

PAPER • OPEN ACCESS

Highly Accurate Water Level Measurement System Using a Microcontroller and an Ultrasonic Sensor

To cite this article: Saleem Latteef Mohammed *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **518** 042025

Recent citations

- [Direct Non-Invasive Measuring Techniques of Nanometric Liquid Level Variations Using Extrinsic Fiber Fabry-Perot Interferometers](#)
Patrick Chawah *et al*
- [Liquid Level Sensing Using Commodity WiFi in a Smart Home Environment](#)
Yili Ren *et al*

View the [article online](#) for updates and enhancements.



The Electrochemical Society
Advancing solid state & electrochemical science & technology

240th ECS Meeting ORLANDO, FL

Orange County Convention Center Oct 10-14, 2021

Abstract submission due: April 9

SUBMIT NOW

Highly Accurate Water Level Measurement System Using a Microcontroller and an Ultrasonic Sensor

Saleem Latteef Mohammed¹, Ali Al-Naji^{1,2}, Mashael M. Farjo¹ and Javaan Chahl^{2,3}

¹Department of Medical Instrumentation Techniques Engineering, Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq

²School of Engineering, University of South Australia, Mawson Lakes, SA 5095, Australia

³Joint and Operations Analysis Division, Defence Science and Technology Group, Melbourne, VIC 3207, Australia

E-mail: ali_abdulelah_noori.al-naji@mymail.unisa.edu.au (Ali Al-Naji)

Abstract. In many conditions, the conventional liquid data monitoring based on an ultrasonic sensor provides the unreliable readings due to the dynamically changed water level. In addition, in some conditions, it needs not only measuring water level but also needs to measure the volume and control water surplus or deficiency. To solve these issues, this paper proposes an accurate non-contact water measurement system based on a microcontroller and an ultrasonic sensor to measure the level and volume of liquids in small tanks without any contact. The proposed system also provides automatically controlling the water level with an alarm system to provide early warning of water surplus or deficiency. Microcontroller PIC16F877A is used to drive the sensor circuit and measure the time change of the reflected echoes from the water surface received by the ultrasonic (PING) sensor that correspond to the changes in the water level. The experimental results illustrate the effectiveness of the proposed system to measure the level and volume of water over 30 cm range with small error rates (SSE= 0.033 cm, RMSE= 0.034 cm and MAE= 0.029 cm for level measurement and SSE= 0.025 liter, RMSE= 0.026 liter and MAE= 0.021 liter for volume measurement) and excellent correlation coefficients (SCC=0.9997 and KCC=0.9951), thus provide accurate results for continuous measurement of the water level and volume in industrial applications.

Keywords— Non-contact water measurement system, PIC16F877A Microcontroller, ultrasonic (PING) sensor.

1. Introduction

Many industrial applications require the installation of multiple data-acquisition systems to measure liquid level and volume in tanks and containers. The collection of data from liquid tanks plays an essential role in many industrial applications, such as oil tanks, fuel containers, public water supplies, reverse osmosis (RO) systems and fish aquariums [1-4].

A range of technologies was proposed to collect data from liquid tanks using different types of sensors, such as sensors based on optical fibre [5-11], Doppler effect [12-18], pressure [19, 20], capacitance changes [21-26], surface plasmon resonance [27] and wedge waves [28]. However, each technology has its strengths and weaknesses under different conditions, leading to a number of challenges for the research community to consider, including implementation cost, ambient environmental conditions, installation, detection distance and long-term maintenance [2, 10, 26]. The principles, strengths and weaknesses of these technologies have been discussed in many studies [2, 8, 9, 24]. The technological tools to create an efficient liquid data acquisition system already largely



exist; thus, the focus of this work is on developing a non-contact water measurement system based on a microcontroller and ultrasonic sensor to extend the applicability of such systems with regard to the stability, measurement resolution and cost effectiveness. Among most promising technologies for liquid data monitoring, an ultrasound Doppler detection was developed to extract water level and volume without any physical contact.

Ultrasonic sensors seem promising in this regard for liquid data monitoring, since they have high accuracy, low cost and can work with pressures of up to 2 megapascal (MPa), temperatures of up to 100 °C, and ranges up to 30 m [13, 29].

