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Development of Non-Submersible Capacitive Sensor for Water Level Detection

Asmita[1], Amit Patwardhan[1], Prakash Vishwanathan[1], Jayant Pawar[1], Ashish Patel[1], Rabinder Henry[1], Pratik More[1]

[1]Hope Foundation's Pralhad P.Chhabria Research Center, Pune-,411057, India.

Abstract

Present work describes the design and development of non-submersible capacitive sensor for liquid level detection. The prototype implementation is done using glass container. Aluminum strips on the outer surface of the container forms the capacitor. The change in water level inside the container, changes the capacitance value. This changes the signal frequency which is analyzed using microcontroller. Hence, this proposed prototype successfully detects the change in level of water without submersing the sensor inside the container.

Keywords: Capacitive sensor, double distillation plant, dielectric medium, signal conditioning

I. INTRODUCTION

Water level detection has wide commercial and industrial applications. There are various other water level measurement techniques. A report by sensor intelligence [1] describes various water level measurement techniques. A. Qurthobi, R. F. Iskandar, A. Krisnatal, and Weldzikarvina [2] have designed capacitive sensor to measure the level of water by placing the sensor inside the container. R.Geethamani, Dr.S.Sheeba Rani, N.Ramyarani, C.Pavithra[3] have discussed the non-contiguous capacitive liquid level sensing by measuring the fluid level with the help of Texas Instrument FDC1004 breakout board [4]. The use of breakout board would increase the development cost. Most of the present methods require the sensing element to be inserted inside the water.

The proposed work is the part of project to automate the monitoring of double distillation plant. Fig 1 shows the plant set up in Nano material laboratory. The main aim is to design the system to increase the working hour of plant without manual monitoring. Its requirement is to detect the level of water inside the plant and auto control the actuators. It's not feasible to insert the sensor inside the distillation plant. Turbulence in water during boiling, variation in temperature, insulation of sensors are some of the major challenges.

The present work describes the prototype implementation of non-submersible water level sensing technique . The capacitive sensing technology enables to detect water level without inserting sensor inside the water.

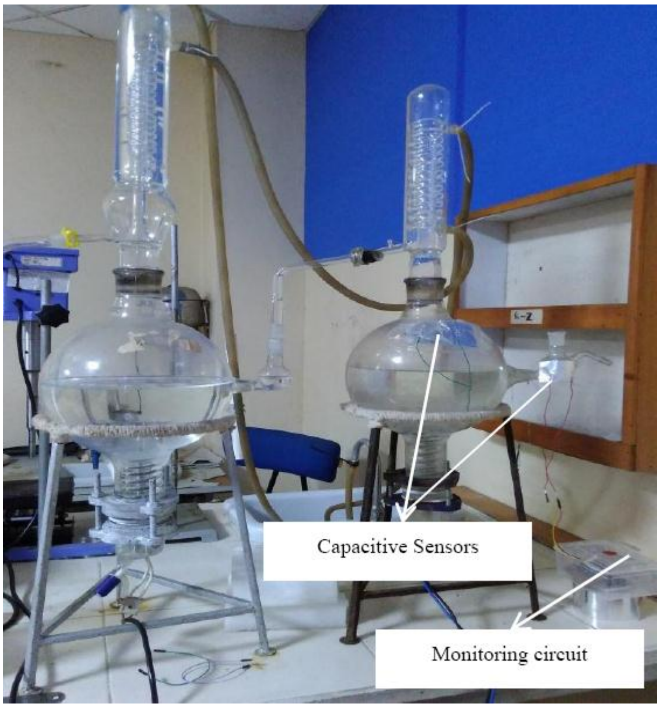

Fig 1: Double distillation plant.

This has major application in systems where it's difficult to modify water container. It also overcomes the problems related to insulation. Placing sensor on the surface of the container provides flexible implementation on already existing systems like distillation plant. The development of the present prototype uses a 250 ml glass beaker as the container. The capacitor is designed using Aluminium strips. The astable oscillator circuit using NE555N (IC555) generates the signal at particular frequency. The signal frequency changes with the change in capacitance value. This change is analysed using 14 stage binary ripple counter SN74HC4060 (counter IC) and the microcontroller ATMEGA328P.

