Design and Development of a Simple and Efficient Low Cost Embedded Liquid Level Measurement System

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***Abstract*— Measuring the level of liquid or solid is an important process in a container in various process industries. This paper presents the design of a capacitance transducer using a 555 timer circuit measuring the capacitance in terms of frequency and interfaced to a microcontroller to provide an accurate level measurement system. The whole system was tested and calibrated with a standard graduated tank (5-95%). The loading and unloading error percentages and the hysteresis error are determined and the maximum range to which the variation corresponds to is observed. The measurement quality of the system was further improved by linearization and the results are analyzed.**

Keyword- Level measurement, capacitive transducer, 555 timer, Atmega32, Calibration

I. Introduction

Measurement of the level of the liquid stored in an uniform container or vessel is a critical process in various industries like petrochemical industries, Ice cream units, Juice plant, Water treatment plant etc., Radar based level measurement, Electromechanical level measurement, ultrasonic level measurement, Hydrostatic Pressure based level measurement, Weight based level measurement, Capacitance based Level Measurement and 3D Level Scanner are proven instrumentation technique for measuring the level of the liquid[1]. In [2] optical liquid level detection method that does not depend on the liquid properties using an LED and a photo transistor placed reciprocally with a shift in their optical axes was presented by Eldar Musayev and Sait Eser Karlik. In [3] Tatsuo Nakagawa, Akihiko Hyodo, Kenji Kogo and Hideaki Kurata discussed a novel approach of contact less level measurement using millimeter wave to see through an opaque container.

Johanngeorg Otto in his work [4] presented the application and advantages of RADAR in level measurement. Mehdi Hassani, Hamed Tebianian, Saad Mekhilef, Amirhossein Mehbodniya presented the design of an electromechanical level detector Silometer in [5]. Ultrasonic level measurement is well established instrumentation technique though, it suffers from changes is sound velocity. Hydrostatic pressure based level measurement system works on the principle that the pressure at certain depth in a liquid container is directly proportional to the liquid column above that. The 3D level scanner is a level measurement device used for measuring the average volume of solid substances stored in small containers, overcoming the challenges of harsh and dusty environments. These provide continuous measurement readings on displays but demand higher expenses due to which they are not often used.

Various application of capacitive sensors like proximity sensing, switches etc., and capacitance measurement techniques are well explained in [6]. Capacitive level sensors are typically used in industries where the level of powered and granular solids, liquid metal, corrosive materials etc., is to be measured. In [7] Lu Guirong and Chen Shuyue presented the design of four electrode capacitive sensor to determine the level of the liquid and also the gradient status of the container.

In [8] Mauro Bramanti discussed a new capacitive sensor transducer design with high sensitivity, in which the change in capacitance is measured in terms of phase shift between voltage and current in a series RLC circuit. The capacitive to frequency transducer discussed in this paper is low cost but the true trade off is the sensitivity of the transducer. The capacitive sensor and the transducer circuit are discussed in the first section; the microcontroller setup, the measurement of frequency and capacitance are discussed in section two; Measurement of level by the embedded level measurement system and linearization is presented in section three followed by the results and conclusion at the end.

Determination of the liquid level and taking the necessary control action, corresponding to the particular level plays a very important role in daily industrial processes. Thus citation of accurate liquid level and further proceeding with the perfect control action form the base of a process.

The embedded liquid measurement system presented in this paper highlights the way by which an accurate level reading can be obtained.

II. THE CAPACITIVE SENSOR AND TRANSDUCER CIRCUIT-

A. *Coaxial Capacitive Sensor*

Coaxial Capacitors consist of two concentric cylinders sharing the same axis as shown in schematic Fig. 1. A closed circuit is obtained on connecting a voltage source to one of the plates and completing the circuit with the other plate. The Capacitive sensor used in this paper is shown as in Fig. 2.