The aim of this work is to propose an efficient, low cost and precise device for simultaneously monitoring the level and volume of liquids inside the tanks based on detection of the reflected echoes from liquid surfaces using an ultrasonic (PING) sensor controlled by PIC16F877A microcontroller. The proposed system has good reliability, high resolution, low cost, is easy to implement, easy to program, portable and has low power consumption. In addition, the proposed system is suitable for displaying a level change in real time with an alarm system in case of a full or empty tank event.

The remainder of this paper is organized as follows: Section 2 describes the system design of the proposed measurement system. Section 3 presents the software description of the proposed measurement system with suitable flowchart. Section 4 depicts the experimental results derived by installing the proposed measurement system in a small rectangular tank. Finally, section 5 provides a conclusion and future research directions.

2. System Design

In this paper, a PIC16F877A microcontroller was used to drive and collect the data from water tanks using an ultrasonic PING sensor without any direct contact with the water. The circuit diagram of the experimental measurement system is shown in Figure 1.

2.1. Ultrasonic PING Sensor

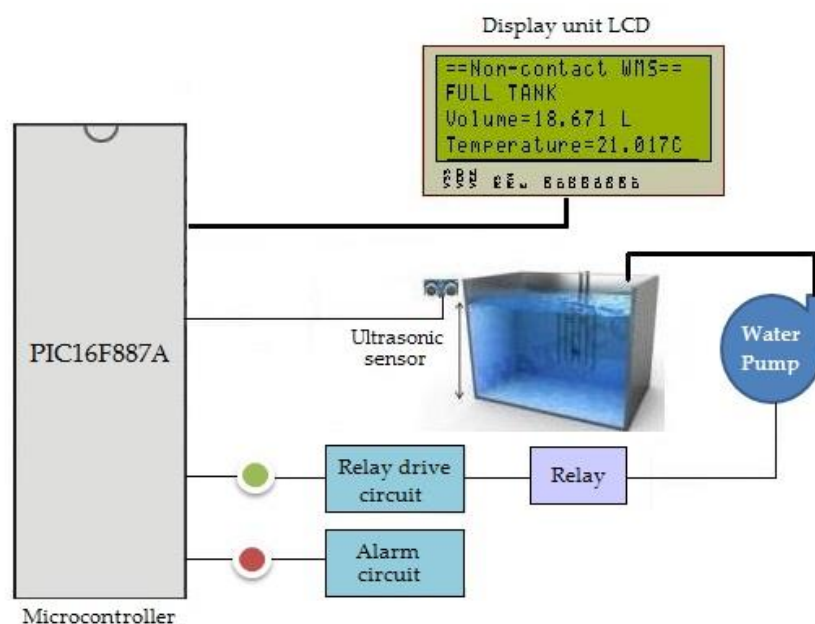


Figure 1. Circuit diagram of the proposed measurement system.

The ultrasonic PING sensor is one of the most cost-effective range sensors made by Parallax Inc. [30] that is used in many engineering applications [31-34]. This sensor propagates electrical energy as acoustic waves with high frequencies and detects the reflection, or echo signal from the obstacle, thereby, measuring range based on the speed of sound. The physical shape of ultrasonic PING sensor is shown in Figure 2.

The PING sensor can detect the liquid surface profile by transmitting echo pulses and measuring the return time of the received echoes. The PING sensor can provide accurate and remote distance measurements from 2 cm to 3 m [30].

If the speed of sound in a medium is known, then, the distance (S) between the transducer and the



Figure 2. Physical shape of ultrasonic PING sensor.

liquid surface can be calculated as follows:

$$S = \frac{1}{2} v \cdot \Delta t \quad (1)$$

where v is the acoustic propagation velocity in m/s in a medium and Δt is the time between the transmitted pulse and the received echo pulse.

To measure liquid height (h) in a tank with a height of 30 cm (h_{ref}), subtract S from the height of the tank as follows:

$$h = h_{ref} - S \quad (2)$$

For the rectangular shaped tank with known dimensions, the volume of water (vol) inside the tank in liter can be measured by:

$$vol_{in\ Liter} = (l \times w \times h) cm^3 \times 0.001 \quad (3)$$

where l is the length of the tank (43.25 cm), w is the width of the tank (17.27 cm), and h is the liquid height (level) in cm. Eq. (3) depends on the shape of the tank and it changes according to the shape of the tank in use. However, the acoustic propagation velocity, v , is affected by the temperature of the medium through which the sound propagates [35]. Thus, variations in ambient temperature will lead to incorrect liquid level readings. The acoustic propagation velocity in air can be approximated in terms of temperature as [13]:

$$v = 331.3 + kT \quad (4)$$

where k is the rate at which the speed variations regarding to temperature, which is approximately 0.607 m/s for every change of 1°C in temperature and T is the ambient temperature in °C. At room temperature of 15 °C, the ultrasonic wave propagation velocity in the air is 340 m/s. The proposed system was also supported by a contact thermometer sensor to measure the temperature of the liquid in the tank.

