FINAL YEAR PROJECT REPORT

(Ultrasonic Distance Measurement System)

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Abstract

Ultrasonic distance measurement has received considerable attention in the recent past, several distance measurement algorithms have been proposed as means to get distance of different objects precisely. With the advancement of technology several methods and techniques has been proposed i.e. TOF (time of flight), TFCW etc. In this project, we used MFCW Multiple Frequency Continuous Wave ultrasonic range system, medium of waves is air. This system is based on Radio Frequency distance measurement rather than air based TOF method. The method presented here is based on comparative phase shifts generated by the three different frequency continuous waves but closely spaced. It is high resolution low cost effective and precise technique with a precision up to ±0.05m.

Dedication

First of all we are very thankful to ALLAH ALMIGHTY who has given us enough courage to complete this task. Then it is dedicated to our kind teacher **Sir Muhammad Asim Butt &Our Parents** who enlightened our minds with Knowledge, tried hard to encourage us for hard work so that we could have a bright future in terms of being good human and turn out to be competent Engineers with powers to take challenging problems.

Ackwnoledgements

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Contents

List of figures

List of Figure **Page No.**

Introduction:

Ultrasonic Waves

Ultrasound is a mechanical disturbance that moves as a pressure wave through a medium. When the medium is a patient, the wavelike disturbance is the basis for use of ultrasound as a diagnostic tool. Appreciation of the characteristics of ultrasound waves and their behavior in various media is essential to understanding the use of diagnostic ultrasound in clinical medicine. 1–6

History:

In 1794, Spallanzi suggested correctly that bats avoided obstacles during flight by using sound signals beyond the range of the human ear.
In 1880, French physicists Pierre and Jacques Curie discovered the piezoelectric effect.[7] French physicist Paul Langevin attempted to develop piezoelectric materials as senders and receivers of high-frequency mechanical disturbances (ultrasound waves) through materials.[8] His specific application was the use of ultrasound to detect submarines during World War I. This technique, sound navigation and ranging (SONAR), finally became practical during World War II. Industrial uses of ultrasound began in 1928 with the suggestion of Soviet Physicist Sokolov that it could be used to detect hidden flaws in materials. Medical uses of ultrasound through the 1930s were confined to therapeutic applications such as cancer treatments and physical therapy for various ailments. Diagnostic applications of ultrasound began in the late 1940s through collaboration between physicians and engineers familiar with SONAR.[8]

Ultrasound Wave Characteristics

Frequency Classification of Ultrasound

Frequency (Hz)	*Classification*
20–20,000	Audible sound
20,000–1,000,000	Ultrasound
1,000,000–30,000,000	Diagnostic medical ultrasound

During the propagation of an ultrasound wave, the molecules of the medium vibrate over very short distances in a direction parallel to the longitudinal wave. It is this vibration, during which momentum is transferred among molecules, that causes the wave to move through the medium.

Ultrasound Intensity

As an ultrasound wave passes through a medium, it transports energy through the medium. The rate of energy transport is known as "power." Medical ultrasound is produced in beams that are usually focused into a small area, and the beam is described in terms of the power per unit area, defined as the beam's "intensity." The relationships among the quantities and units pertaining to intensity are summarized in Table below. Intensity is usually described relative to some reference intensity.

Quantity	*Definition*	*Unit*
Energy (E)	Ability to do work	joule
Power (P)	Rate at which energy is transported	watt (joule/sec)
Intensity (I)	Power per unit area (a), where t = time	watt/cm^2
Relationship	$I = \frac{P}{a} = \frac{E}{(t)(a)}$	

For example, the intensity of ultrasound waves sent into the body may be compared with that of the ultrasound reflected back to the surface by structures in the body. For many clinical situations the reflected waves at the surface may be as much as a hundredth or so of the intensity of the transmitted waves. Waves reflected from structures at depths of 10 cm or more below the surface may be lowered in intensity by a much larger factor. A logarithmic scale is most appropriate for recording data over a range of many orders of magnitude. In acoustics, the decibel scale is used, with the decibel defined as

$$dB = 10 \log \frac{I}{I_0}$$

Where I_0 is the reference intensity. Table below shows examples of decibel values for certain intensity ratios. Several rules can be extracted from this table:

- Positive decibel values result when a wave has a higher intensity than the reference wave; negative values denote a wave with lower intensity.
- Increasing a wave's intensity by a factor of 10 adds 10 dB to the intensity, and reducing the intensity by a factor of 10 subtracts 10 dB.
- Doubling the intensity adds 3 dB, and halving subtracts 3 dB.