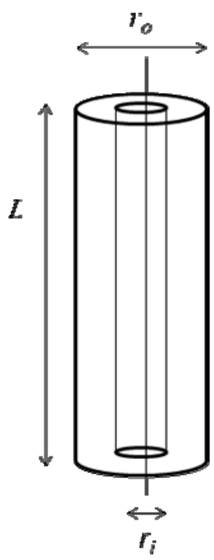

Fig. 1. Schematic of Coaxial Capacitive Sensor

Capacitance C is given by:

$$C = \frac{Q}{V} \qquad \text{(i)}$$

$$C = \frac{2\Pi L \in}{\ln\left(\frac{r_o}{r_i}\right)} \qquad \text{(ii)}$$

Where

L is length of coaxial sensor

$\in$ is the permittivity

r_o is the outer radius

r_i is the inner radius

Fig. 2. Coaxial Capacitive Sensor used in the System

B. *Transducer Circuit*

The 555 general purpose integrated circuit timer is typically used for generating timing pulses accurately and having two modes of operation namely: monostable and astable. Present discussion is limited to astable multivibrator mode. The astable multivibrator is also called as the timer circuit or clock. 555 operating as an astable multivibrator are elaborately explained by in [9] and [10].

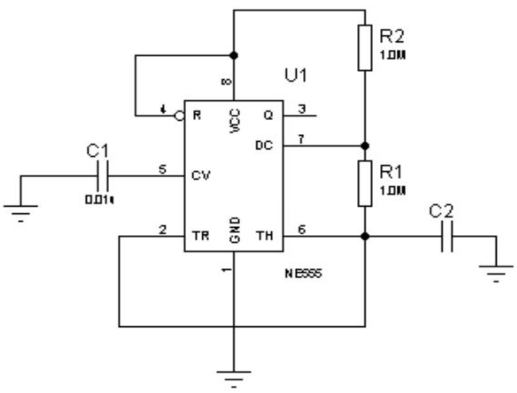

Fig. 3. Capacitance to Frequency Transducer Circuit

In Fig. 3.

C1=Control voltage

C2=Measured Capacitance (or) Capacitance of the coaxial sensor

The output frequency of the timer circuit in astable mulitvibrator mode (as shown in fig.3) is given by:

$$f = \frac{1}{0.693*(R_b + 2R_a)*C2} \quad (1)$$

The liquid used in this system is water and it was observed that the transducer circuit best responded for:

$$R_a = R_b = 1MOhm \quad (2)$$

By substituting (2) in (1) we get a direct relation between capacitance and frequency:

$$C2 = \frac{480}{f} \quad (3)$$

Where the units of $C2$ is nF and f is in Hz.

III. MICROCONTROLLER SETUP

ATmega32, a low power 8-bit microcontroller based on AVR enhanced RISC architecture is used in this system as a computational device. ATmega32 has 32 general purpose input output (GPIO) pins which includes three external interrupts. This microcontroller features two 8-bit timers and one 16-bit timer of which one 8-bit timer TIMER2 is used in this system. One external interrupt pin (INT0) of the microcontroller is used along with the TIMER2 of microcontroller to measure the frequency output of the capacitance sensor circuit.

A. *Capacitance Calculation*

In order to calculate the capacitance, the microcontroller should calculate the frequency of the square wave generated by the 555 timer circuit (shown in figure 3). The output pin of the 555 timer IC is connected to the INT0 pin of the controller. Registers associated with external interrupt of the controller is configured such that the external interrupt is triggered on the rising edge and for every trigger is counted as an additional ‘pulse’. For every one second the frequency is given by the value of ‘pulse’ and the variable ‘pulse’ is assigned with a zero.

For every one second:

$$f = pulse \quad (4)$$
$$pulse = 0$$

Substitute (4) in (3):

$$C2 = \frac{480}{pulse} \tag{5}$$

IV. Level Measurement

A cylindrical tank with a standard calibration scale on it was used for testing and further calibration of the embedded level measurement system. The scale on the tank is a percentage volume scale and the range is 0% to 100%. For test purpose the liquid level was varied at steps of five percent and the capacitance corresponding to levels from 5% to 95% was tabulated. Table I shows the capacitance as measured by the system developed.

