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Microcontroller-based ultrasonic fluid level measurement system for domestic and industrial applications

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Abstract

Accurate and precise monitoring of fluid is a fundamental requirement for process control in industry. Apart from temperature and pressure other parameters such as fluid level, viscosity and concentration are of special interest. Despite the current traditional fluid measuring methods, a more qualified method for obtaining better information can significantly enhance the process quality and thereby product properties. Ultrasonic sensors or sensor systems can contribute immensely in this regard. The current research work presents a contactless microcontroller-based ultrasonic fluid level measurement system. The system uses a low power, programmable and large memory Atmega-328 microcontroller to monitor and control the generation sound pulse at 40kHz. The HC-SR04 ultrasonic module is responsible for both generation and detection of the ultrasound required for level computation and the level is displayed on the Liquid Crystal Display (LCD) unit. The device can measure fluid levels within a range of 20cm to 400cm. Fluid level measurements of three different samples, water, petrol and kerosene were carried out with both a measuring tape and the constructed (current) device. The results indicate a difference of +1cm to +2cm with negligible percentage errors. Also, as the water level may be obtained while filling or emptying the tank, the volumetric flow maybe estimated. However, when the fluid level is so low that it is not detectable by the ultrasonic module, the system goes out of range by displaying error message, OOR (Out-of-Range) on the LCD. Therefore, this device can be of great importance for applications in areas like fuel storage, providing flood warnings and simple water level control in homes just to mention a few.

Keywords: Microcontroller, ultrasonic, fluid level, measurement, system

1. Introduction

Fluid level measurement and monitoring is a critical part of industrial processes. With recent technological advances, affordable and reliable fluid level technology is paramount for industrial, domestic and other applications [1,2]. Although, there has been traditional fluid level measuring devices like those that are based on electromechanical techniques, however, these techniques suffer from intrinsic safety concerns in explosive environments [2]. Other methods such mechanical, capacitive, inductive, ultrasonic as well as optical methods have been shown to be implemented for level measurements [3, 4]. While mechanical and ultrasonic methods are mainly applied in level of solid materials, optical methods give better results for detection of fluids level [3].

Currently, Various level measurement devices have been developed particularly optical fiber sensors for liquid level measurements [3-7] due to their well-known advantages such as high accuracy, compact size, cost effective and ease of multiplexing. However, various literatures [8-13] have also shown that most of these sensors exhibit some drawback such as low sensitivity, limited range, long term instability, limited resolution, high cost and so on [3]. Thus, ultrasonic sensors also known as transceiver is a device that converts energy into ultrasound: a sound waves above the normal range of hearing for humans (about 20 Hz) were considered [8].

Ultrasonic sensors also known as transceivers works based on a principle similar to radar or sonar which evaluate attributes of a target by interpreting the echoes from radio or sound waves respectively. To determine the object distance, the sensor generates high frequency sound waves and evaluate the echo received back by computing the time interval between sending and receiving of the echo. Apart from fluid level measurements, ultrasonic sensors can be used for measuring wind speed as well as direction (anemometer), in humidifiers, ultrasonography and so on [9].

To date, research efforts were being made in the areas of developing microcontroller-based fluid level sensors because of their unique features such as being easily programable and their automation property. In this regard, Abdul Shear *et al.* [14] came up with ultrasonic range finder using microcontroller. The authors designed an ultrasonic range meter using stock electronic components with hardware complexity. In their work, an ultrasonic transducer pair driven by a 555-timer chip was used to generate the voltage required to drive the ultrasonic transmitter unit. Also, Khalid Reza *et al.* [15] carried out research on microcontroller based automated water level sensing and controlling.

In another development, Shamnas *et al.* [7] designed a fully automated water level indicator that uses microcontroller as the basic component for the water level indicator. Although, Mohd *et al.* [5] came up with an improved design with a microcontroller unit that can measure and control fluid level accurately, Marques *et al.* [10] designed high performance system based on polymer fiber Bragg gratings in silicon rubber diaphragms. Their proposed configuration displays a highly linear response, high resolution and good repeatability. However, the design is complex and costly.

