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Ultrasonic Obstruction Detection and Distance Measurement Using AVR Micro Controller

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Abstract: This paper describes the practical implementation of a short range ultrasonic obstruction detection and distance measurement device. By employing an ultrasonic transducer pair for producing ultrasonic sounds and sensing the reflected sound waves, the obstructions are detected. The hardware interface uses an Atmel ATmega8 AVR microcontroller to facilitate the generation of 40 KHz signal burst which is used in the transmitter circuit, and also to process the received signal for measuring the time of flight of reflected waves and exact distance of the obstruction. The program for this device is developed in WinAVR, and the code generated is dumped into microcontroller using AVR Studio. Educational aspects of this project include the mastery of a programming language and corresponding tools, the design of a functional and intuitive embedded application, and the development of appropriate hardware to build the device. *Copyright © 2008 IFSA.*

Keywords: Ultrasonic transducers, Obstruction detection, Distance measurement, AVR microcontroller, Signal conditioning

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1. Introduction

There are several ways to measure distance without contact. Some products have infrared light emitters and receivers to determine an object's distance. Other devices have laser-based systems which have improved accuracy and precision. Presently, the detection techniques of laser, radar, infrared ray and ultrasonics have been widely applied at the aspect of obstruction detection and distance measurement. Because of the expensive price, the distance measurement system of laser and radar is only set on the minority of instruments. So the research of the distance measurement system backing up with high ratio of capability to low price has ended at Ultrasonic Range Finder. Ultrasonic sounds are used in many ways, for various applications such as water level measurement, flaw detection in metals and other material malfunctions. In the current application, ultrasonic signals are used for obstruction detection by producing a burst, and detecting its reflections after they hit the obstruction. Basically this is the technique used by bats to travel in the nights.

Principle: Bats produce ultrasonic waves, and the sound waves get reflected after any obstruction is encountered in their path. Hence bats either change their direction or continue with their path based on the received echo. The same principle can be used for obstruction detection by electronic means as it is very simple to produce ultrasonic signals using electronic circuitry and ultrasonic transducers. For measuring the distance, time of flight for reflected ultrasonic signals is calculated. Ultrasonic signals have good directionality, and they are easily reflected by solid objects. By finding the time taken for ultrasonic signals to reflect, the distance traveled by sound can be easily calculated, as velocity of sound is a known quantity. This is known as pulse echo technique, which is used here for distance measurement. Time of flight of ultrasonic sounds is calculated using high speed microcontroller.

2. Hardware

This project is divided into two modules. The first module is the hardware design, which includes the design of the three components of our range finder device. These components are: the transmitter, the receiver and the signal conditioning and processing circuit. The second module is the software design of these individual components, which will be explained in the later sections. In the present section we see, various hardware components employed in this project, and their significance. This section can be divided into 3 major sub sections.

1. AVR Microcontroller (Fig. 1)
2. Ultrasonic Transducers (Fig. 2)
3. Signal Conditioning and Processing Circuit.

2.1. AVR Microcontroller

In this project, we employ high-performance, low-power AVR® 8-bit Microcontroller, ATmega8L from Atmel Corporation, which has many special features compared to any other microcontroller. This is widely suitable for all 8-bit applications. It is used in a wide range of embedded applications, and the experience has been so positive that most of the embedded system designers and developers intend to use only Atmel AVRs for all in-house microcontroller projects.

Role of AVR microcontroller: The main role of an AVR Microcontroller employed in this current project is to generate bursts of 40 kHz electrical pulse trains, with required time delay inserted. This 40 kHz burst is applied to ultrasonic transmitter, with in turn produces ultrasonic sound waves. Similarly on the reception of signals at receiver, a PLL is triggered each time a signal burst of 40 kHz is appeared. As soon as the burst is detected, the microcontroller calculates the time gap between transmitted and received signal. By dividing the time gap into half, the actual time of flight is obtained. As the velocity of sound in air is a known quantity, the distance of the obstruction can be easily determined AVR functions as the heart of the system. It is used for generation of signal and calculation of distance of the obstruction. Apart from this, the microcontroller itself generates the distance output, which can be sent to either a display device or and control mechanism to perform predetermined action. Apart from the above mentioned services, microcontroller also enables the device to be connected and interfaced with other devices, through its I/O ports. Thus intercommunication between different peripherals is made possible. This device also can be connected to a PC through its serial port for sending and receiving data. This enables data acquisition and data logging.

