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Design, Implementation and Testing of Ultrasonic High Precision Contactless Distance Measurement System Using Microcontroller

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Abstract

This paper reports on design, implementation and testing of a ultrasonic high precision and low cost non-contact distance measurement system using microcontroller. Use of PIC16f877a microcontroller lowers the system cost and the use of ultrasonic transducer module HC-SR04 makes the system non-contact. Recommended range for the ultrasonic sensor is 2 cm to 4 m at accuracy of 3 mm. The ultrasonic module transmits ultrasonic sound waves at non-audible frequency of 40 kHz, then picks up its echo that comes from an object to the source. Time period of the output wave form is proportional to the distance between the source and the object whose distance is being measured. The microcontroller receives the output signal, performs the necessary information processing inside it and finally displays the corresponding measured distance on the LCD screen. The sample test results reveal that the system can calculate distances accurately from any object to the source of the ultrasonic wave generator between which the distances are being measured. Percentage of error is then calculated between the measured and actual distances. It is found from the performance test that the designed system works very well.

Keywords: *Microcontroller, Ultrasonic Wave, Contactless Distance Measurement.*

I. Introduction

Various industrial processes and systems require information about placement of various kinds of objects. Non-contact distance measurement systems are used for the determination of the position of the objects in many cases. There have been lots of different ways for noncontact distance measurement like laser/infra-red optical sensor, ultrasonic technique, radar devices etc. (B. Duval, 2004), and complete measuring systems may cost some hundred dollars (S. Y. Yurish, 2009). Low cost short distance measuring systems with a price up to some tens dollars can be built based on the infrared light sources (S. Boedecker *et al.*, 2010). Such systems are using infrared optical sensors with the output signal proportional to the distance between sensing element and object. For example, a low-cost short distance measuring system, described in (P. Arce *et al.*, 2004) uses frequency of the output optical sensor (infrared light source and infrared light-to-frequency converter), has 35-60 mm measuring range, and from 0.25 s to 1 s measurement time. An optical sensor with a laser source (of 532 nm) for real-time measurement of lignin content in moving paper sheets is described in (M. K. Ramasubramanian *et al.*, 2005). Different structures of a contactless position sensor have been realized by using a magnet as the target and an inductance as the sensing element by local saturation of its core by a magnet (B. Legrand *et al.*, 2003). A low-cost, non-contacting, nondestructive technique is presented for measuring the thickness of thin liquid or solid films and coatings in real time by utilizing the resonance properties of micro-strip structures in (L. F. Root *et al.*, 1992). Besides, microwave based moisture sensor has been developed for the food industry (T. Hinz *et al.*, 1996).

Among the various techniques of noncontact measurement, ultrasonic technique is the best (U. Grimaldi et al., 1995 and P. Purnell *et al.*, 2004) when we need stable and accurate distance of obstacle, no matter what color it is. It is also usable outside in the sun. As the human ear's audible range is 20 Hz to 20 kHz, it is insensitive to ultrasonic waves, and hence

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the ultrasound waves can be used for applications in industries or vehicles without hindering human/other activity.

With the development of technology, microcontroller is becoming more suitable chip to control various electro-mechanical devices (M. H. Bhuyan *et al.*, Jan 2010, M. H. Bhuyan *et al.*, Jun 2010 and M. K. Russel *et al.*, Dec 2012). Microcontrollers are used in automatically controlled products and devices. By reducing the size and cost, microcontrollers make it economical to digitally control even more devices and processes (M. A. Mazidi *et al.*, 2007).

This work reports a microcontroller based high precision distance measurement system using ultrasound sensor. The software is developed in such a way to get the optimum result in terms of accuracy and time consumed. This device consumes low power, is portable and cheap. From the experimental results, it is seen that the designed system works very well with high level of accuracy.

II. Working Principles of the System

The designed system mainly consists of a 40-pin microcontroller unit (PIC16f877a), a 4- pin sonar sensor (HC-SR04), an LCD display, a 20 MHz crystal oscillator to provide clock frequency, two 22 pf capacitors etc.