More recently, Mohammed *et al* [16] presented another highly accurate water level measurement systems using microcontroller and ultrasonic sensor. The system can provide automatic fluid level control and at the same time trigger warning alarm for fluid surplus or deficiency. In their design, Ahfas *et al* [17] employed ultrasonic sensor as a chemical percol fluid level control system instead of a level switch. In this design, Atmega 16 was used a controller. Also, pereira *et al* [18] employed ultrasonic sensor system to evaluate water level in flowing channels.

Finally, a noninvasive fluid level sensing technique using laser-generated ultrasonic waves for nuclear power plants application was presented by Howuk *et al* [19]. Although, their designed system was for managing the coolant system safety and stability in the plant structure, the design is complex and limited to only nuclear power plants. The current research work presents affordable microcontroller based ultrasonic fluid level system with an improved design of embedded stand-alone fluid level device technology. The design combines both features of localized monitoring and the ability to access state of the system from a distance.

2. Materials and Methods

2.1 System Design

The system was design to operate as illustrated in Figure 2.1(a), while the complete circuit diagram is presented in Figure 2.1 (b):

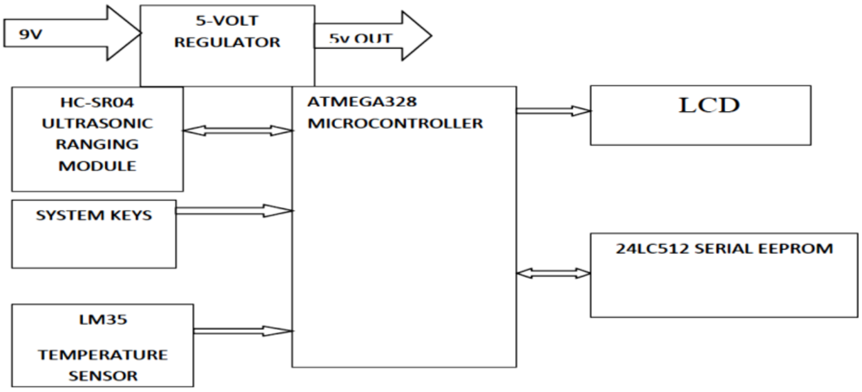

Figure 2.1(a): Block diagram of the designed fluid level measurement system

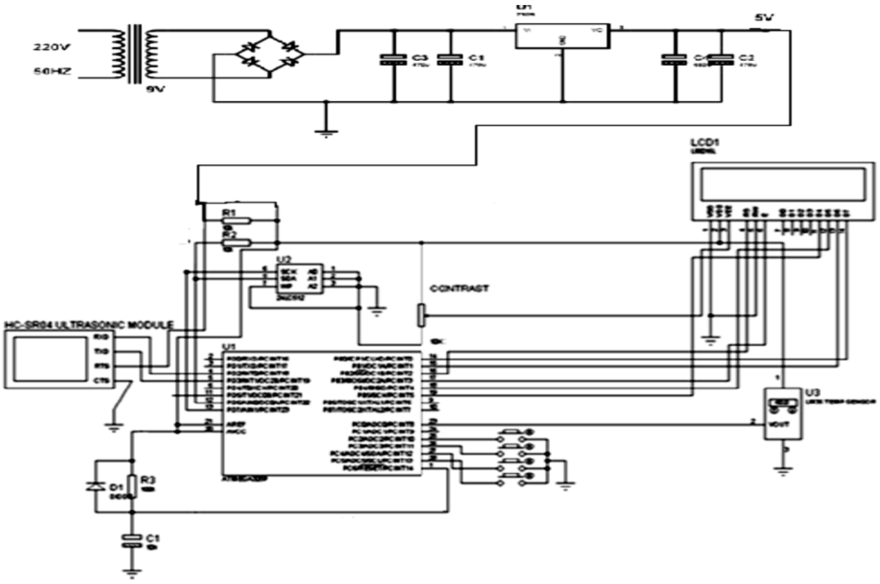

Figure 2.1(b): Complete circuit diagram of the system

From the Figures 2.1a, and 2.1b, the power supply section is designed to supply the system with a regulated voltage of 5V. The microcontroller (ATMEGA 328) was configured to be an interface between the HC-SR04 Ultrasonic Ranging Module, System Key, LM 35 Temperature sensor, Liquid Crystal Display (LCD) and 24LC512 Serial EEPROM.

