be expressed in equation (1):

$$r_i (t) = \beta_i s(t-\tau_i) + w_i(t),\ 0 \leq t \leq T \qquad (1)$$

where $s(t) = a(t) \cos(2\pi f_c t)$ denotes ultrasonic transmit signal (the modulated signal by m sequence a(t) and ultrasonic carrier $cos(2\pi f_c t)$, β_i is the attenuation coefficient, r_i is the time delay, $w_i(t)$ is echo which isn't correlative with s(t), T is observation time of the received signal.

When the reference distance L_0 between S_1 and VNS is known, take the received signal $r_0 (t) = \beta_0 s(t - \tau_0) + w_0(t)$ as the reference signal, where $w_0(t)$ is echo which isn't correlative with s(t). If the received signal $r_1 (t) = \beta_1 s(t - \tau_1) + w_1(t)$ when the distance to be measured is L_1, where $w_1(t)$ is echo which isn't correlative with s(t) and $w_0(t)$:

$$\begin{matrix} r_0 (t) = \beta_0 s(t - \tau_0) + w_0(t) \\ r_1 (t) = \beta_1 s(t - \tau_1) + w_1(t) \end{matrix},\ 0 \leq t \leq T \qquad (2)$$

Digitize the above formula (2) to the below formula (3),

$$\begin{matrix} r_0 (t) = \beta_0 s(nT_s - \tau_0) + w_0(t) \\ r_1 (t) = \beta_1 s(nT_s - \tau_1) + w_1(t) \end{matrix},\ 0 \leq t \leq T \qquad (3)$$

Where T_s is the sample interval, T=NT_s. If it obtained $r_0(nT_s)$ and $r_1(nT_s)$, how to obtain the estimation value τ_{10} of $\tau_{10} = \tau_1 - \tau_0$. After τ_{10} is obtained, the distance L_1 can be estimated by equation (4):

$$L_1 = L_0 + c\ \tau_{10} \qquad (4)$$

Where c is the sound velocity in air.

III. DEVELOPMENT OF HARDWARE FOR VEHICLE NAVIGATION SYSTEM

A. General Structure:

The system architecture has a non-contact type ultrasonic distance measuring device that includes a micro controller for controlling operation of a transducer that function as both a transmitter and receiver. Micro controller works in the modes of its operation such as speed and obstacle detection. The vehicle and obstacle distance is picked up by a series connected comparator, counter circuit with an interface to Digital to Analog Converter and displays it in a LCD [8].

B. Sensor:

The distance measurement 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 have two major categories - digital and analog. The digital electronics generate the ultrasonic frequency. Voltage – 5 V_{DC}; Current - 30mA; Frequency - 40 KHz; Max Range - 3 m; Min Range - 3 cm; Sensitivity - Detect 3cm diameter broom handle at > 2 m; Echo Pulse - Positive TTL level signal, width proportional to range. The transducer then switches to the receiver mode where 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 ha lf the time measured. The distance value was returned through a RS 232 port to the control computer. A pulse of electronically generated sound is transmitted toward the target and the resulting echo is detected. The system converts the elapsed time into a distance value. The digital electronics generates the ultrasonic frequency and all the digital functions are generated by the microcontroller. Operating parameters such as transmit frequency, pulse width, blanking time, and the amplifier gain are controlled by software.

The microcontroller gathers the information from the ultrasonic transducers as Pulse Width Modulated (PWM) signal directly proportional to the distance of the nearest obstacle. The microcontroller measures the width of the transmitted pulses and converts it into empiric distance. Following a comparator circuit, the distance is determined between the sensor and the obstacle. The comparator output voltage is given to a counter circuit which counts and decides the about the reception of a signal to the receiver and then displays the distance value through a proper Digital to Analog Converter circuit to indicate the distance by an LED through a PIC Microcontroller connected in the receiver circuit [8].

The system provides a static module to measure the distance when vehicle is static and obstacle is dynamic, with a maximum distance of 3 m. But a continuous monitoring method can be achieved to make a periodic measurement with improvisation in the circuit.

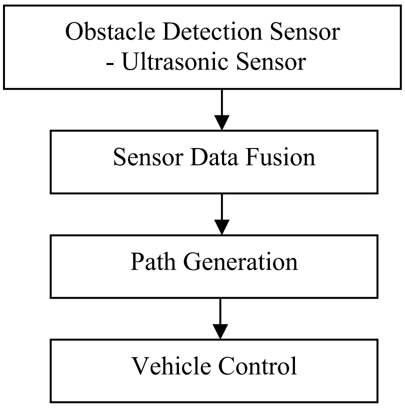

Fig 1: Structure of Vehicle Navigation system

IV. DEVELOPMENT OF SOFTWARE FOR VEHICLE NAVIGATION SYSTEM

Obstacle detection is one of the main problems to ensure safe navigation in any area. A simple embedded architecture is used to develop new obstacle sensing device. Using the above Hardware model, the distance measurement in LCD is not same as the theoretical value. Then it is find out that more echo signals are received by the sensor and which is eliminated by the TDE algorithm which is developed to minimize the error signal using FFT technique [5].