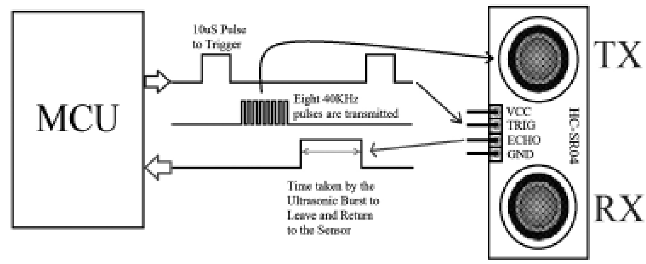

Figure1: Communication between microntroller unit and ultrasound sensor. In between HC-SR04's timing diagram is shown

The designed system works on a similar principle of radar which evaluates the target by interpreting the echo from sound or radio waves as shown in Fig. 1.

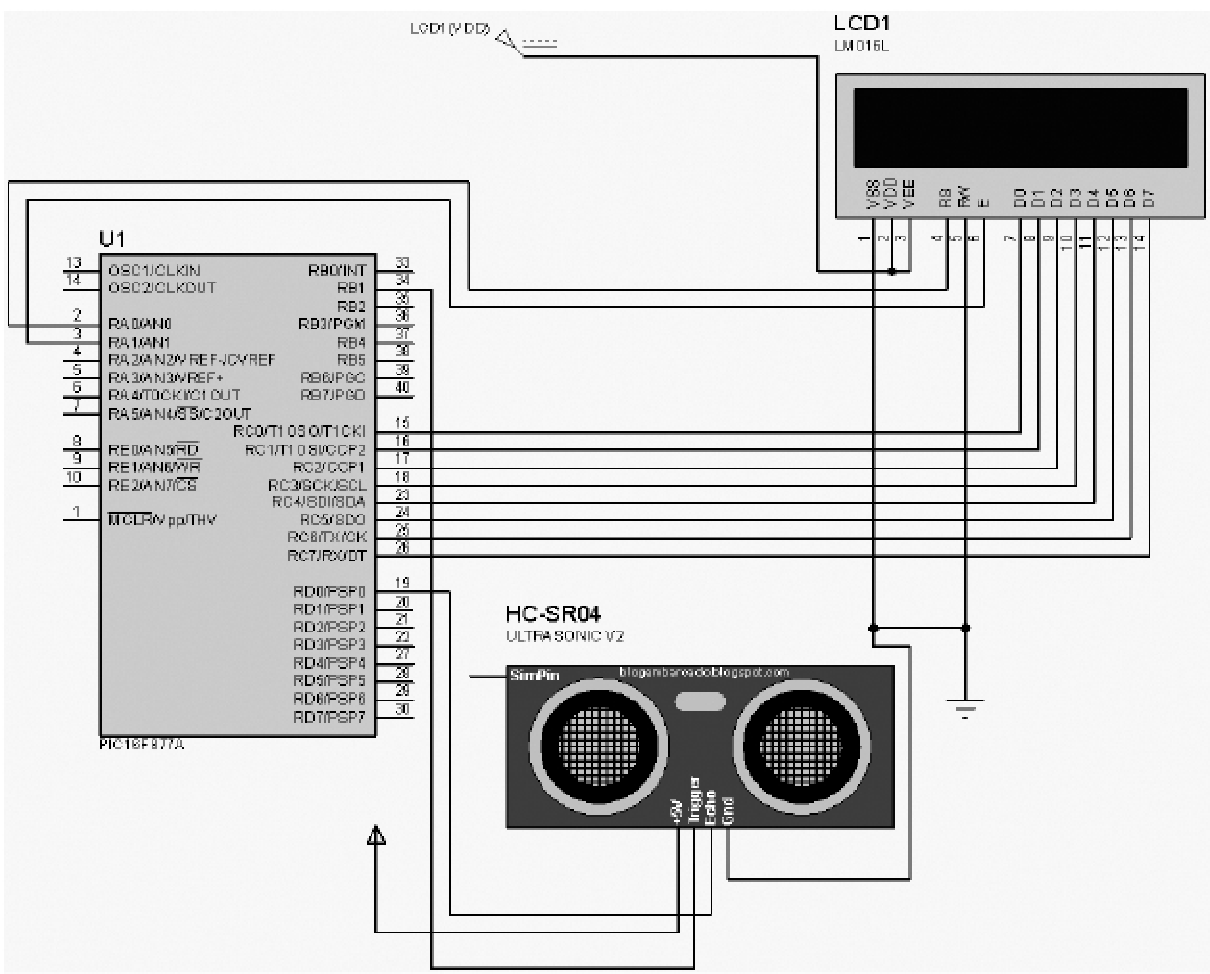

Figure 2: Schematic diagram of microcontroller based distance measurement system using ultrasonic sound