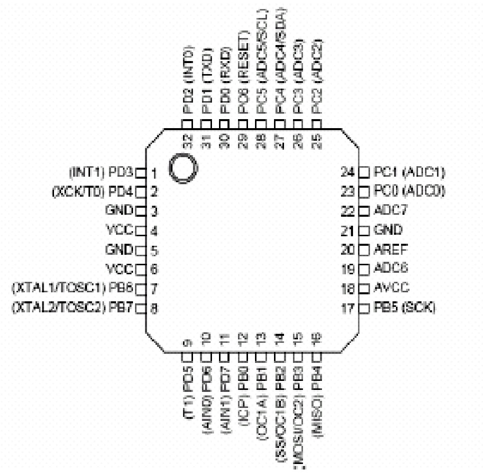

Fig. 1. ATmega8 Pin Configuration.

2.2. Ultrasonic Transducers

Ultrasonics is the study and application of high-frequency sound waves, usually in excess of 20 kHz (20,000 cycles per second). Modern ultrasonic generators can produce frequencies of as high as several gigahertz (several billion cycles per second) by transforming alternating electric currents into mechanical oscillations, and scientists have produced ultrasounds with frequencies up to about10 GHz (ten billion vibrations per second). There may be an upper limit to the frequency of usable ultrasound, but it is not yet known.

Transducer: Ultrasonic devices transmit and/or receive sound waves above the frequency range of human hearing which is typically much above 20 kHz. Ultrasound devices require line-of-sight and have a much smaller effective angular range. However, the delay of sound propagation is far easier to measure, and ultrasounds can be transmitted in the range of distance required for the present application. Ultrasound transmitters and receivers come in a much variety. Since the common types of ultrasound devices fit our specifications nicely, this made it much easier to select devices.

Fig. 2. Ultrasonic Transducer.

2.3. Signal Conditioning

In the transmitter circuit, the electrical generated from the microcontroller is passed through an inverter, before it is supplied to the ultrasonic transmitter. For this purpose IC 74LS04, a hex NOT gate inverter is employed. This gate inverts the given input. If the input is logic low, output is high, and if the input is logic high, output will be low.

a) Amplifier (TL084 CN): The TL084 JFET-input operational amplifier family is designed to offer a wider selection than any previously developed operational amplifier family. Each of these FET-input operational amplifiers incorporates well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit. The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient. Offset adjustment and external compensation options are available within the TL084 family. The C-suffix devices are characterized for operation from 0 °C to 70°C.

b) Schmitt Trigger 7413: The output of FET input amplifier is in analog form. Also it contains various voltage components, few of which may be unwanted noise signals. To detect the required signal components and convert them into square wave form, a Schmitt trigger is employed. Schmitt trigger performs regenerative comparison to eliminate false triggering. Schmitt trigger contains a positive feedback mechanism for noise elimination. It also has upper and lower threshold points, with which, the unwanted voltage levels in the received signal can be removed. The difference in upper threshold voltage and lower threshold voltage is known as hysteresis voltage. In this application we use, IC 74LS13 which is dual 4 – input NAND Schmitt trigger. It belongs to TTL logic family, with upper threshold voltage 1.7 V and lower threshold voltage 0.9 V, when operated at VCC +5 V.

c) Phase locked loop - lm567: The LM567 tone and frequency decoder is a highly stable phase locked loop with synchronous AM lock detection and power output circuitry. Its primary function is to drive a load whenever a sustained frequency within its detection band is present at the self-biased input. The bandwidth, center frequency and output delay are independently determined by means of four external components.

Operating Instructions

- Select R1 & C1 for desire center frequency.
- Select LPF capacitor C2 based on the bandwidth requirement.
- Selection of C3 is not so critical. If C3 is too small, frequency just outside detection band can switch the output. If the value is too large, delayed ON & OFF occurs.
- R2 (130k) sets the threshold for largest 'NO OUTPUT' input voltage.

3. Block Diagram

System design is most crucial part of this project. This can be explained with the help of a simple block diagram (Fig.3). This block diagram consists of few simple blocks and displays their interconnectivity.