Ratio of Ultrasound Wave Parameters	*Intensity Ratio* (I/I_0) *(dB)*	*Amplitude Ratio* (A/A_0) *(dB)*
1000	30	60
100	20	40
10	10	20
2	3	6
1	0	0
1/2	−3	−6
1/10	−10	−20
1/100	−20	−40
1/1000	−30	−60

No universal standard reference intensity exists for ultrasound. Thus the statement "ultrasound at 50 dB was used" is nonsensical. However, a statement such as"the returning echo was 50 dB below the transmitted signal" is informative. The transmitted signal then becomes the reference intensity for this particular application. For audible sound, a statement such as "a jet engine produces sound at 100 dB" is appropriate because there is a generally accepted reference intensity of 10−16 W/cm2 for audible sound.[10] A 1-kHz tone (musical note C one octave above middle C) at this intensity is barely audible to most listeners. A 1-kHz note at 120 dB (10−4 W/cm2) is painfully loud.
Because intensity is power per unit area and power is energy per unit time thus we could also write:

$$dB = 10 \log \frac{\text{Power}}{\text{Power}_0} = 10 \log \frac{E}{E_0}$$

Ultrasound wave intensity is related to maximum pressure (*Pm*) in the medium by the following expression:

$$1 = \frac{P_m^2}{2\rho c}$$

Where ρ is the density of the medium in grams per cubic centimeter and *c* is the speed of sound in the medium. Substituting yields:

$$dB = 10 \log \frac{P_m^2/2\rho c}{(P_m^2)_0/2\rho c} = 10 \log [P_m/P_{m0}]^2$$

$$= 20 \log \frac{P_m}{P_{m0}}$$

When comparing the pressure of two waves, Eq. above may be used directly. That is, the pressure does not have to be converted to intensity to determine the decibel value. An ultrasound transducer converts pressure amplitudes received from the patient (i.e., the reflected ultrasound wave) into voltages. The amplitude of voltages recorded for ultrasound waves is directly proportional to the variations in pressure in the reflected wave.

Problem:

Distance measurement is simple physical relationship as defined by the formula:

$$S= vt$$

Our mission is to calculate the distance using ultrasonic waves. In a simple case we can calculate the distance as stated above. we know the speed of sound in air is 340 m/s and through any channel if we able to calculate the time of flight of ultrasonic burst from source to destination the distance can easily be calculated by the formula mentioned above.

But using this phenomenon, ERROR can easily penetrate into the results due to amplitude degradation at receiving side as well as temperature also have effect over ultrasonic waves. In air the higher the frequency greater the attenuation per unit distance. Hence there is a need to introduce any other method to minimize the error and increase the precision.

Proposed solution:

To eliminate the error from the desired results the required methodology is to choose a way which is less affected by the environment so a system based upon frequency and phase relation is much better than amplitude based system. By the relationship between phase data of a steady state frequency of received signal and transmitted signal, we can calculate accurate distance. This is done because the distance is derived from the phase difference of a repeating signal which is sampled for a statistically significant number of wave periods. Thus random variations in the phase shift eliminates out the surrounding and electronic component noise etc.

Phase shift analysis of single frequency continuous wave transmission can be used to reduce the error. If the transmitter is given a sinusoidal signal as input then the returning echo can be written as

$$V(t)= A\sin(wt+Ø)$$

Where ”A” is the peak amplitude of echo and “w” is the resonant angular frequency of the transducer and “Ø” is the phase shift of echo which is linearly proportional to the target distance. The distance can be determined by the phase shift of the single frequency if the maximum target is not far more than full wave length otherwise phase ambiguity will occur. The maximum achievable range using 40 KHz transducer is 8mm

corresponding to the ultrasound velocity 340 m/s which is obviously too short for any ultrasonic ranging application.

