ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 4, Issue 6, June 2017

Capacitive Sensors: The Future of Level-Sensing Systems

[1] Vishal V,[2] Sayantan Gangopadhyay,[3] Vivek D, [4] Supreeth Sakrepatna
[1][2][3][4]Sir M Visvesvaraya Institute of Technology

***Abstract* - Level-sensors are basically used to detect the level of liquids and monitor their fill. These sensors can be used in overhead tanks or in laboratory equipment's to monitor the rate of the chemical fill, and also give us an indication regarding the same. Capacitive Sensors are one of the best level-sensors since they can measure the level without being in contact with the container. Water -level management at homes will help in reducing the power consumption as well as the water overflow from the overhead tanks. Capacitive sensors are much used due to their accuracy and resolution of measurement. Since they are sensitive to external factors like environmental changes, the inclusion of an environmental-reference sensor eliminates the drawback. Capacitive sensors are thus replacing the conventional level-sensors due to their versatility, and their precision during measurement applications.**

Index Terms-- Capacitive level sensing, FDC1004EVM, Laboratories, Overhead tank system, water management, Xbee serial communication.

1.INTRODUCTION

Capacitive sensors are one of the greatest advancements in technology today, being based on capacitive coupling, which can detect and measure any substance having a dielectric different than air. It is used in proximity-sensing, humidity variation detection, and liquid-level sensing applications. In this proposal we are concentrating on the use of capacitive sensors in measuring the liquid levels.

A. Technical Background

Fresh water, which was once an abundant natural resource, is becoming scarcer day by day due to disasters such as droughts and overuse by the human population. Water Resource Development Act (WRDA) [1] enacted by Congress deals with various aspects of water resources. It throws light on water management which is the activity of planning, developing, distributing and managing the optimum use of water resources. Monitoring the liquid level in overhead tanks at our houses is the first step to effectively manage water resources. Most of the time water overflow occurs at a large extent and leads to wastage of water. Capacitive Level Sensors are being used to monitor the fluid rate, avoid the water-overflow and also indicate if the container is empty, thus requesting that water be pumped into it.

The measurement of liquid levels in solvents, acids and alkalis is a main thing of concern in the laboratories at high temperature or under high pressure conditions. A slight variation in level measurement while conducting research can lead to a major variation in the output. Capacitive sensors, being highly precise in sensing and monitoring the liquid level, can be of great help in such scenarios.

B. Proposed Solution

The Capacitive Sensor (FDC1004) manufactured by Texas Instruments can be used to monitor the liquid levels. Capacitive sensors has gained much popularity due to their high accuracy and resolution in the measurement field. In the overhead tank, the fill is monitored using the FDC1004, and an automated switch is used to close the valve inlet, followed by the interfacing of the Pump 'OFF' condition. An upper and lower threshold is set too. If the liquid level exceeds the upper threshold, the pump is switched off followed by a long buzzer, and if the level is below the lower threshold, the pump is switched on and the tank is filled up to the upper threshold value.

In laboratory applications, the chemical level, based on the experiment performed, is set and monitored using FDC1004, and the steps are followed as suggested in the overhead tank system. With capacitive sensors, being sensitive to external changes, care should be taken in such a way that human intervention is avoided to the maximum extent.

We can interface the FDC1004 on any microcontroller, but for better conservation of power we use MSP430 which is well known for its low power applications [2]. It remains active in its sleep-mode consuming very little power, and any change in

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 4, Issue 6, June 2017

level is automatically sensed while it comes back to the normal mode of operation.

C. Organization of the Paper

The paper has six sections. Section I focuses on the Introduction part, and Section II introduces the FDC1004 and its use in capacitive liquid level-sensing application. Section III encases the design of the liquid level sensor prototype model, followed by its working. Section IV focuses on the simulated results of the same, and Section V encompasses the conclusion, followed by references in Section VI.