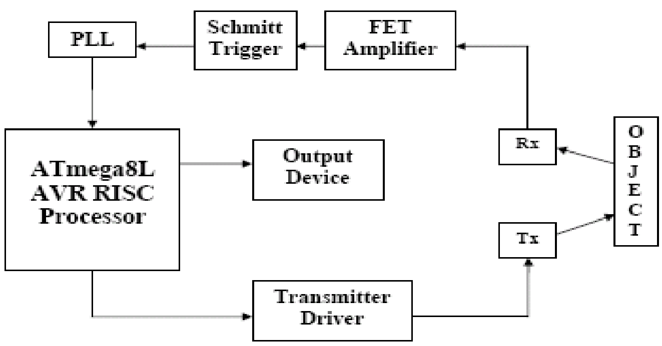

Fig. 3. Range Finder Block Diagram.

3.1. Description

The essential components in above block diagram include The AVR Microcontroller, Transmitter Driver, Ultrasonic Transmitter Object, Ultrasonic Receiver, Amplifier Circuit, Schmitt Trigger and PLL. The output device may be a simple display system or any control device. The AVR RISC Processor is the heart of the system. It generates a 40 kHz electrical signal which is fed to Transmitter Driver. Generation of 40 kHz signal burst can be done by simple code. This code is written in C language and compiled from WinAVR to generate its corresponding Extended Intel hex file i.e., .hex file. Once the signal burst is generated it is supplied to the ultrasonic transmitter. After receiving the 40 kHz electrical signal the Ultrasonic Transmitter produces ultrasound waves. These waves propagate in the air, and if any obstruction is detected, they reflect on to the receiver, as shown in the block diagram. The receiver converts the reflected ultrasounds to electrical signals of the same 40 kHz frequency. But these are potentially weak signals, which need amplification and processing, to become useful. Output of the receiver is fed to signal conditioning circuit which includes an Amplifier, Schmitt trigger and a PLL. Schmitt trigger converts the received signal into square wave form, and eliminates noise. PLL is employed to detect 40 kHz bursts in the received signal. Once they are detected, PLL swings from logic level high to low. This output is fed to microcontroller, which calculates the time of flight, and determines the distance of the obstruction. The generated output may be displayed on an output device or supplied to control mechanism.

3.2. Transmitter Circuit

Transmitter circuit is a simple circuit, consisting of signal generator, inverters, and an ultrasonic transmitter. AVR Microcontroller functions as signal generator, producing 40 kHz electrical signal burst. This signal is inverted using NOT gate and connected to first pin of the Ultrasonic Transmitter. Same signal is inverted twice and connected to second pin of transmitter, such that there is constant voltage difference between two terminals of transmitter, while having oscillatory electrical input pulses. High voltage pulses excite the piezoelectric element in the ultrasonic transducer, causing this element to oscillate at 40 kHz frequency. This will cause the transducer to produce an oscillatory acoustic output, and thus ultrasonic sound waves are generated due to piezoelectric effect.

3.3. Circuit Diagram

The Transmitter (Fig.4) operates at 5 V and the produces a transmission sound pressure level at the rate of 120 dB per 10 VRMS at a distance of 30 cm. The output of Microcontroller is collected at 15th pin OC2 which is Timer/Counter2 Output Compare Match Output. To select PB3 (OC2) as output pin, we should set the Port B Data Direction Register – DDRB to be 0x08 such that DDB3 is set to 1 to serve this function.

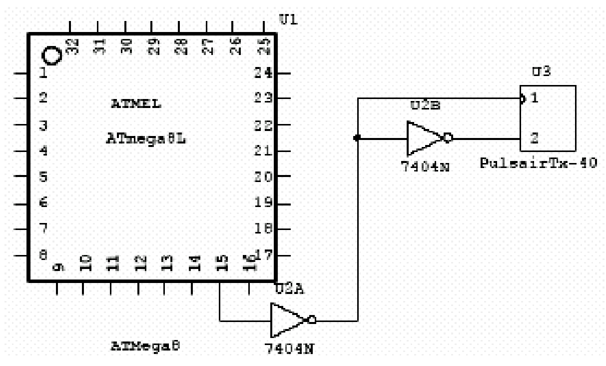

Fig. 4. Ultrasonic Transmitter Circuit Diagram.