The microcontroller sends 10 μs pulse to the trig pin of the ultrasonic transducer. It reads when the echo arrives; it finds the time taken in microseconds for to and from travel of sound waves using TIMER1. Using velocity of sound 340 m/s, it does the calculations and shows on the LCD module and display the distance in cm. From the timing diagram as shown in Fig. 1, we can see that the 40 kHz pulse train is transmitted just after the 10 μs triggering pulse and the echo output is obtained after some more time. The next triggering pulse can be given only after the echo is faded away, and this time period is called cycle period. The cycle period for HC-SR04 must not be below 400 μs. The complete schematic diagram of the system is shown in Fig. 2.

III. Distance Calculation

The formula used for distance calculation is as follows:

$$D = (vt)/2 \quad (1)$$

where D is the distance between ultrasonic sensor and target, v is the speed of sound in the air (34000 cm/s) and t is the time obtained from the microcontroller by the relationships shown in equations (2) and (3).

$$t = (TMR1H{:}TMR1L)\times 10^{-6} \quad (2)$$

$$TMR1H{:}TMR1L = (TMR1H<<8) + TMR1L \quad (3)$$

where *TMR1H* and *TMR1L* are the timer values obtained from the microcontroller. The calculated time is in second. So, the measured distance will be in centimeter.

IV. Software Development

The flowchart of the assembly language program written for the microcontroller for the distance measurement system using ultrasound is given in Fig. 3. The program is developed in MPLAB v8.60 using C language in an IBM PC. A programmer or burner called Pickit-2 is used to transfer the hex code of the assembly language program from the computer to the microcontroller. Finally, the result is shown on an LCD screen.

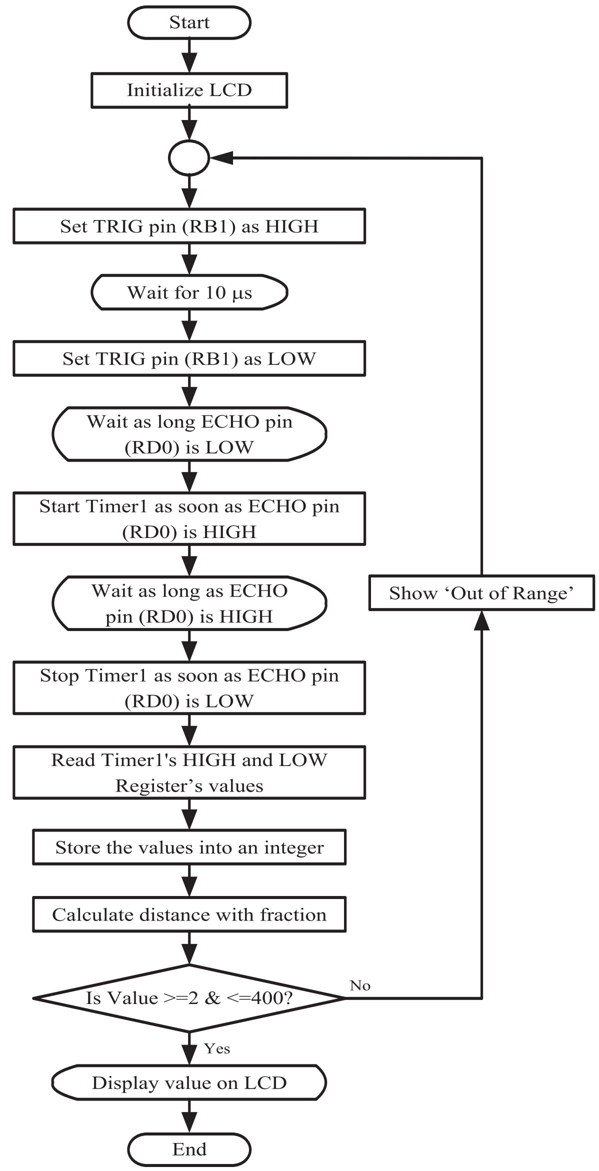

Figure 3: Flowchart of the microcontroller program

V. Results and Discussions

The system is implemented using required parts and wires in bread board as shown in Fig. 4. To test the system, a steel scale is used to measure the actual distance in centimeter. Room wall is used as the object from where the system will measure the distance. The designed system is moved from the wall and then actual distance is measured by the steel scale in centimeter. Distance measured by the developed system is found from the LCD screen in centimeter.