II. OVERVIEW AND WORKING OF CAPACITIVE LIQUID LEVEL SENSOR FDC1004

Capacitive sensing is a growing technology, and is undoubtedly going to replace the current optical detection methods along with mechanical designs for applications, namely proximity/gesture detection, material analysis, liquid level sensing etc. One of the main applications of capacitive sensors, which this proposed paper focuses on, is the liquid-level sensing. Capacitive sensor has the ability to sense changes at larger distances with a better accuracy. It is cost efficient, and the microcontroller on which it is interfaced has low power features, meeting the required power constraints.

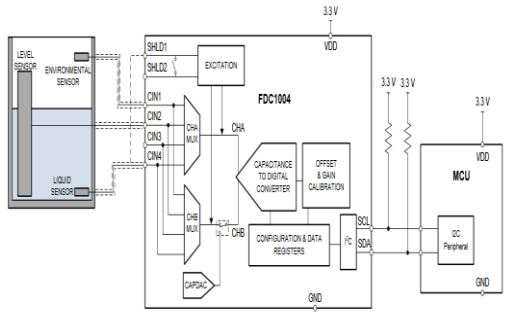

Figure 1: Capacitive Sensor for Level Sensing Internal Circuitry Diagram [3]

The internal circuitry diagram of FDC1004 IC, used as level-sensors, manufactured by Texas Instruments is given in Figure 1. The capacitive-based liquid level sensing design is based on the FDC1004 capacitance-to-digital converter and has an environment sensor to avoid the outside environment fluctuations which may interfere with the level-sensor readings [3].

A. Concept of Liquid Level Sensing using Capacitive Sensors:

Liquid level-sensing is based on ratiometric measurement, using three sensors, namely the level sensor, reference-level sensor and the reference-environment sensor.

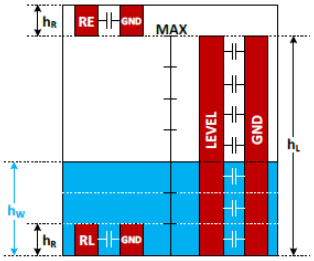

Figure 2: Ratiometric measurement setup

Referring to Figure 2 we have:

- Level Sensor: It is an electrode whose capacitance is proportional to the liquid height (hw).
- Reference Liquid (RL): It is used to set a lower threshold value for a liquid. The liquid should be above the reference liquid level for level sensing.
- Reference Environment (RE) – It is an optional reference electrode placed above the maximum allowed level of the liquid, which isolates it from the liquid level, allowing it to track environmental variations.

B. Principle:

All the three above-mentioned sensors are driven with the same excitation signal, where the change in excitation signal due to varying capacitance is measured and used to measure the liquid level. Fringing capacitance is measured between the level electrode and the ground electrode by the application of parallel-fingers topology. Fringing capacitance is a function of variation in dielectric and is proportional to liquid level. [4]

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 4, Issue 6, June 2017

C. Equations:

$$C \propto hw\varepsilon w + (hL - hw)\varepsilon a \qquad (1)$$

Equation 1 gives the relationship between capacitance and the dielectric variation, indicating that they are proportional, where

- h_L = maximum height of the liquid
- h_w = height of liquid
- ε_w = dielectric of liquid
- ε_a = dielectric of air

$$\text{Level} = h_{RL} * ((C_{level} - C_{level}(0))/(C_{RL} - C_{RE})) \qquad (2)$$

Equation 2 gives the level height calculation formula, where

- h_{RL} = the unit height of the reference liquid sensor
- C_{level} = capacitance of the Level sensor
- $C_{level}(0)$ = capacitance of the Level sensor when no liquid is present
- C_{RL} = capacitance of the Reference liquid sensor
- C_{RE} = capacitance of the reference environmental sensor

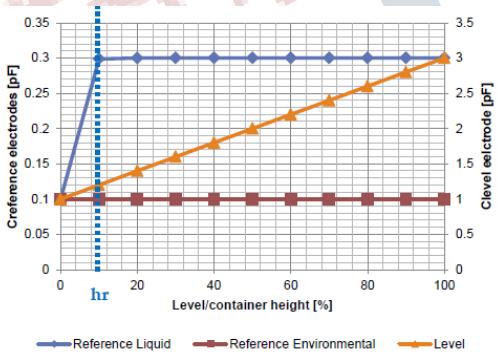

Figure 3: Plot Containing Capacitive Measurements of RL, RE and LEVEL Electrodes

From Figure 3, we notice that the level electrode capacitance increases linearly as the liquid level increases. RL capacitance saturates and shows a constant behaviour. Any variation in environmental factors is indicated by RE electrode. [4]