To overcome this problem a technique can be used in which phase shift of two or more frequencies are compared, allowing us to calculate the distances much larger than one wave length. Such a system can calculate up to precision of ±0.0005m over a range of 1.5m, utilizing three different ultrasonic frequencies and getting back the corresponding phase shifts. Multi frequency channel wave (MFCW) is based on two frequency continuous wave (TFCW), also called the two tone method. Increasing the number of frequencies increase the maximum range for given accuracy, at the cost of increased time required to measure the range. MFCW is identical to TFCW initially the specific contribution of MFCW relative to TFCW is reduction of error contributed by addition of second or higher number of frequencies and the associated extension to useful range.

TFCW

The method is as follows. The first frequency f_1 continuous wave is transmitted from an ultrasonic transducer. The first phase shift Ø1 transmitted signal relative to received signal is calculated by digitized phase information and the first frequency's transmission/reception/calculation period is completed, the second frequency f2 continuous wave is transmitted yielding us the second phase shift Ø2. Comparing the two phase shift results in target range of several meters by using the following calculations

$L=(n1+ Ø\ 1/2\pi)* \lambda 1 \qquad (1)$

$L=(n2+ Ø\ 2/2\pi)* \lambda 2 \qquad (2)$

Where L is the distance between the receiver and the transmitter λ is the wave length of the ultrasound "n" is the integer, "Ø" is the phase shift. The difference of the phase shift due to the difference of the wave length may be derived from the Eqs. 1 & 2:

$L *(1/\lambda 1-1/\lambda 2)= \Delta Ø /2\pi \qquad (3)$

The Integers n have two possible values n1=n2 and n1=n2+1. So the difference of phase shift can be defined as below

1. If Ø 1> Ø 2, $\Delta Ø = Ø\ 1- Ø\ 2$
2. If Ø 1< Ø 2, $\Delta Ø = Ø\ 1+2\pi- Ø\ 2$

If the velocity of ultrasound is constant, say c the wave length λ can be determined as follows:

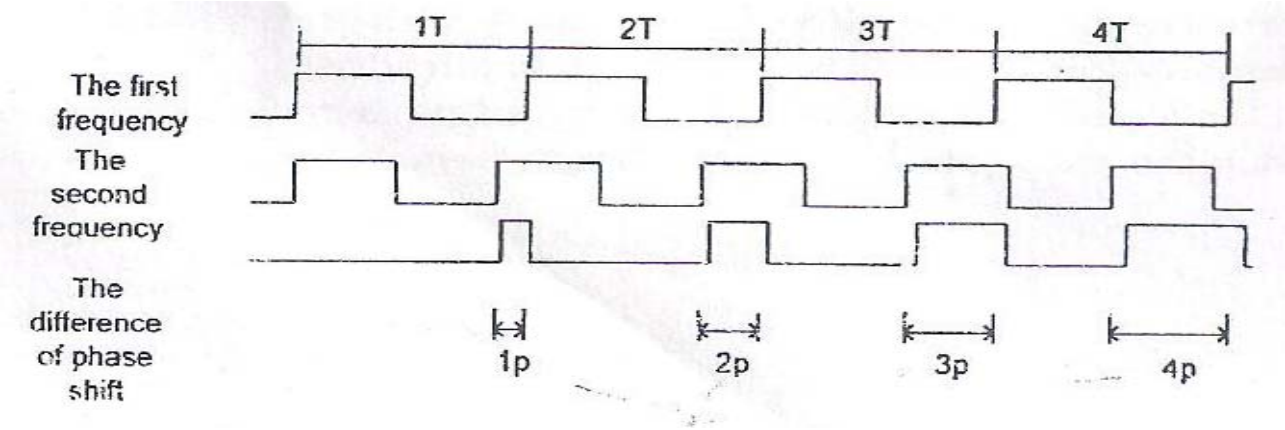
$\lambda 1=c/f1, \qquad \lambda 2=c/f2$

Where f1 & f2 is the frequency of first and second ultrasonic wave respectively now using Eq. (3) the distance can be expressed as

$L=\Delta \varnothing /2\ \pi*(c/\Delta f) \quad (\Delta f = f1-f2)$

The distance L can be uniquely determine by the difference of phase shifts delta Ø,if the maximum ranging distance does not exceed one period of the difference frequency "delta f" otherwise a phase ambiguity will occur. The maximum achievable range with TFCW (at delta f=200 Hz) is about 1.7mm.