3.4. Receiver Circuit

Receiver circuit (Fig. 5) consists of many components, essential for signal amplification, conditioning and detection of required frequency components. Receiver circuit mainly consists of

1) Ultrasonic Sensor
2) FET Amplifier
3) Schmitt Trigger
4) Phase Locked Loop.

The reflected sound waves are detected by the ultrasonic sensors. When an acoustic wave reaches the piezoelectric element; the element produces a voltage which is the sensor signal. This signal is generally of low amplitude, and less strength. This signal may also contain unwanted noise signals, which are generated from atmospheric sources. Those signals received from transducer are fed to FET Amplifier for amplification. The Amplifier is designed in such a way that it produces an overall gain of 100, in two stages. This amplifier in operated in inverting mode with negative feedback. Amplifier output is collected across 7th pin and connected to 4 -input NAND gate, which functions as a Schmitt trigger. All the pins 1, 2, 4 and 5 are connected to the amplifier output, through a variable resistance of 10kOhm. This variable resistance is used for Range and Sensitivity adjustment. Pin 3 of IC7413 is not connected, and output is collected at 6th pin of the Schmitt trigger IC.

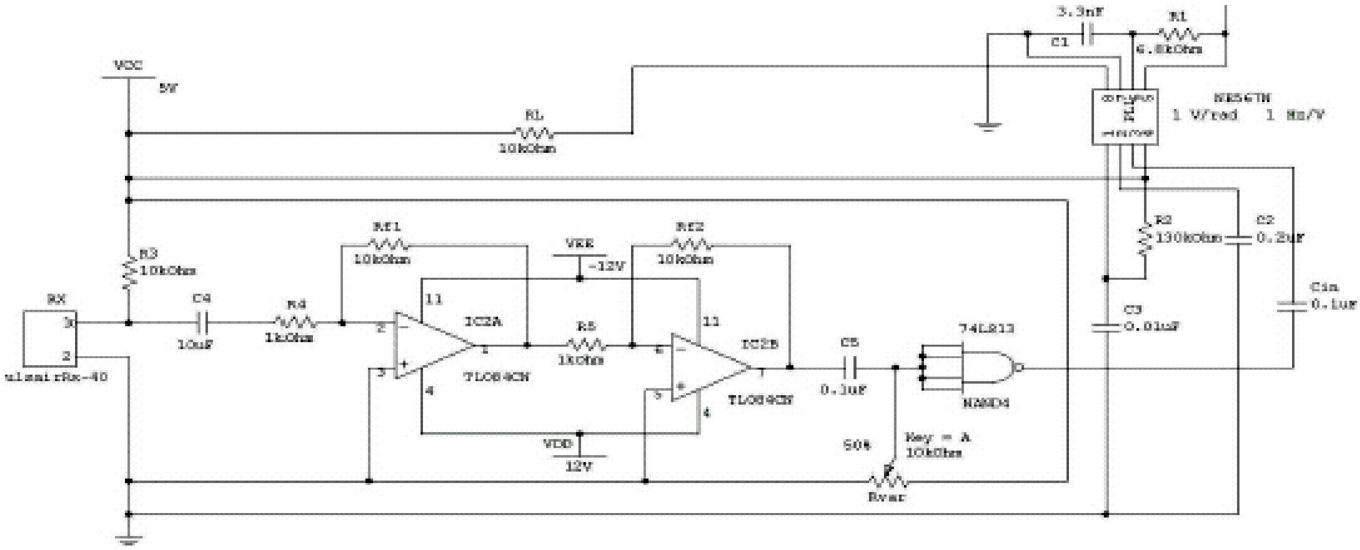

Fig. 5. Ultrasonic Receiver Circuit Diagram.

The output of Schmitt trigger is an exact replica of 40 kHz input electrical signal, in case if no noise is present. Schmitt trigger basically converts any waveform into square waveform, with noise eliminated.

However it is not possible to completely eliminate the noise signals. This Schmitt trigger output is fed to input pin of PLL.PLL circuit is designed such a way that, if it detects 40 kHz pulse in the input signal its output will become low. For any other frequencies, output is high. The PLL (LM567) acts as a tone decoder set to lock onto 40 kHz signal. The output of the tone decoder is HIGH when no echo is heard and swings LOW when an echo is detected. The output from the tone decoder is fed into a microcontroller to determine when an echo was received.