C. Design Considerations:

- Increasing the width of electrode increases the sensitivity.
- Minimal gap must be kept between the electrodes and the container. Sensitivity reduces if air gap is present.
- In remote sensing applications, where the electrode is not in contact with the container, we need to maximise the electrode width to compensate for the losses due to air gap.
- Sensitivity and resolution depends on the width of electrodes, the gap between them, the container material and its thickness.

III. DESIGN IMPLEMENTATION

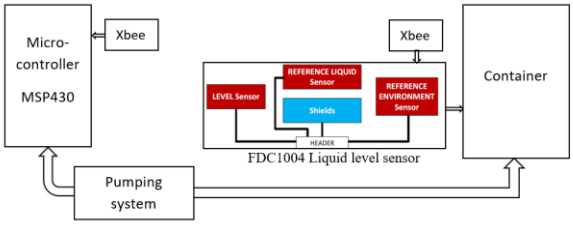

Figure 4: Block diagram of the Setup

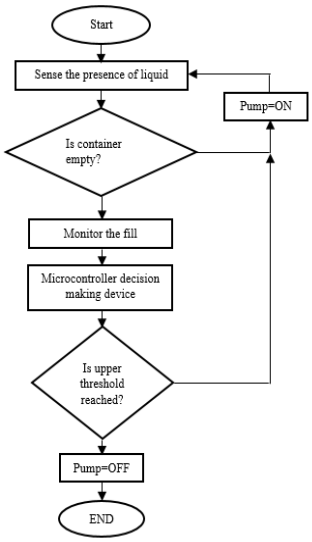

Figure 5: Flowchart

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 4, Issue 6, June 2017

The block diagram of the setup consisting of Capacitive Liquid level sensor using FDC1004 is as shown in Figure 4, and the flowchart is shown in Figure 5. The container can be an overhead tank to monitor water level in it or an apparatus at a laboratory where the liquid level needs to be monitored in cases wherein sophisticated conditions need to be met for a particular reaction.

The setup has five basic parts:

- Level sensing strip
- FDC1004EVM connector
- A container (overhead tank or a laboratory equipment)
- A pumping system
- Open/close valve

Figure 6: Level Sensor Strip by TI

Figure 7:FDC1004EVM with the Level Sensor Detached

Figure 8: XBee Module for Serial Communication

A. Level Sensor Strip and FDC1004EVM Module:

Figure 6 shows the level sensor strip manufactured by Texas instruments for liquid level sensing. It is paired up with FDC1004EVM and GUI to allow the user to evaluate the level sensed results. It consists of the three electrodes, namely Level electrode, Reference Liquid electrode, and the Reference Environment electrode. The header part is connected to the FDC1004EVM as shown in Figure 7. It has a USB port which can be plugged into the PC to get the sensor readings or else, it can be connected to a receiver end when we are serial communicating via XBee modules. The Xbee modules are paired and one acts as coordinator Xbee whereas the other acts as router Xbee [6]. An Xbee module is shown in Figure 8. Any liquid level can be detected using the capacitive sensor. Care is to be taken that the viscous liquids do not leave a thin residue layer after each trial which may interfere with the measurement.

B. Container and the Pumping System with the Valve for Liquid Inlet:

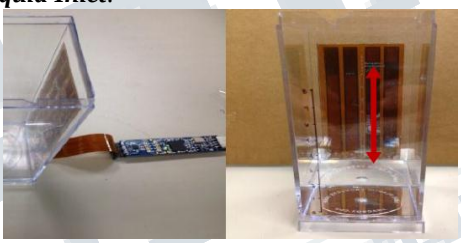

Figure 9: Container with Capacitive Level Sensor and FDC1004EVM

The level sensor strip is connected to the outer layer of the container and the header is connected to the FDC1004EVM chip as shown in Figure 9. The air gap between the container and the sensor is to be nil for a good sensing output. Reference Level (RL) sets the lower threshold, and the liquid fill is maintained higher than RL.