2.1.1 *Power Supply section Circuit*

The power supply section of the system was provided by considering the voltage requirements of the various sections. Thus, a step-down transformer is used to step down the AC Supply of 220V to 9V. Then, the 9V AC passes through a regulated circuit (see Fig. 2.2) to produce the 5V DC required by the system.

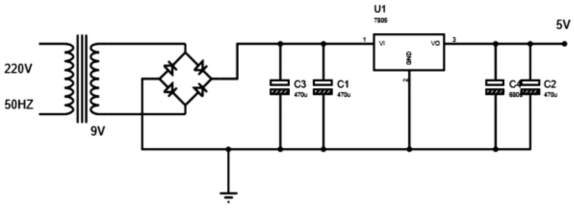

Figure 2.2: The Regulated 5V DC supply Circuit diagram

2.1.2 Microcontroller section

The microcontroller "ATMega 328" used in the design is responsible for monitoring and control of the generated 40 kHz sound pulse at a velocity of 340 m/s. It was configured such that, it reads when the echo arrives to calculate and display the distance on the LCD Module. This model of microcontroller was selected because it has high processing speed, it is programmable and large memory capacity.

2.1.3 Ultrasonic ranging module circuit design

The HC-SR04 ultrasonic ranging module used in the system is responsible transmitting and receiving the sound wave at 40kHz. It was interfaced with the ATMega328 via PORT D unsigned two pins: PD0 for the TRIGGER and PD1 for the ECHO return. The ultrasonic ranging module provides 2 cm - 400cm non-contact measurement function with a ranging accuracy of about 3 mm. The module includes ultrasonic transmitters, receiver and control circuit as shown in the figure 2.3 below:

Figure 2.3: HC-SR04 Ultrasonic Ranging module

2.1.4 The Liquid Crystal Display (LCD) section

This section enables viewing of certain keyed-in operations and also prevents entering of wrong information and labels. To ensure efficiency of the device, An LCD module with display size of 16 columns by 2 rows alphanumeric was selected. The data transfer between the microcontroller and the LCD module uses 4-bits interface which required four data lines port (D4 to D7, see Fig. 2.4).

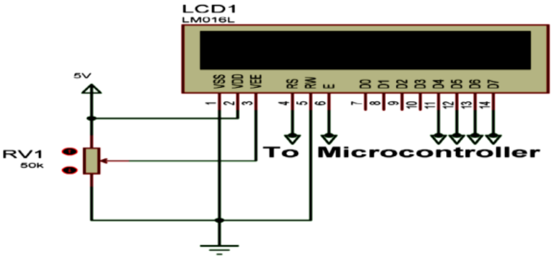

Figure 2.4: The Alphanumerical LCD

From the figure above, the pin configuration and module parameters can be seen in the LCD module. The variable resistor connected to the V_{EE} terminal controls the voltage across the terminals, hence the contrast of the LCD backlight. This resistor is selected to allow current within the range of 0.09 – 0.15 mA to pass through.

2.1.5 The 24LC512 Serial EEPROM

The 24LC512 serial EEPROM is an electronic erasable programable read-only memory that provide a simple user menu interface and also enables the configuration of certain system parameters such as temperature compensation into the output reading of the system, or the choice to disable temperature compensation. These settings shall be held in non-volatile memory storage for recall at next system start-up.

2.1.6 The System Keys Section

This section provides control and decision input during preset through push buttons connected to the microcontroller. The buttons pad enables ease of function assignment and less cost in engineering design. For this research, a four (4) buttons pad used are meant to pull-down the logic level to zero (0) on the microcontroller port when pressed. The pull-up resistors installed provide a logic high level on the connected MCU port at any point in time. The pull up resistors was designed to allow maximum input current of the microcontrollers based on ohms law. The circuit is presented in figure 2.5 below:

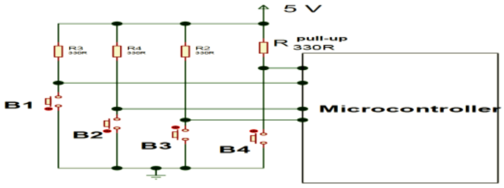

Figure 2.5: The designed push button Circuit

2.1.7 The Lm35 precision centigrade temperature sensor

This is an additional sensor that allows independent temperature calculation of distance, without loss of accuracy imposed by temperature variations. The sensor is an integrated-circuit temperature sensors see Figure 2.6, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. It has numerous advantages over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling.