2.2. PIC16F877A Microcontroller

PIC16F877A microcontroller is an embedded digital control device, made by Microchip Technology, which integrates a number of microprocessor functional subsystems on to single chip. PIC16F877A microcontroller has five I/O ports (33 pins), 8K×14 flash program memory, 256×8 EEPROM data memory, three timers and an 8 bit timer/counter, 10-bit ADC, and operates at 20 MHz clock frequency. The PIC16F877A microcontroller is suitable for many digital applications [3, 36, 37] due to its wide availability, low cost, powerful interrupt structure, low energy consumption, and ease to programming and re-programming with flash memory [37].

The I/O port pins of the PIC16F877A were connected to the PING sensor, DC motor circuit, alarm circuit and LCD display unit (20×4) as shown in Fig. 1. The PING sensor pins were connected to the I/O port, where the PIC triggers the PING sensor with a pulse and then measures the amount of time elapsing until the arrival of the reflected signal perceived by the sensor. The DC motor circuit was connected to an output pin of the PIC via a relay circuit which is connected to a transistor. The collector of this transistor is connected to the relay circuit and the emitter is grounded. The alarm circuit was connected to an output pin of the PIC with a light emitting diode (LED) and a sound buzzer. The LCD display unit was connected to the output port of the PIC to display the level, volume and temperature of the water.

3. Software Description

The PIC programming flowchart of the proposed measurement system is depicted in Figure 3. The proposed measurement system was programmed using PicBASIC language on Proton plus (Proton Integrated Development Environment IDE) software as shown in Figure 4. Proton IDE is a high-level programming language that is used to easily program many microcontroller families and provides more efficient, intelligent control and syntax error detection than other programming languages. On completion, the machine code file generated from Proton IDE was loaded into the microcontroller memory using the Topwin6 programmer. After finishing programming, the PIC becomes ready to connect to the hardware circuit.