The Reference Environment section is placed above the upper threshold value.

The pumping system is 'ON' once the liquid is above RL and below the required fill value. Once the liquid level rises up to the fill required, the valve closes preventing the inflow of liquid.

C. WORKING:

There are two main areas we are focusing on regarding the Liquid level monitoring namely the overhead tank system at homes where the water management is to be taken care of by avoiding the water overflow by switching the pump system 'OFF', which in turn, saves power and in laboratories where the fill is to be monitored while developing new drugs since a little surplus in the fill will lead to a different reaction, hampering the output. Some sophisticated

experiments needed to be performed without human intervention too. In such cases, capacitive sensors helps in monitoring the reaction by examining the fill-rate at regular intervals in the container.

D. Overhead-Tank Water Level Monitoring:

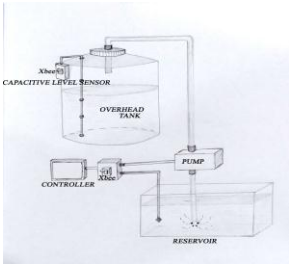

Figure 10: Overhead Tank System with Capacitive Sensor

The overhead-tank system design is as in Figure 10. The capacitive sensor strip is attached to the overhead tank with the header connected to the FDC1004EVM. The upper and lower threshold values of water level is set. The capacitive sensor checks the water level at regular intervals and once the level reaches the lower threshold, the pump system is 'ON' to let water in, filling the overhead tank, and once the fill reaches the upper threshold, the valve is closed and the pump system is switched 'OFF'. This prevents wastage of excess water. The communication is carried via XBee modules which communicates with the control system from a longer distance. Here, the communication takes place from the overhead tank to the controller in the ground floor. We can interface the level-sensing system using the capacitive sensor FDC1004 with any microcontroller (preferably MSP430 microcontroller due to its low power operation).

E. Level Sensing in Laboratory:

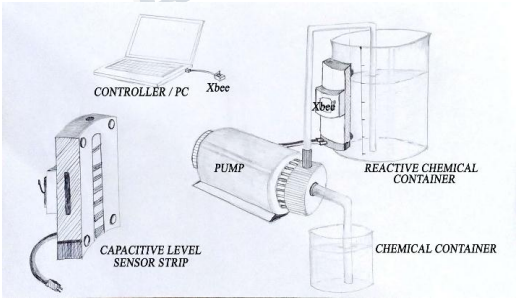

Figure 11: Capacitive Sensor Used in Laboratory Equipment

The use of capacitive sensors for liquid level-sensing at laboratories is shown in Figure 11. Conduction of experiments using certain chemicals in the laboratory requires high level of attention and sophisticated environment control. Every reaction requires certain level of chemicals in the containers to be added or located at the receiver's end. Human intervention in some cases leads to wrong outputs. The use of capacitive sensors for liquid level-sensing at laboratories helps us in monitoring the liquid levels at every stage without human intervention. Capacitive sensors has a major advantage in this case, as it does not need to be in contact with the chemical (liquid) and can monitor the fill from outside. Reference environmental electrodes monitor the external temperature and pressure and makes sure that the outside environmental changes does not affect the level sensed output. This way we monitor the experiments conducted at laboratories in a controlled environment without human intervention. The level sensor is embedded with the apparatus as shown in Figure 9. We can also monitor the fill from outside the laboratory by the use of XBee modules for serial communication.

IV. RESULTS

The results of the experiment conducted is as follows. Figure 12 shows the simulated results for the overhead-tank system using a GUI interface where we monitor the pump system automatically based on the water level in the overhead-tank. The results of the capacitive sensor measurements using water as the base liquid is given in Table 1. The result is almost equal to the expected output, and from this we can infer that the capacitive liquid level sensor FDC1004 is one of the best options for level-sensing applications. Figure 13 shows the graph of the actual result versus the expected result [4]. Contamination of these liquids result in a wrong outputs as indicated in Figure 14. The capacitive value, which had to be 23 pF, is deviated by a small figure due to the presence of particulates, detergents etc. [5].