3.5. Design Formulate

Op-Amp gain formula: In the negative feedback mode of operation, operational amplifier gain is given by,

$$AV = Rf / R1$$

PLL Center frequency: In PLL tone detector, the free-running frequency of the current controlled oscillator in the absence of an input signal, is known as center frequency, which is given by,

$$fO = 1 / (1.1\ R1\ C1)$$

PLL Detection Bandwidth: The frequency range, centered about fO, within which an input signal above the threshold voltage (typically 20 mVRMS) will cause a logical zero state on the output. The detection bandwidth corresponds to the loop capture range.

$$BW\ (\text{in \% of } fO) = 1070\ V1 / (fO\ C1)$$

Velocity of Sound in air: The velocity of sound, V, in gas such as air, for frequencies above 200 Hz is given by,

$$V = \sqrt{(\gamma\rho / e)}, \text{ which is 332 m/s}$$

The velocity of sound for 1 μ sec is .34 mm.

4. Flow Chart

The flow chart is shown in Fig. 6.

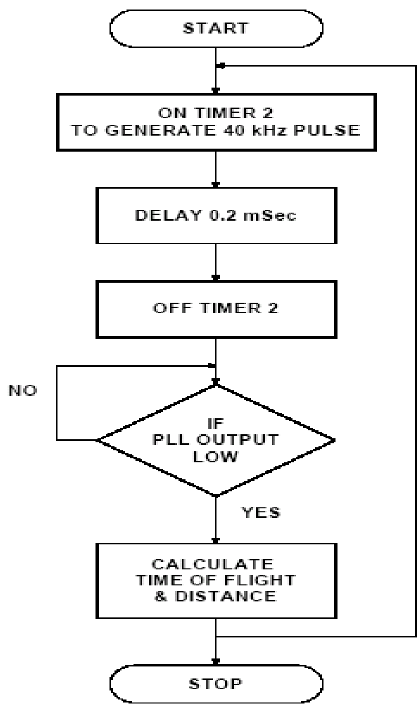

Fig. 6. Flow Chart.

5. Results

Once the hardware is designed, the Microcontroller was programmed to generate 40 kHz pulses. The receiver found responding to distances up to 10 meters and above in the initial stages. But this caused a problem of false triggering and inaccurate results. To avoid this, the range of the device has been greatly reduced by decreasing the amplifier gain and adjusting the variable resistance for range and sensitivity. Range finder encountered problem of false triggering, which was successfully eliminated by adjusting the locking frequency of Phase Locked Loop. Once this task is accomplished, software code is written for calculation of time of flight and distance measurement. The measured values are sent to PC through serial port using USART. Ultrasonic range finder found to be working efficiently, in the laboratory environment, where stray noises are less. However in open environment, it has produced less accurate results. Software algorithms can be employed to eliminate this problem in future. Ultrasonic range finder has successfully detected obstructions at a distance of 6 meters, while it produced accurate results when the obstruction is placed with in the range of 25 cm to 2 meters. With efficient algorithms, and filtering techniques, measurement range can be improved to a greater extent.

6. Conclusions

The objective of this project is to design and implement an Ultrasonic Obstruction Detection and Distance Measurement device. As described in this report a system is developed that can detect objects and calculate the distance of the tracked object. With respect to the requirements for an ultrasonic range finder the following can be concluded.

- The system is able to detect objects within the sensing range.
- The system can calculate the distance of the obstruction with sufficient accuracy.
- This device has the capability to interact with other peripheral if used as a secondary device.
- This can also communicate with PC through its serial port.
- This offers a low cost and efficient solution for non contact type distance measurements.

The Range Finder has numerous applications. It can be used for automatic guided vehicles, positioning of robots as well as measuring generic distances, liquid levels in tanks, and the depth of snow banks. The device can serve as a motion detector in production lines. The ultrasonic detection range relates with size, figure, material and position of the object. The bigger the reflector is, the better the reflectance is, and the stronger the reflection signal is. The ultrasonic distance measurement is an untouchable detection mode. Compared with else detection modes, it does not get much influenced by ray, temperature and colour etc, and it has the great capability to adapt to various circumstances and ambient conditions. A restricted target angle (it requires a near-perpendicular surface) and large beam, which can create poor resolution, seem to be the Range Finder’s only limitations. Also there is a blind area and distance limitation in ultrasonic distance measurement. Despite these drawbacks, we find the device’s main features to be extremely useful.

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