Without loss universality, if $L_1 > L_0$, i.e., $\tau_{10} > 0$., then ultrasonic carrier doesn't contain any time delay information, so it process the envelope of $r_0(n)$ and $r_1(n)$ to to acquire τ_{10}. In addition, the reference signal $r_0(n)$ is known before distance measurement, so it can precedingly obtain the part envelope $a_1(n)$ ($0 \leq n < M$, $M < N$) of $r_0(n)$ that includes pseudo-random signal by squire-filter or Hilbert method. Assign $1(n)$ with $a_1(n)$and write the received signal $r_1(n)$ in the shape of equation (5):

$$r_1(n) = Re[a_1(n - N_{10})e^{j\varphi}] + w_i(n) \qquad (5)$$

where $N_{10} = (\tau_{10} / T_s)$, $T_s = (\omega_c / 2\pi f_c)$.

Initially, the vehicle is activated with its mechanism. When any obstacle crosses, the ultrasonic sensor used in the system senses the obstacle and indication is given to the PIC microcontroller through a transmitter circuit. The microcontroller gathers the information as a PWM signal and measures the width of the transmitted pulse and converts it into empiric distance.

Next step is to determine the distance of an obstacle. It is necessary that the user keeps in mind that the sensor locates the distance with the static vehicle and the moving obstacle which passes nearby. If the obstacle is located on the floor at sufficient distance the vehicle will sense the corresponding obstacle.

With the values of $r_1(n)$, $w_i(n)$ are correlated and computed in advance and stored. So, one FFT, one inverse FFT and N complex multiplication is needed in a distance measurement. The whole calculation is $(N+log_2N)$ complex multiplication and $2Nlog_2N$ complex addition.

Moving obstacles can also be localized using the same principle taken into account the users own displacement. Different methods presented for obstacle localization are validated in next section.

V. EXPERIMENTAL RESULTS

A. Test Methodology:

To evaluate the system a method to test the results has developed. A vehicle is placed and an obstacle is made to cross it. Detection is confirmed by assuring the distance displayed with the manual measurements. To evaluate the dynamic obstacle avoidance, a person is allowed to walk towards the vehicle. This simulation is performed in such a manner to be as close to the real condition of application.

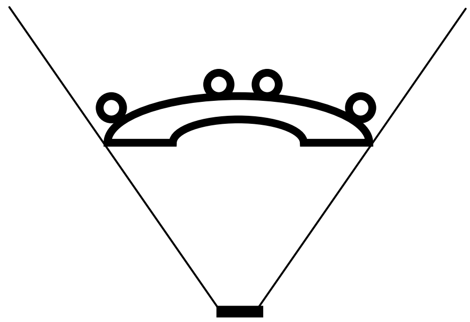

Fig 2: Equal Responses for different positions

C. Comparison Charts::

The following charts list the details of obstacle position and distance with theoretical and practical values;

System / Criterion	Obstacle Position		Distance Accuracy	
	Theory Value	Practical Value	Theory Value	Practical Value
By Hardware	2 m	1.65 m	3 m	2.65 m
By Software	2 m	2.02 m	3 m	3.05 m

The above table illustrates the details of obstacle which detects the position and distance accuracy. The software detects distance accurately than hardware used.