TABLE I
Capacitance measured by the system at different levels of liquid in tank

Standard % of Water Level	**Loading**	**Unloading**
	Capacitance C2 (nF)	
5	0.0785	0.0797
10	0.0853	0.0863
15	0.0913	0.0922
20	0.0988	0.0996
25	0.106	0.1066
30	0.1121	0.1134
35	0.1192	0.1209
40	0.1268	0.1278
45	0.1325	0.1344
50	0.1395	0.1414
55	0.146	0.1483
60	0.1535	0.1549
65	0.1598	0.1621
70	0.16689	0.1687
75	0.1741	0.1759
80	0.1814	0.1849
85	0.188	0.1921
90	0.1943	0.1955
95	0.2018	0.2018

From Fig. 4. it can be clearly observed that the output of the transducer is almost linear for a wide range during the loading and unloading process. However a slight hysteresis error can be observed from the values in Table 1 and from the graph in the 75% to 90% range.

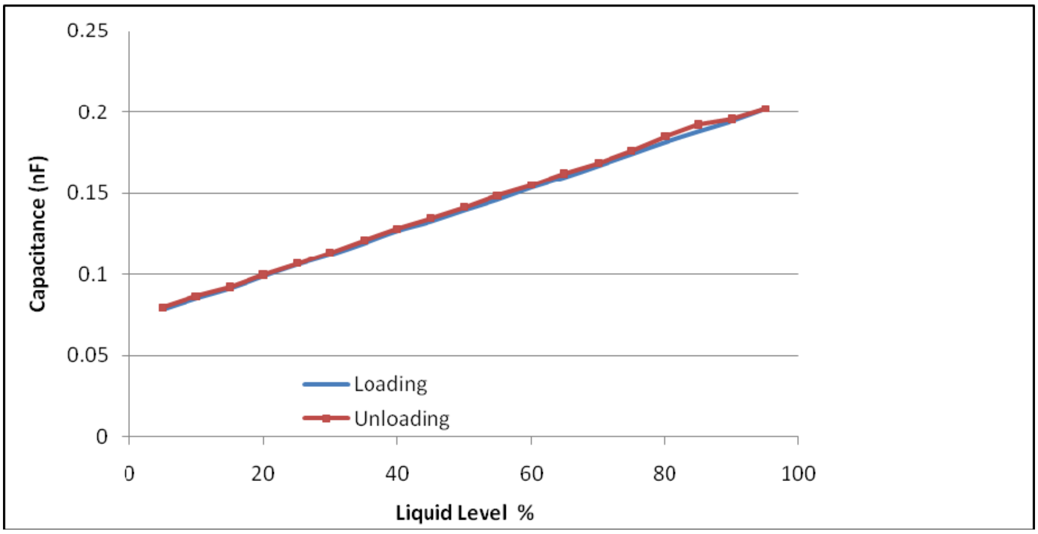

Fig. 4. Capacitance measured versus true liquid level

A. System Calibration

From figure 4 it can be observed that the relation between the percentage volume of the liquid level present in the tank and the capacitance is linear. Using the values presented in the Table I, liquid level is given as a linear function of capacitance:

$$\%Level_1 = (C2 * 735.29) + (-52.5) \tag{6}$$

Now the system firmware was modified to calculate the level and display it on LCD. The system was then checked with the same tank and the level displayed by the system on its LCD for levels varying 5% to 95% is tabulated in Table II.