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 4, Issue 6, June 2017

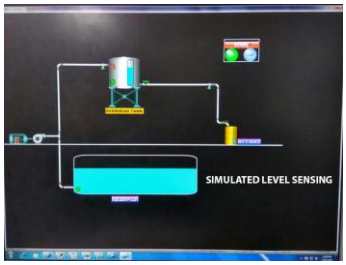

Figure 12: Simulated level sensing setup

ACTUAL LEVEL (cm)	LEVEL CAPACITANCE (pF)	RL CAPACITANCE (pF)	ERROR FROM EXPECTED (%)
0	0.1525	-1.042	0
1	0.7075	-0.5746	2.28
2	1.2315	-0.5669	0.09
3	1.7311	-0.5718	-0.56
4	2.2517	-0.5723	-0.31
5	2.7605	-0.5745	-0.20
6	3.2412	-0.5750	-1.24

Table 1: Results of Level Sensor Using FDC1004 for Water

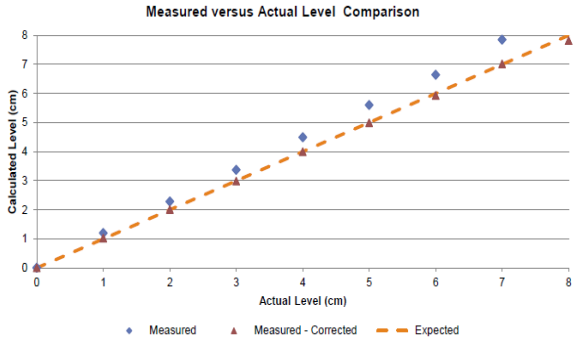

Figure 13: Measured Level Values Variation with the Expected Values

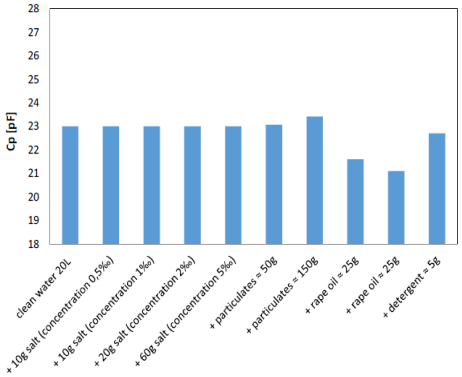

Figure 14: Measured Sensor Capacitance versus Contamination Concentrations

V. CONCLUSION

Capacitive liquid level-sensing is a rising technology which is definitely going to gain a lot of traction in the near future. It has already gained quite the popularity due to its efficiency and reliability. The use of these sensors for minimal-contact measurements of the fill is also an added advantage, which can hence be used in laboratories at strictly monitored environments in order to measure the chemical levels precisely. Water, being one of the essential resources for our survival, needs to be preserved and managed efficiently for the future. The use of capacitive sensing technologies in overhead-tanks help in monitoring the water level at regular intervals and prevents the water overflow from the system. The entire system is automated and has a lot of advantages and applications. The use of MSP430 as a microcontroller conserves power as it performs its operations at low-power levels.

REFERENCES

[1] WRDA ACT:

https://www.congress.gov/bill/114th-congress/house-bill/5303

[2] MSP430 Launch Pad Low Power Mode:

http://processors.wiki.ti.com/index.php/MSP430_LaunchPad_Low_Power_Mode

[3] FDC1004: 4-Channel Capacitance-to-Digital Converter for Capacitive Sensing Solutions-August 2014:
http://www.ti.com/lit/ds/symlink/fdc1004.pdf

[4] Capacitive Sensing: Liquid level technique-January 2015:
http://www.ti.com/lit/an/snoa925/snoa.pdf

[5] The capacitive sensor for liquid level measurement:
http://ac.els-cdn.com/S187770581502439X/1-s2.0S187770581502439X-main.pdf?_tid=9f683680-37a8-11e7-ba3b 00000aab0f27&acdnat=1494658482_81256b5ef20a70707779b327f0167984

[6]Xbee:

https://learn.sparkfun.com/tutorials/exploring-xbee-and-xctu