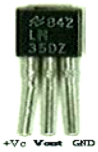

Figure 2.6: The Lm35 temperature sensor

3. Results and discussion

Prior to the system performance test, all the sensors as well as the LCD display units were tested to ensure the accuracy of the results. Then the system was powered and operated upon using several possibilities. Three different fluid samples (water, petrol and kerosene) in three different tanks of the same size were measured using tape and the constructed device. The tanks were label as "Tank A, B and C". The Tank A contains water, Tank B contains Petrol and Tank C contains Kerosene. The results obtained from different measurements conducted with both tape and the device on Tank A are presented in Figure 3.1 below:

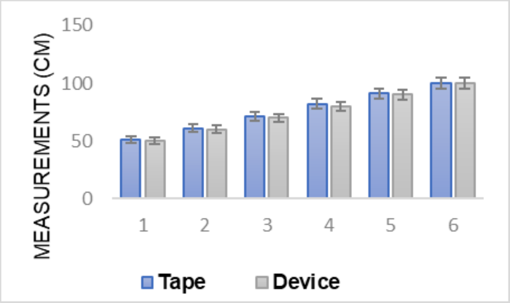

Figure 3.1: Variation of fluid level measurements for Tank A (Water)

From the Figure 3.1 above, the fluid level measurements conducted on Tank A show differences of +1 between the direct measurement (using measuring Tape) and the constructed device measurement, except at 100 cm where both the direct and the constructed device measurements were the same. The total percentage error obtained has a value of about +1.33%. Also, for the Tank B, the fluid measurements conducted at different distance were presented in the Figure 3.2 below:

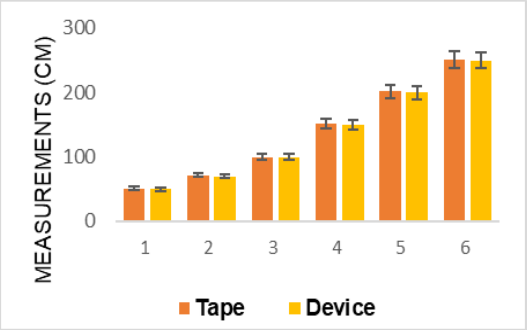

Figure 3.2: Variation of fluid level measurements for Tank B (Petrol)

From the Figure 3.2 above, slight variations between the direct measurements and the device measurements were recorded. Unlike what was observed in the case of water (Tank A), the differences between direct and the device measurements for Tank B (petrol) ranges from +1 to +2 and this may be attributed to differences in the densities of water and petrol. Although the variation was not constant, an overall percentage error of about +0.53% obtained was far less than that of Tank A (water).

Finally, the results of both real and the constructed device measurements conducted on Tank C (Kerosene) were presented in Figure 3.3 below:

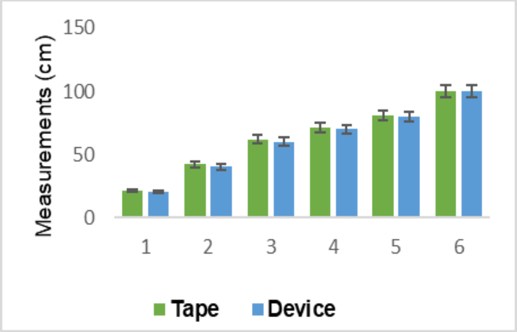

Figure 3.3: Variation of fluid level measurements for Tank C (Kerosene)

From the results presented in Figure 3.3, the variation of real and the device measurements at different distance is similar to what was observed from the Tank B, where the difference between the real and device measurements ranges from +1 to +2 respectively. However, the total percentage error of +1.63% obtained is higher than what was obtained from both Tank A and Tank B. However, observing all the three results presented in Figures 3.1 – 3.3, the deviation was very close therefore, suggesting that, the device is actually perform the task with little or no errors.

4. Conclusions

In this work, microcontroller based ultrasonic fluid level system was successfully developed and tested for vast applications. The device was able to detect liquid/objects within the sensing range of 20 cm to 400 cm without physical contact with the liquid/object itself. Also, the measurements conducted were independent of pressure and the presence of vapor or foam on the surface of the liquid. Therefore, this work suggests that, the device can be used for both domestic and industrial applications in areas like fuel storage, providing flood warning and simple water level control in our homes.

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