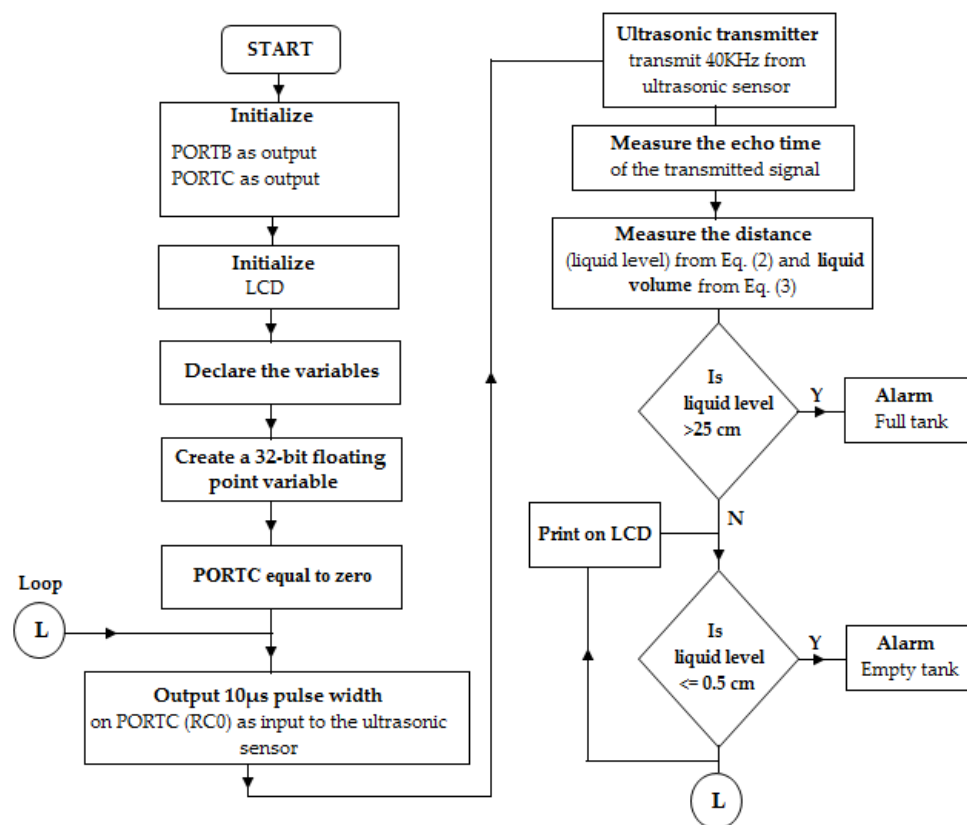


Figure 3. Flowchart of the proposed measurement system.

4. Experimentation

4.1. Experimental Setup

A rectangular water tank with dimensions of 43.25cm×17.27cm×30 cm was used to test the proposed measurement system. The tank was fitted with an ultrasonic PING sensor near the top left of the tank and a contact temperature thermometer. The tank was filled with water levels ranging from

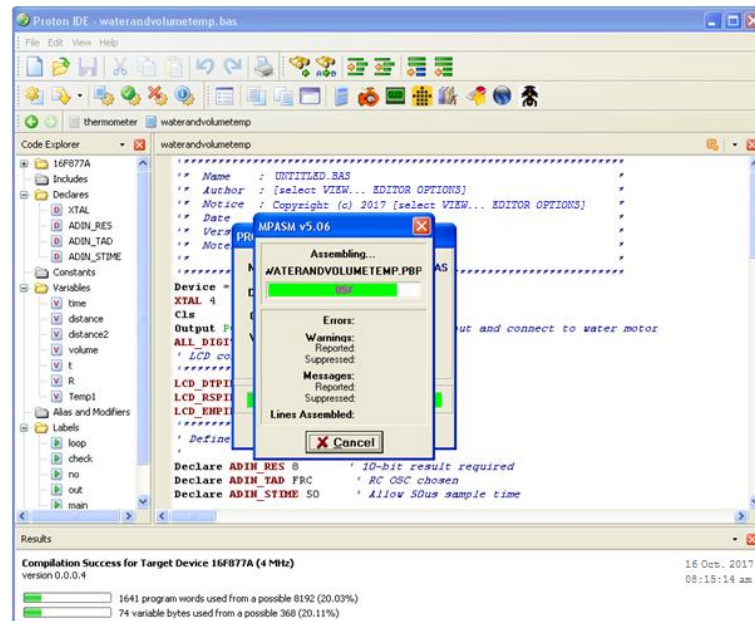


Figure 4. Proton IDE coding of main program.

approximately 1 to 18 liters in the experiment using DC water pump. The actual level readings were obtained using a scale ruler attached vertically to the tank. Figure 5 shows the experimental setup of the experimental water measurement system.

4.2. Readings and Statistical Results

The readings and statistical results of the proposed measurement system are discussed in this section. The correlation, error rate and limits of agreement were calculated using a correlation plot, sum of squared error (SSE), root mean square error (RMSE), mean absolute error (MAE), Spearman correlation coefficient (SCC), Kendall correlation coefficient (KCC) and Bland-Altman plot [38, 39]. At room temperature of 15 °C, the readings of water level, water volume and water temperature could

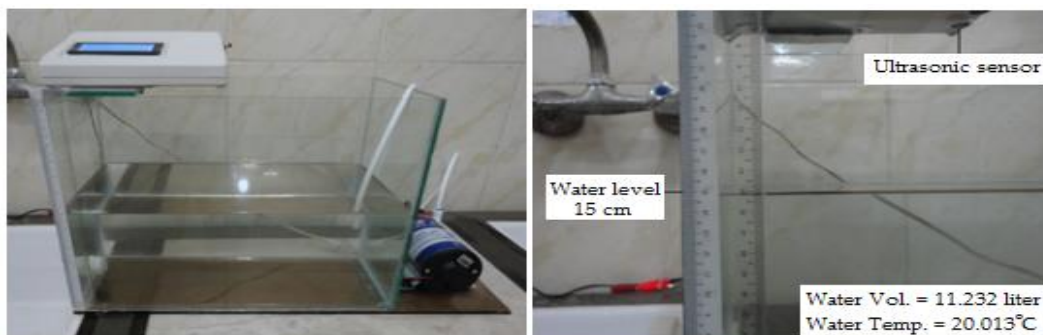


Figure 5. Experimental setup of the proposed measurement system.

be seen in LCD display unit as shown in Figure 6. A message “No signal” would appear at empty tank and a message “Full tank” would appear at 25 cm water level, the DC water motor will stop pumping water at this level.