II. PROPOSED METHODOLOGY

At initial stage, few of the methods that were implemented to understand capacitive sensing, are discussed here.

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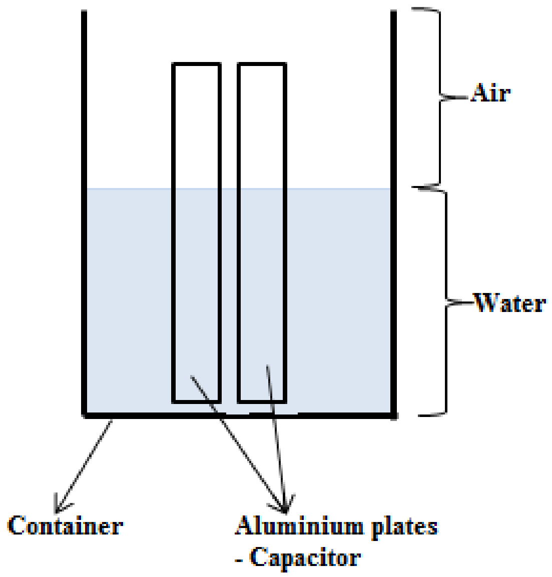

Fig 2: Aluminium plate capacitor placed on the surface of glass container

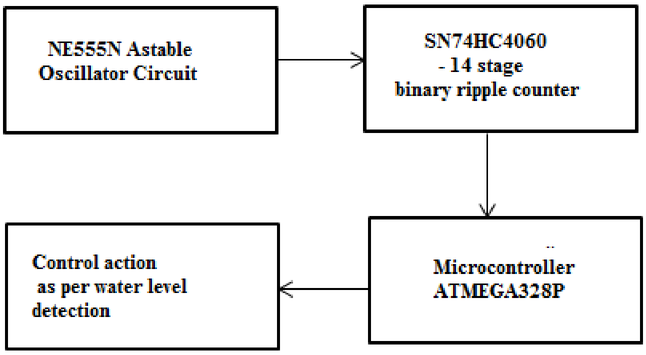

Fig 3: Block Diagram

The application note from Texas Instruments on basics of capacitive sensing and applications [4] covers the basic concepts of parallel plate, fringing effect and capacitive sensor design. The application note from Microchip on measuring small changes in capacitive sensors [5] discusses about the switched capacitor circuit to measure the small changes in the capacitance. Capacitive-based liquid level sensor reference design from Texas Instruments, demonstrates the working principle of liquid level sensing using reference electrode [6]. With the reference to these implementations, the proposed method for the prototype has been discussed further.

Two conducting plates with non-conducting material between them form a capacitor. Change in level of dielectric medium between conducting plates changes the capacitance value. Fig 2 shows the capacitance formed by placing two Aluminium plates on the container surface. The dielectric constant of air is 1 and that of water is 80. So, as the level of water changes inside the container, the capacitance value is changed accordingly. This changes the signal frequency of oscillator circuit.