TABLE II
Level measured by the system at different levels of liquid in the tank

Standard % of Water Level	**Loading-Measured % of Water level**	**Unloading-Measured% of Water level**
5	6.9926	7.3176
10	11.4325	12.1286
15	16.372	16.5484
20	21.5076	21.4919
25	26.5683	26.604
30	31.2565	31.8408
35	36.7161	36.9896
40	42.0874	42.0364
45	46.9753	46.8342
50	51.462	51.8646
55	56.6439	56.7801
60	61.7327	61.8819
65	66.4246	67.2784
70	71.9147	72.1804
75	76.5906	77.0201
80	82.5624	83.6647
85	88.0343	89.1708
90	91.7373	91.7371
95	96.9675	96.9675

From the values in Table II, the loading and unloading error percentages and the hysteresis error percentage can be determined and the non linearity can be observed as shown in Fig. 5. The maximum loading and unloading error percentages amounted to 39.852% and 46.352% respectively, corresponding to the liquid level range from 5 % to 25 %. From the graph it a slight hysteresis error is observed in the 75% to 90% range.

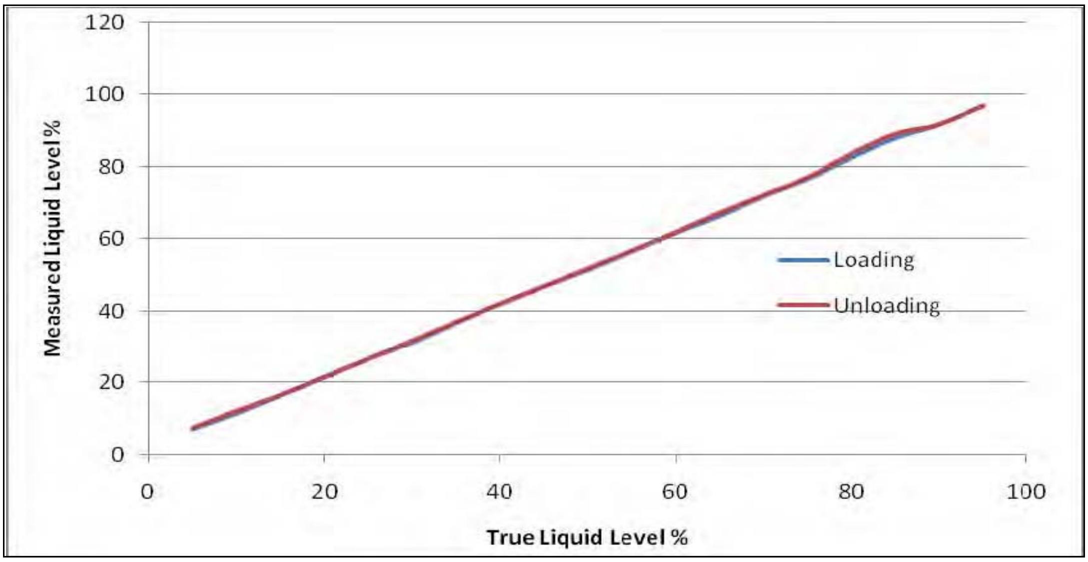

Fig. 5. Measured liquid level versus true liquid level

From Table II and Fig. 5. a considerable amount of error can be observed for each of the measured values of the liquid level. Further linearization of the system was performed using the values in Table II to reduce this error:

$$\%Level = (\%Level_1 * 1.00040016) + (-1.9779912) \quad (7)$$

TABLE III
Level measured by the system at different levels of liquid in the tank

Standard % of Water Level	Loading-Measured % of Water Level	Unloading-Measured % of Water Level
5	5.1062	5.437
10	10.0099	10.623
15	14.638	14.84
20	19.6606	20.018
25	24.8855	25.296
30	29.651	30.498
35	34.579	35.805
40	39.9975	40.837
45	44.5173	45.779
50	49.9233	50.356
55	54.8299	55.544
60	59.8515	60.554
65	64.9132	65.848
70	69.8302	70.667
75	74.6968	75.841
80	80.9938	81.463
85	84.9553	86.967
90	89.508	90.276
95	94.1184	94.1184

The system firmware was again modified to give the accurate measurement of the liquid level and the system was tested with the same tank and the levels measured by the system and the real levels are tabulated in Table

III. From Table III it can be observed that the further linearization helped in reducing the error significantly. The graph plotting the level determined by the system while loading and unloading is shown in Fig. 6.