To examine the resolution of the proposed system, 50 readings of the actual water level in cm were compared with the measured water level (1-25) cm at room temperature using MATLAB. The statistical results between the actual level readings and the measured level readings at the room temperature are presented in Figure 7.

Based on the statistical results of the correlation plot shown in Figure 7 (a), it was found that the maximum error between the actual level readings and the measured level readings was approximately 0.07 cm and the minimum error was approximately 0.01 cm with error rates of 0.033 cm, 0.034 cm



Figure 6. The LCD display unit shows the readings of level, volume and temperature of the water inside the tank.

and 0.029 cm for the SSE, RMSE and MAE, respectively. Based on the Bland-Altman plot shown in Figure 7 (b), the mean bias, lower and upper limit of agreement between the actual and measured readings were 0.012, -0.052 and +0.076 cm with correlation coefficients of 0.9997 and 0.9951 for the SCC and KCC, respectively.

The statistical results between the actual volume readings and the measured volume readings at room temperature are presented in Figure 8.

Based on the statistical results of the correlation plot shown in Figure 8 (a), the maximum error between the actual and measured volume readings was approximately 0.065 liters and the minimum error was approximately 0.01 liter with error rates of 0.025 liter, 0.026 liters and 0.021 liters for the SSE, RMSE and MAE, respectively. Based on the Bland-Altman plot shown in Figure 8 (b), the mean bias, lower and upper limit of agreement between the actual and measured readings were 0.0091, -0.039 and +0.057 liters with correlation coefficients of 0.9997, 0.995 for the SCC and KCC, respectively.

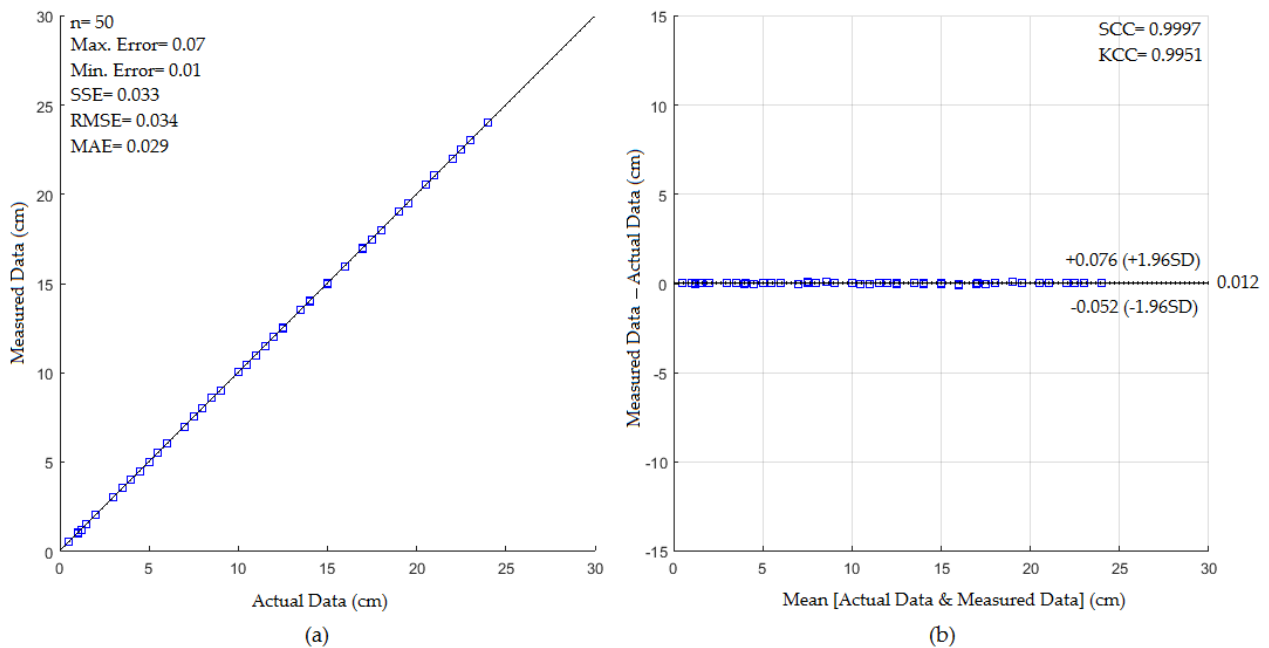


Figure 7. The statistical results of the water level measurements using (a) Correlation plot, (b) Bland-Altman plot.