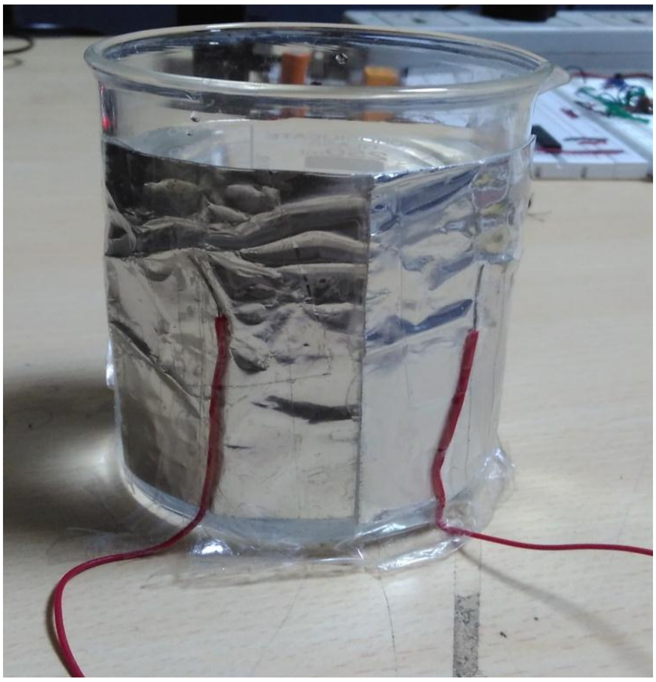

Fig 4: Aluminium plate capacitor on glass container

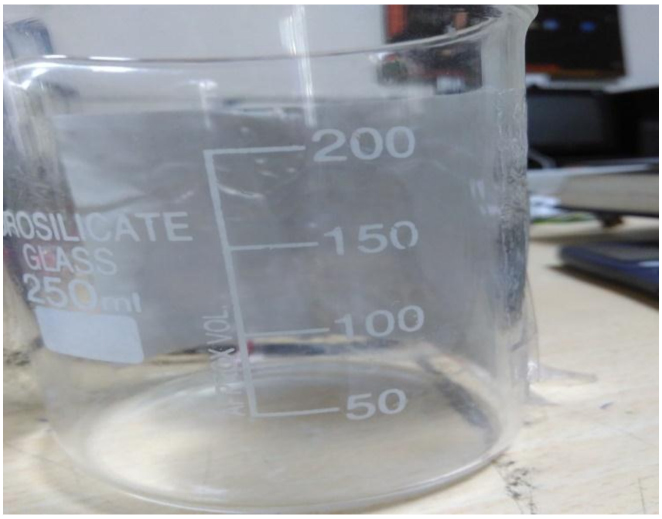

Fig 5: Volume marking on the glass container

Signal conditioning is then done using counter IC. The change in frequency is then analysed by microcontroller and thus water level is sensed. Fig 3 shows the block diagram of proposed method.

III. IMPLEMENTATION

The change in capacitance value changes the frequency of output signal of oscillator. Fig 4 shows the aluminium plate capacitor that is placed on the surface of the glass container. The dimension of capacitor plate is 4.8 cm wide, 7.2 cm in height with overlap of 0.1 cm. For prototype, the 250 ml glass container has the volume marking as shown in Fig 5.

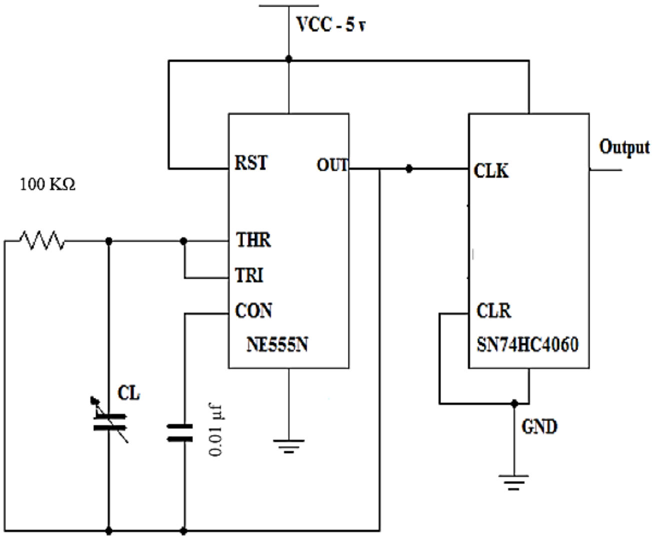

Fig 6: Astable oscillator and signal conditioning circuit

This testing enables to get quantitative analysis of change in capacitance with change in frequency. Fig 6 shows the oscillator circuit design. The variable capacitor CL as shown in figure is replaced by capacitor formed by aluminium plate. Equation 1 shows the relation between frequency and capacitance value.

$$f = 1/ (0.693*2*R*C) \qquad (1)$$

Where:

R = Resistance in ohm

C = Capacitance in farad

With reference to equation 1, the oscillator circuit was tuned at 160 Hz frequency. The value of resistance obtained was 100 KΩ. The capacitor CL was then replaced with the Aluminium plate capacitor. As the level of water inside the container changed, the capacitance value was changed; this changed the frequency of output signal of oscillator circuit. The signal was given to microcontroller for analysis. Due to very small value of capacitance (in picofarad) and high frequency, microcontroller was unable to detect the signal frequency.