TFCW is based on the concept that the differential phase shift of two simultaneously propagating waves of different frequencies will generate progressively larger phase shifts, the value of this increase being constant (1p), as the travel time or corresponding distance of travel increases. By detecting the two signals at some distance, and knowing the original starting time of each or knowing that they both at the same time, measured phase shift (np) can be divided by (1p), yielding the number of wave periods which have occurred to generate the measured phase difference, and, given a constant velocity. The distance can then be calculated. This relation is summarized in fig1.



From the above algorithm, it can be seen that the maximum difference of the phase shift is a constant 2π, and any phase measurements in excess of a certain range will cycle again through the 0-to-2π range, giving ambiguous range results.

The minimum resolution and the maximum range are determined by the choice of frequencies (f1, f2). Here the velocity of ultra sound is 350 m/s, f1=40 KHz, f2=39.9 KHz (the difference between f1 and f2 Δf=100 Hz), so the maximum difference is 350/100=3.5m and the sensitivity of the distance is 3.5/360 (m/degree) = 9.722(mm/degree). The next choice of frequencies f1, f2 with a higher difference (Δf=1 KHz) is used to measure the range 350/1 k = 0.35 m with the finer ranging resolution (0.9722 mm/degree) due to the smaller change in the measured range creating a greater difference of phase shift than with the difference between f1 and f2 (Δf=1 KHz) [10]. In general, the measurement range attainable using the proposed system is about 3m a choice of f1, f2 such that Δf=100 Hz can achieve a 3.5 m range, with a large range error. However, choosing the f1, f2 such that Δf=1Khz can reduce range error, with a 0.35 m range.

MFCW:

MFCW increases the number of frequencies utilized for phase comparison to correct the range errors and extend the useful range.

Most commercial ultrasonic transducers are fabricated on the principle of frequency resonance for achieving a high sensitivity at lower operating frequencies (40±2 KHz), which results in narrow-bandwidth devices. Fortunately, MFCW can achieve a narrow bandwidth ultrasonic ranging system. In such a system, the distance can be measured by the following steps:

In the first step, phase shift $\varnothing_1$ is generated by comparing the sent and received f1 signals (40 KHz). In the second step, phase shift $\varnothing_2$ is generated with f_2 (39.9 KHz) and comparison of $\varnothing_2$ with $\varnothing_1$ yields $\Delta\varnothing_1$, with a frequency difference (Δf_1) of 100 Hz. In the third step, as above, phase shift $\varnothing_3$ is generated by comparing sent and received f_3 signals (38 KHz), and comparison of $\varnothing_3$ to $\varnothing_1$ gives $\Delta\varnothing_2$, resulting in a frequency difference (Δf_2) of 2 KHz. The estimate of target distance can be expressed by the following algorithm:

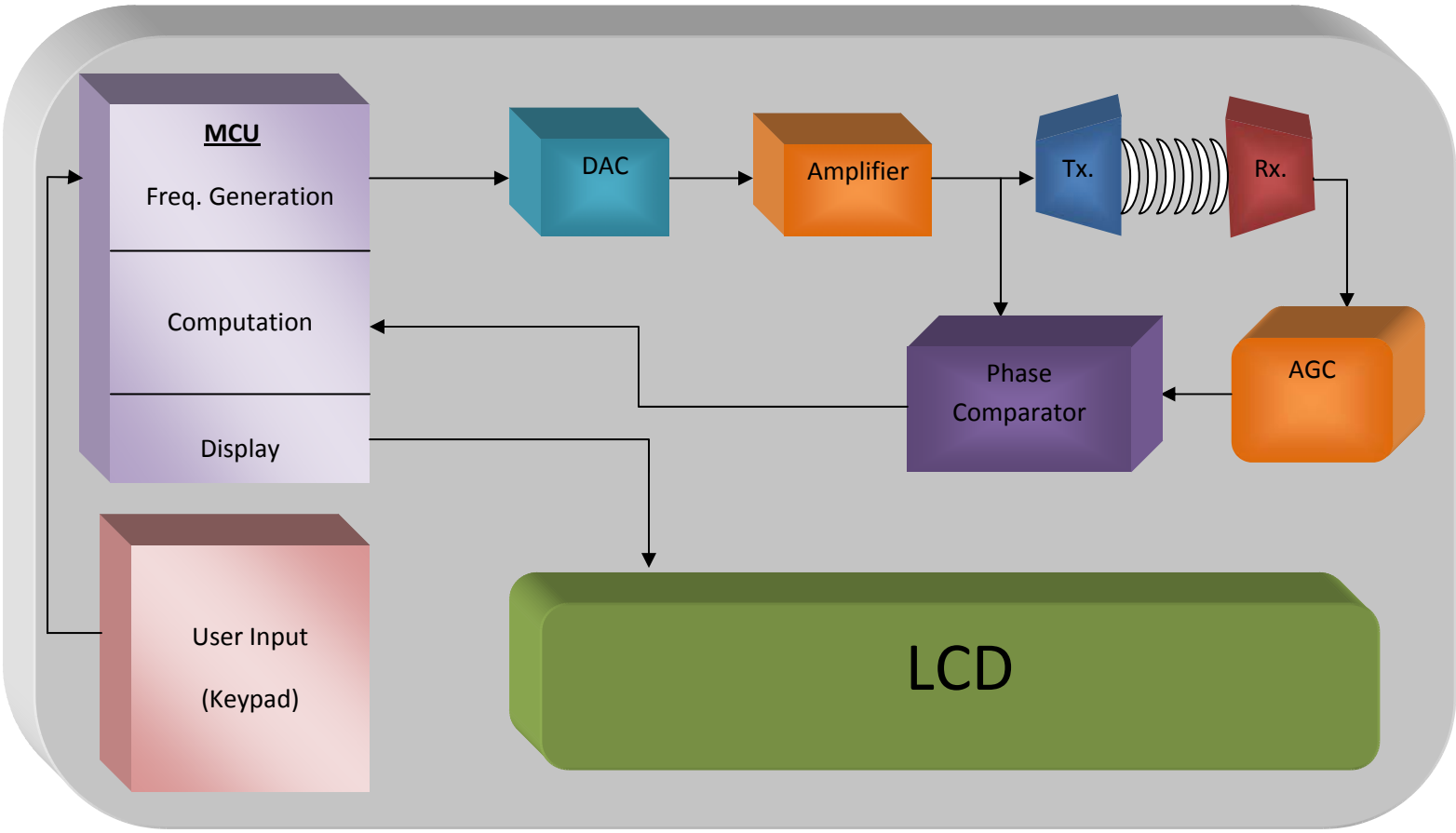
$$d = \mathrm{int}\left[\frac{\Delta\theta_1}{2\pi}\frac{\Delta f_2}{\Delta f_1}\right]\frac{c}{\Delta f_2} + \mathrm{int}\left[\frac{\Delta\theta_2}{2\pi}\frac{f_1}{\Delta f_2}\right]\frac{c}{f_1} + \frac{\theta_1}{2\pi}\frac{c}{f_1} \quad (5)$$

where “int” represents the greatest integer function of the given number. The θ_1, θ_2, θ_3 are phase shifts of frequencies f_1, f_2, and f_3 respectively. The difference $\Delta\theta_1$ is the difference between the phase shifts θ_1 and θ_2. The difference $\Delta\theta_2$ is difference of θ_1 and

θ_3. Similarly, Δf_1, is the difference between the two frequencies f_1 and f_2 while Δf_2, is the difference between the two frequencies f_1 and f_3. The variable c denotes the sound velocity and is given by 340m/s

Design Implementation

Block Diagram:



Block diagram of the whole system above, consisting mainly a frequency generation portion, transducers, auto-gain-control and phase comparator. Finally computation is done inside the controller and results are shown over a LCD.