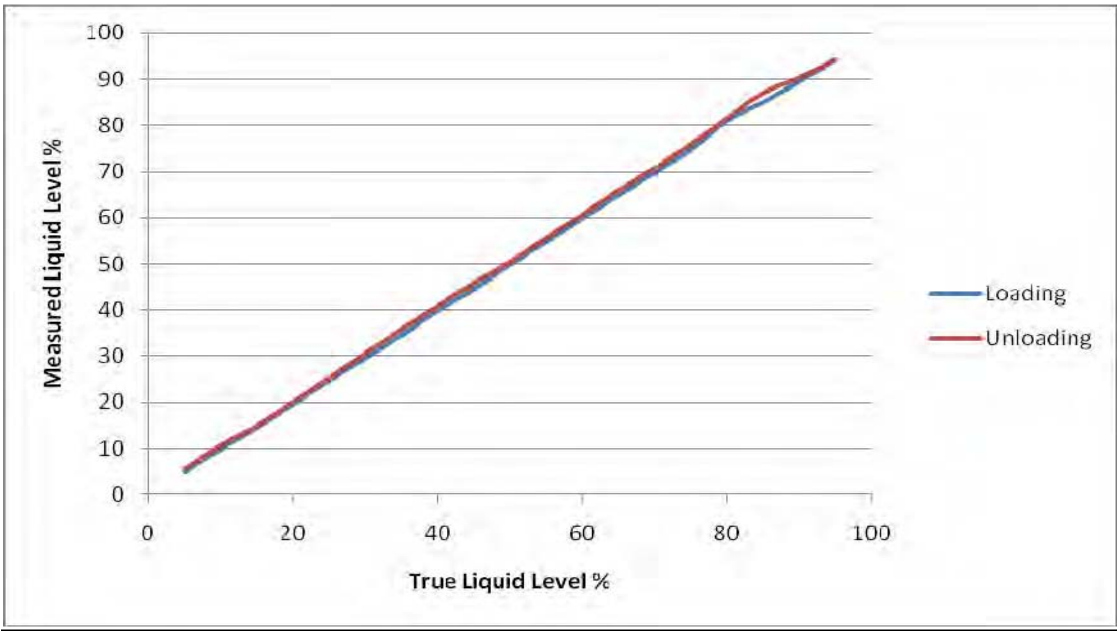

Fig. 6. Final liquid level measured versus true liquid level

From the values in Table 3, we can see that the loading and unloading error percentages have been reduced to 2.413% and 8.74%, belonging to the liquid level range of 5% - 15%. The hysteresis error remains even after further linearization. However the deviation of the measured value from the true value is reduced significantly.

V. Results and Discussions

This article presents a design and development of a precise liquid level measurement system as shown in Fig. 7. These schemes involve a low cost implementation and provide a very close ideal system for measurement. It involves the interfacing of a capacitive sensor to a 555 circuit (transducer circuit) and development of a microcontroller based system to give accurate liquid level measurement. The error percentages were determined at each stage of testing and were reduced from 39.892 % (Loading) and 46.352 % (Unloading) to 2.413 % (Loading) and 8.74 % (Unloading) by further linearization. The hysteresis error depends more on the sensor and was not completely eliminated in the current system.

Fig. 7. Liquid level measurement system.

Summary

A capacitive transducer circuit was designed using the 555 timer, to measure the capacitance in terms of frequency. It is interfaced to a microcontroller to display the liquid levels of test capacity (the system was tested in the range of 5% to 95%). The loading and unloading error percentages were observed at both the stages and were reduced to a large extent by linearization of the system. This provides a sensor which is characterized using a micro-controller to correct the non-linearity. The system was tested with water as the liquid. The flexible system firmware is easy to modify and with slight changes in the system firmware, the system can be used for different liquids

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