To overcome this limitation, signal conditioning was done using counter IC. It is a 14 stage binary ripple counter. Every subsequent flip-flop is clocked using previous flip-flop. So, it increases the count, hence increases the time period of the signal. After signal conditioning, the time period of the signal was analysed by the microcontroller. Without water, the time period of the signal was 88 milliseconds (11.36 Hz). The variation in signal time period was observed with change in water level. Thus, the level of water was detected.

Fig 7 shows the hardware implementation of Oscillator and signal conditioning circuit on general purpose board. In this circuit the output of IC555 is given to the counter IC. Its output is then given to microcontroller for analysis. The hardware connection of prototype is shown in Fig 8.

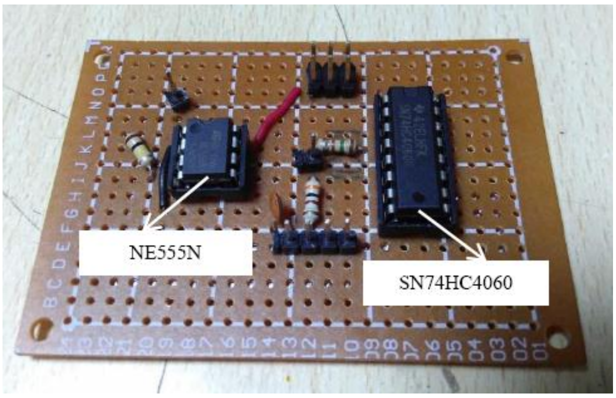

Fig 7: Astable oscillator and signal conditioning hardware

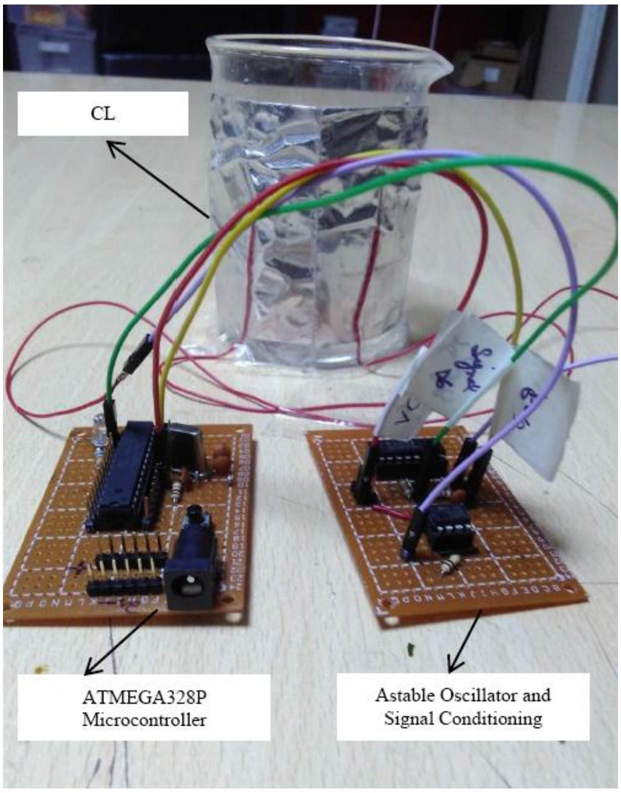

Fig 8: Prototype implementation.

IV. RESULT AND DISCUSSION

The result obtained shows the variation in signal frequency with change in water level. The waveform was observed on the serial plotter. The y-axis shows the magnitude of signal and each tick on x-axis shows the number of points for each executed print instruction. Fig 9 and Fig 10 show the captured waveform of signal without water and with 100 ml of water respectively. It shows that as the level of water was increased from 0 to 100 ml, the time period of the signal was increased.