The results, i.e. distance measured by the scale (D_m) and by the developed system (D_s), are recorded in Table I. It shows that the system can measure any distance in the range of 2 cm to 4 m almost accurately.

To evaluate the performance of the designed system, we took 22 sample distances in the desired range of distance. For each sample we ran the system and measure the actual distance using scale and take the distance measured by the system from the display of the LCD screen. From the data of Table 1, we computed the percentage of error (ε) for each sample and also computed the average percentage of error (εa) as shown in Table I. The percentage of error is computed by using the equation (4).

$$\varepsilon = \frac{D_m - D_s}{D_m} \times 100\% \tag{4}$$

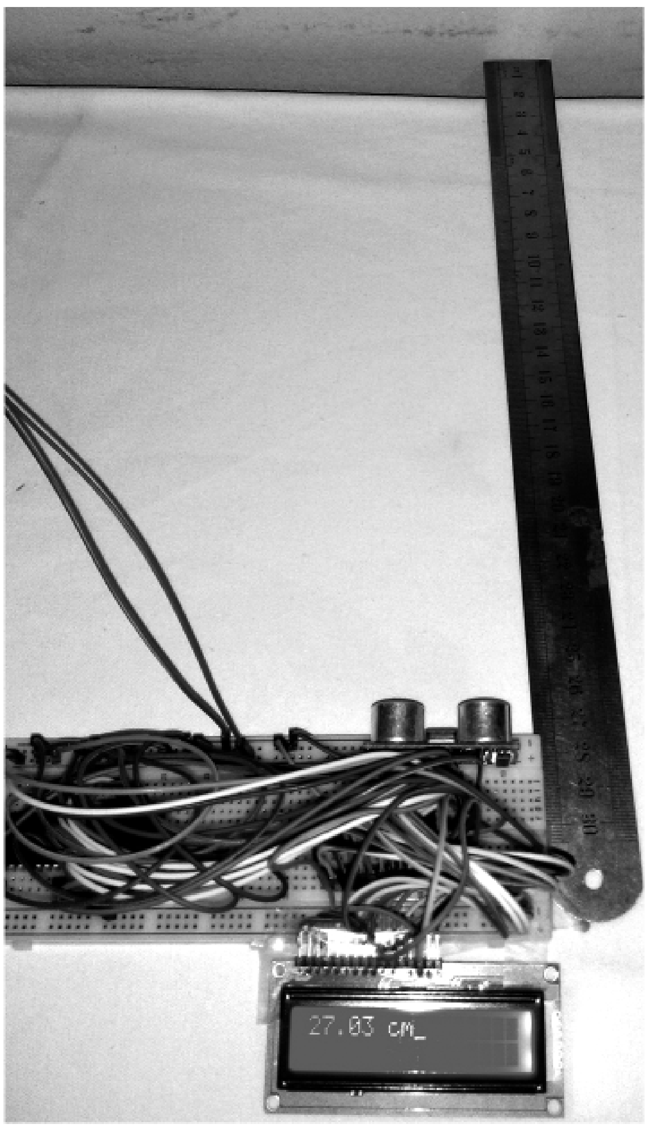

Figure 4: Photograph of the microcontroller based ultrasonic distance measurement system