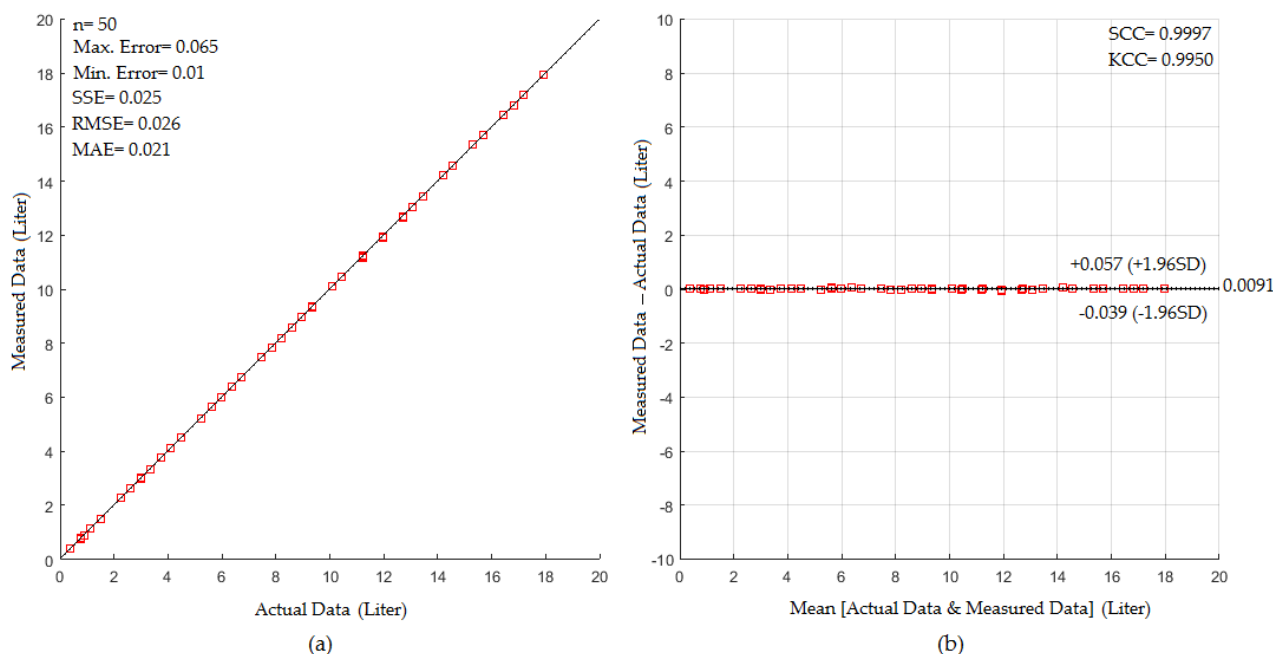


Figure 8. The statistical results of the water volume measurements using (a) Correlation plot, (b) Bland-Altman plot.

4.3. Limitations

Although the proposed measurement system was accurate, cost effective, easy to use, easy to program, portable and low power consumption, it has some limitations. The first limitation is the influence of ambient environmental temperature. The influence of temperature on the measurements was shown using Eq. (4) for temperature changes from 0 and 50 °C as shown in Figure 9.

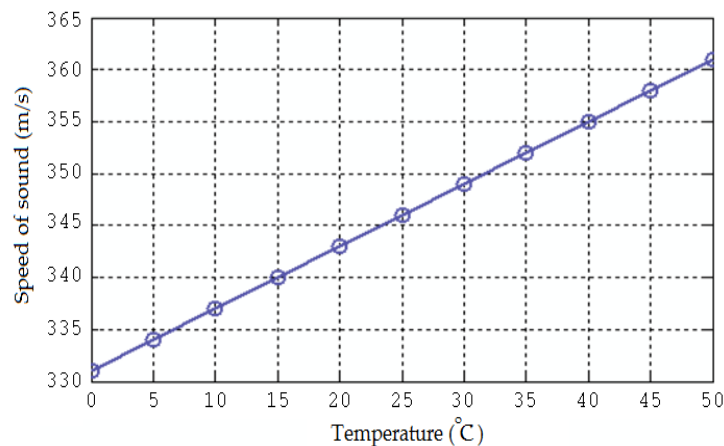


Figure 9. The influence of temperature changes on the speed of sound.