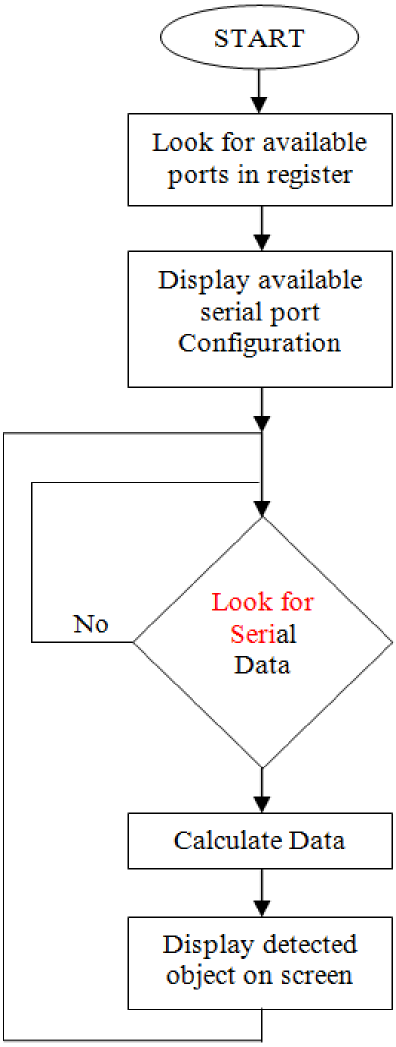

Fig 3: Flowchart for PC

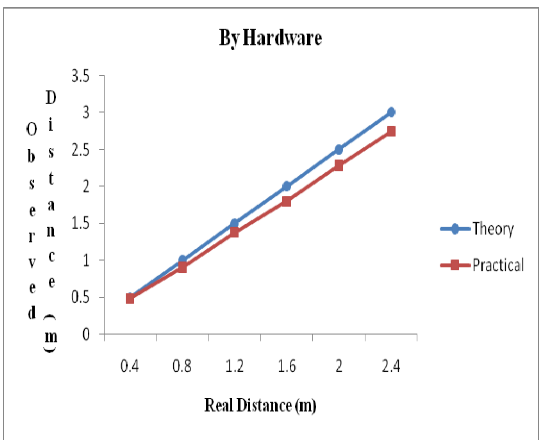

Fig.4 : Distance Comparison Chart – By Hardware

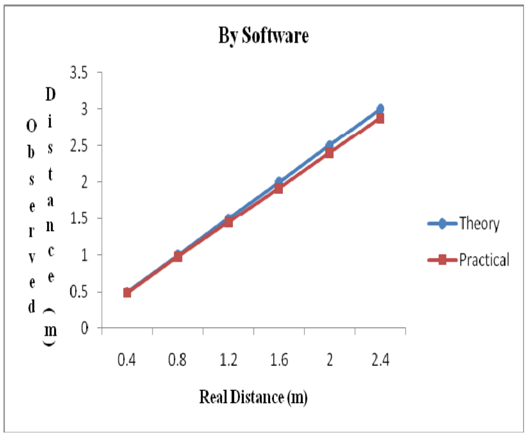

Fig.5 : Distance Comparison Chart – By Software

This chart clearly indicates the distance of static obstacle with the dynamic vehicle in both Hardware and Software measurements.
The distance between the vehicle and the obstacle are much closer with the real value and the observed value. Also the TDE algorithm makes more easily observed than the hardware part. This algorithm is feasible with the result obtained.

Result shows that the system is quite useful when the distance measurement in Software part is quite normal and correct rather than Hardware part.

D. Discussion:

This ultrasonic sensor is widely used for obstacle detection and avoidance. With the static system the region in which the obstacle lies can be determined. It needs a rule based approach to avoid obstacles. The system has noise and it is difficult to reduce the error. The dynamic system gives a more accurate position for the obstacle and has the advantage of using only one sensor. The distance accuracy measured by the hardware is lower than that obtained by the software. Dynamic obstacle detection still needs improvement. In fact, this system approximates with less error in predicting the distance to the obstacle but it is still hard to localize it precisely. Another disturbing phenomenon is that the echo signals picked up by the sensor and the threshold value of the sensor circuit deviates. Also the usability at close range makes it very less.

VII. HARDWARE SETUP

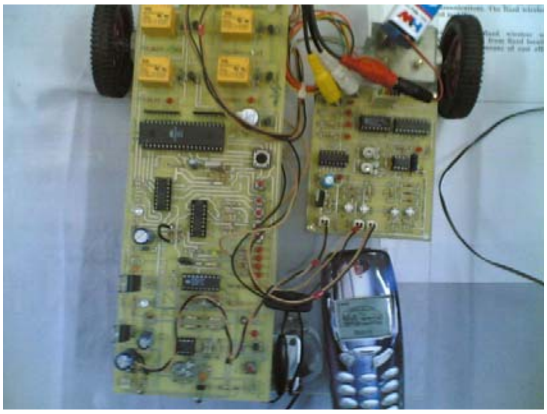

Fig.6 : Hardware Setup

VI. CONCLUSION AND FUTURE WORK

The ultrasonic distance measurement system is more economical than the other system and easy to implement since the amount of data received is less. However, there is a loss of accuracy with the increase in complexity of the systems. With this system it is difficult to develop path planning systems and the algorithms are reactive, it gives data which can be used for mapping and planning the navigation of the robot.

In this paper, the principle used to measure the distance is by using proper sensors. In fact, measuring the distance using LCD and computer based system is analyzed. The conclusion is that the "closest" obstacle is inconvenient when trying to map the environment. The problem becomes obvious when the system is used to sense by software is more accurate than by hardware. A software based distance measurement using image capturing techniques is being explored to improve the results.

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J.VENU GOPALA KRISHNAN graduated in Madras University at 1992 in Electronics & Communication discipline and started his teaching carrier. Then he pursue his Master degree in Optical Engineering in CEG, Anna University and awarded at 2001. He is doing research work in the field of Image processing. Now he is a Professor & Head in the department of Electronics & Communication Engineering of Jeppiaar Engineering College- Chennai. He presented 14 papers in National and International Conferences.