Table 1: Measured and Test Data

No of obs.	*Distance Measured by the Scale* D_m *(cm)*	*Distance Measured by the System* D_s *(cm)*	*Percentage of Error* *ε(%)*	*Average Percentage of Error* ε_a *(%)*
1	2.00	2.02	0.500	0.074
2	4.00	4.01	0.250	
3	6.00	6.01	0.167	
4	8.00	8.01	0.125	
5	13.00	13.02	0.154	
6	18.00	18.01	0.056	
7	25.00	25.02	0.080	
8	30.00	30.02	0.067	
9	35.00	35.01	0.029	
10	40.00	40.01	0.025	
11	50.00	50.01	0.020	
12	70.00	70.02	0.029	
13	90.00	90.02	0.022	
14	120.00	120.03	0.025	
15	150.00	150.02	0.013	
16	180.00	180.03	0.017	
17	210.00	210.02	0.010	
18	250.00	250.01	0.004	
19	280.00	280.03	0.011	
20	310.00	310.02	0.006	
21	340.00	340.02	0.006	
22	390.00	390.03	0.008	

Table I shows a very good agreement between the measured distance by the scale and by the developed system. In all of the cases of distance measurement, the percentage of error is less than 1 and hence its average, too. Results of the other distances are not reported in this paper for brevity.

We also plotted a graph of Ds vs. Dm as shown in Fig. 5. From the plot, we obtained a regression equation where regression co-efficient are obtained as 0.0135 and 1 respectively using EXCEL. Thus the linear regression line obtained from the data is shown in equation (5).

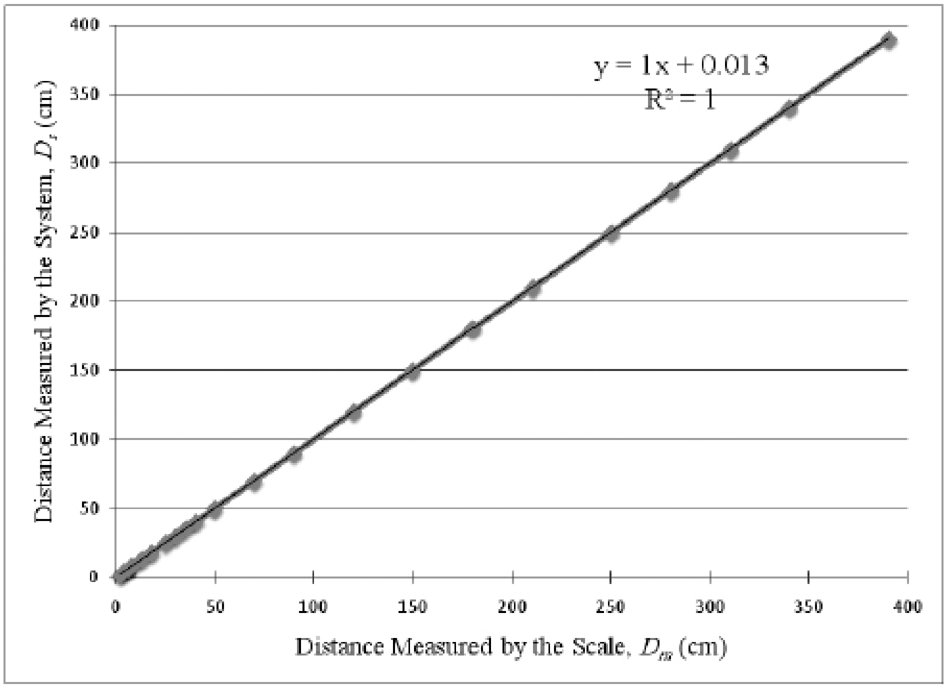

Figure 4: Plot of the actual distance vs. measured distance by the system

$$D_s = D_m + 0.0135 \quad (5)$$

The value of coefficient of determination (R^2) is 1 as extracted from EXCEL, and the slope of the regression line (i.e. regression co-efficient, a_0) is also 1, which signifies that all the data of measured and sample test distances align with each other, and hence the system is performing very well.

VI. Conclusions

In this work, a microcontroller based high precision non-contact distance measurement system using ultrasound sensor has been designed and tested. The experimental data reveal that the sensor measures almost accurate distance. However, effects of other parameters like temperature, density of the medium etc. was not considered during the measurement using this system. The system can be applied in many different fields like vehicles to get protection from accident, water level measurement, robotics and automation etc. As an extension of this work, in future, this project can be used in the several fields like, guidance device for visually impaired persons, obstacle avoidance robot, parking assistance system, accident avoidance car, liquid level measurement, finding break downs in wires or threads etc.

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