The second limitation is the detection range. At distances of greater than 3 m, the electrical echo signals generated by the receiver ultrasonic sensor are prone to degradation because of noise caused by increased free space loss which affects the accuracy of the measurement.

5. Conclusion

The ultrasonic PING sensor driven by the PIC16F877A microcontroller has been used to accurately measure the water level and volume in liquid tanks with an automatic control circuit to fill the tank and provide early warning of water surplus or deficiency. Although several types of sensors (electronic or/and optical sensors) had been already proposed previously with higher resolution for the level monitoring task, the system we propose based on the ultrasonic PING sensor present quite a few advantages, such as simplicity, cost effectiveness, portability and energy efficiency. The maximum error was approximately 0.07 cm for the level measurement and 0.065 liters for the volume measurement with high correlation coefficients (SCC=0.9997 and KCC=0.9951), thereby, the proposed system may have a significant potential for use in many industrial applications. However, further studies on robustness, the environmental temperature conditions, and detection range are needed to consider and achieve better outcomes.

References

- [1] Yamada K, Honda H, Horiuchi S and Kinai T 2009 Liquid-level sensing by trapped-energy-mode thickness vibration *Japanese Journal of Applied Physics* **48** 07GB08.
- [2] Loizou K and Koutroulis E 2016 Water level sensing: State of the art review and performance evaluation of a low-cost measurement system *Measurement* **89** 04-214.
- [3] Kalidoss R, Praniha R, Raveena P and Revathy C 2017 Petrol level indicator with automated audio alert system in *Wireless Communications Signal Processing and Networking (WiSPNET), 2017 International Conference*, pp. 537-539.
- [4] James S W, Khaliq S and Tatam R P A 2002 long period grating liquid level sensor in *Optical Fiber Sensors Conference Technical Digest* Ofs 2002, 15th, 2002, pp. 127-130.
- [5] Wang W and Li F 2014 Large-range liquid level sensor based on an optical fibre extrinsic Fabry–Perot interferometer *Optics and lasers in Engineering* **52** 201-205.