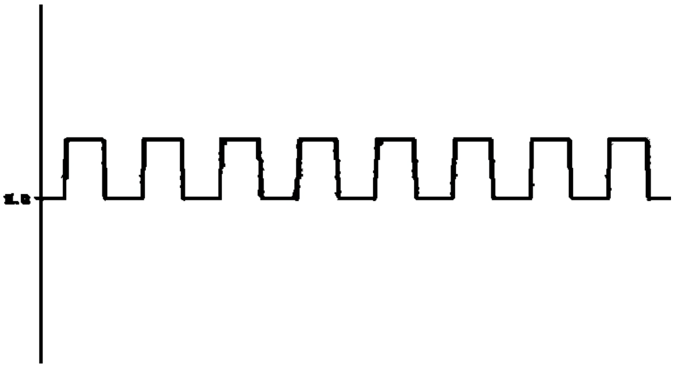

Fig 9: Captured signal without water inside the container

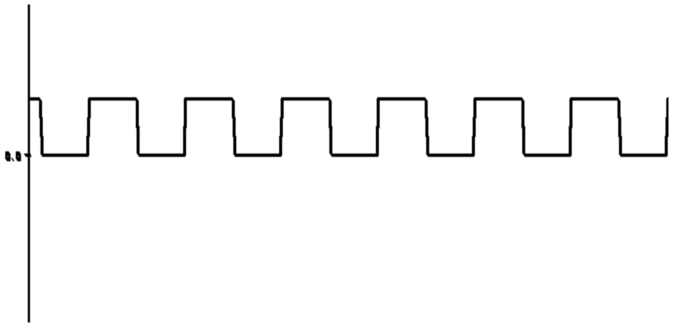

Fig 10: Captured signal with 100 ml of water inside the container

Similarly, further readings were taken for various level of water. These readings were quantitatively analysed through embedded code and the concept of look up table to obtain the signal time period. Table 1 shows the part of data collected from the experimental set up. Different sets of readings were taken to observe the behaviour of signal change. Graphical representation of four sets of collected data is shown in Fig 11. The nature of variation of four signals obtained from four different data sets remains the same.

As the level of water increases, it increases the capacitance value. This results in longer time duration of signal. Hence there is reduction in signal frequency. This is in accordance with the theoretical method as discussed through equation 1.

As discussed in introduction, this work is the part of project to monitor the double distillation plant in Nano material laboratory to automate the system. The developed capacitive sensor would be placed on the surface of glass container of distillation plant. It measures the minimum and maximum level of water inside the plant and accordingly controls the valve and relay. So, in order to get accurate analysis, further work has to be extended forward in field of signal processing. This would appropriately process the data obtained from this developed prototype to automate the system.

The present work could be extended for various other experimental purposes. It includes identification of materials in the container, level detection for other fluids apart from water. For instance dielectric constant of air is 1 and that of water is 80; for petroleum its value is 2.2. As the dielectric constant of material changes, the obtained data varies accordingly.

Table 1: Change in signal time period with respect to water level

Water Level (ml)	Signal Time Duration (milliseconds)
0	88
50	97
100	104
150	113
200	121

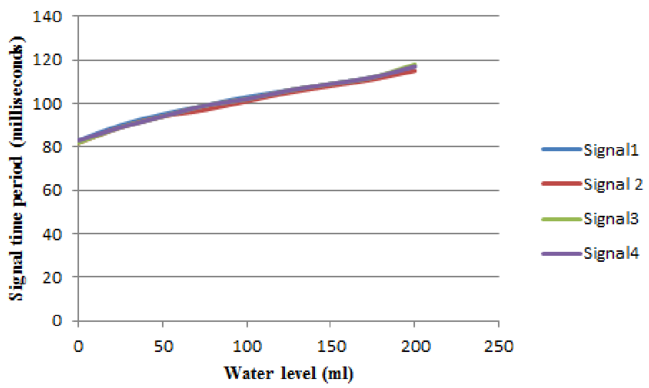

Fig 11: Change in signal time period with change in water level.

V. CONCLUSION

The change in water level inside the container is detected without submersing the sensor. With change in dielectric medium, dielectric constant changes, hence the capacitance value is changed. It has major application in fuel measurement system in vehicle, material identification, level detection, etc. The data obtained from particular medium is collected in the lookup table. The use of lookup tables in software implementation enables the efficient analysis of collected data. Hence the sensitivity of this sensor depends on the dielectric property of the medium and the container.

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