- [6] Vázquez C, Gonzalo A B, Vargas S and Montalvo J 2004 Multi-sensor system using plastic optical fibers for intrinsically safe level measurements *Sensors and Actuators A: Physical* **116** 22-32, 2004.
- [7] Sohn K R and Shim J H 2009 Liquid-level monitoring sensor systems using fiber Bragg grating embedded in cantilever *Sensors and Actuators A: Physical* **152** 248-251.
- [8] Pérez-Ocón F, Rubiño M, Abril J, Casanova P and Martínez J 2006 Fiber-optic liquid-level continuous gauge *Sensors and Actuators A: Physical* **125** 124-132.
- [9] Nath P, Datta P and Sarma K 2008 All fiber-optic sensor for liquid level measurement *Microwave and optical technology letters* **50** 1982-1984.
- [10] Antunes P, Dias J, Paixão T, Mesquita E, Varum H and André P 2015 Liquid level gauge based in plastic optical fiber *Measurement* **66** 238-243.
- [11] Antonio-Lopez J E, Sanchez-Mondragon J, LiKamWa P and May-Arrioja D A 2011 Fiber-optic sensor for liquid level measurement *Optics letters* **36** 3425-3427.
- [12] Zhang B, Wei Y J, Liu Y J, Zhang Y J, Yao Z, Zhao L H and Xiong J J 2017 A liquid level measurement technique outside a sealed metal container based on ultrasonic impedance and echo energy *Sensors* **17** 185.
- [13] Terzic J, Nagarajah C and Alamgir M 2010 Fluid level measurement in dynamic environments using a single ultrasonic sensor and Support Vector Machine (SVM) *Sensors and Actuators A: Physical* **161** 278-287.
- [14] Sakharov V, Kuznetsov S, Zaitsev B, Kuznetsova I and Joshi S 2003 Liquid level sensor using ultrasonic Lamb waves *Ultrasonics* **41** 319-322.
- [15] Ricchiuti A L, Barrera D, Urrutia A, Goicoechea J, Arregui F J and Sales S 2016 Continuous liquid-level sensor based on a long-period grating and microwave photonics filtering techniques in *IEEE Sensors Journal* 1652-1658.
- [16] Liu J, Chen X and Zhang Z 2006 A novel algorithm in the FMCW microwave liquid level measuring system *Measurement Science and Technology* **17** 135-138.
- [17] Li P, Cai Y, Shen X, Nabuzaale S, Yin J and Li J 2015 An accurate detection for dynamic liquid level based on MIMO ultrasonic transducer array *IEEE Transactions on Instrumentation and Measurement* **64** 582-595.
- [18] Khalid K, Grozescu I V, Tiong L K, Sim L T and Mohd R 2003 Water detection in fuel tanks using the microwave reflection technique *Measurement Science and Technology* **14** 1905.
- [19] Niu Z, Zhao Y, Tian B and Guo F 2012 The novel measurement method of liquid level and density in airtight container *Review of Scientific Instruments* **83** 108 125.
- [20] Nikolov G and Nikolova B 2008 Virtual techniques for liquid level monitoring using differential pressure sensors *Recent* **9** 49-54.
- [21] Shim J 2013 Liquid level measurement system using capacitive sensor and optical sensor *Journal of the Korean Society of Marine Engineering* **37** 778-783.
- [22] Reverter F, Li X and Meijer G C 2007 Liquid-level measurement system based on a remote grounded capacitive sensor *Sensors and Actuators A: Physical* **138** 1-8.
- [23] Lu G R, Hu H and Chen S Y 2010 A simple method for detecting oil–water interface level and oil level *IEEJ Transactions on Electrical and Electronic Engineering* **5** 498-500.
- [24] Kumar B, Rajita G and Mandal N 2014 A review on capacitive-type sensor for measurement of height of liquid level *Measurement and Control* **47** 219-224.
- [25] Jin B, Zhang Z and Zhang H 2015 Structure design and performance analysis of a coaxial cylindrical capacitive sensor for liquid-level measurement *Sensors and Actuators A: Physical* **223** 84-90.
- [26] Chetpattananondh K, Tapoanoi T, Phukpattaranont P and Jindapetch N 2014 A self-calibration water level measurement using an interdigital capacitive sensor *Sensors and Actuators A: Physical* **209** 175-182.

- [27] Pozo A M, Pérez-Ocón F and Rabaza O 2016 A continuous liquid-level sensor for fuel tanks based on surface plasmon resonance *Sensors* **16** 724.
- [28] Matsuya I, Honma, Mori M, and Ihara I 2017 Measuring Liquid-Level Utilizing Wedge Wave *Sensors* **18** 2.
- [29] Dunn W C 2006 *Introduction to instrumentation, sensors and process control* Artech House.
- [30] P. Inc, PING ultrasonic distance sensor.
- [31] Tarulescu R Usage of Parallax ultrasonic sensors in distance measurements **500** 1.
- [32] Kuantama E, Setyawan L and Darma J 2012 Early flood alerts using short message service (SMS) in *System Engineering and Technology (ICSET) International Conference* on 1-5.
- [33] Gharkan S K, Noori A A E and Mohammed S L 2013 Determination and detection of blind zones in vehicles based on microcontroller *Journal of Engineering and Development* **17** 1-13.
- [34] Jatmiko S, Mutiara A and Indriati M 2012 Prototype of water level detection system with wireless *Journal of Theoretical and Applied Information Technology* **37** 1.
- [35] Kuttruff H 2012 *Ultrasonics: Fundamentals and applications*: Springer Science & Business Media.
- [36] Noori A A E, Samter M B A and Khalid G A 2013 Design and implementation of audiometric instrument based on microcontroller *Journal of Engineering and Development* **17**.
- [37] Madheswari A N, Latha S and Iswarya M 2017 Solar powered wheel chair with voice controller for physically challenged persons in *Communication and Electronics Systems (ICCES), 2017 2nd International Conference* on pp. 987-991.
- [38] Alnaji A and Chahl J 2017 Simultaneous tracking of cardiorespiratory signals for multiple persons using a machine vision system with noise artifact removal *IEEE Journal of Translational Engineering in Health and Medicine*, **5**, no. 1900510.
- [39] Bland J M and Altman D J 2010 Statistical methods for assessing agreement between two methods of clinical measurement *International Journal of Nursing Studies* **47** 931-936.