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Level Measurement in Liquid Level Process using Multi Sensor Data Fusion

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Abstract: Factors such as higher product quality, less waste, reduced cost, reliability etc can be achieved in any liquid/chemical process industries by improving its accuracy to measure its level. Because of the emerging sophisticated and tight process control systems, there arises a need for a reliable and precise level measurement system. A new technique to measure the liquid level in industries is employed using fuzzy inference engine in MATLAB using the Multi sensor data fusion concept. This is done by forming the membership functions for every sensor used in the multi sensor environment. This system is validated using the ultrasonic sensor and the capacitor level sensor.

Keywords: Fuzzy inference engine, Multi sensor data fusion, Membership functions.

I. INTRODUCTION

In today's world, where the technology is advancing which such a rapid rate, factors like accuracy, reliability, safety etc have become very critical. This is a rapid increase in the advanced automated processing systems which are expected to be error free, safe and precise and the one that needs the meet the strict regulatory requirements.

Thus there arises a need for a better system for the various processes in industries, which will lead to the fine end product. The processes range from temperature control, humidity control, pressure transducers etc depending on the process being carried out. Another important thing to be kept in mind, while dealing with process control systems is the 'measurement'. Then perfect measurement is very critical issue in all the industrial processes.

The different measurements carried out in industries are numerous, naming a few are: weight, height, level, time, mass etc. Liquid level measurement is an important measurement, especially when it comes to the field of medicine, pharmaceuticals, production of various solutions and solvents etc. These measurements may be easy or complex depending upon the material being measured.

There are various methods employed to measure the liquid level of various liquids in the industries, sight glass being the oldest and the simplest way to do so. No doubt, in present day scenario various complex and sophisticated technologies are made use of, to perform various calculations and give us the output. Control systems are so designed, that they take the input from the sensors and give us the required output. Though this looks simple, it is not. This is because they are seriously affected by noise and inference issues.

These complexities can be reduced by making use of various new technologies available. Data fusion is one such technique, which integrates the multiple data representing the same real world to give us more accurate and correct output. Data fusion can be effectively made use of, to get precise level measurements. Various other fields such as in oceanography, military surveillance, medicine, engineering and communication are also making use of the data fusion technique for better results.

In this work an attempt is made to fuse the Data fusion technique with Liquid level measurement, to correctly measure the liquid level of any process. Multiple sensors are employed expecting it to give a better and more accurate result. When a same liquid level is viewed by two or more different sensors, taking different parameters into considerations, its results become more accurate. An analysis of few such readings of input and output, will allow us to write a code to get different readings also. Thus an accurately correct output can be obtained when all the sensors will operate together.

MATLAB is a proprietary programming language which was developed by math works, which allows creations of user interface, matrix manipulations, implementations of algorithms etc.

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It has various tool boxes which can be suitably used for any particular systems. Few of the licensed tool boxes available in all MATLAB are Simulink, Control system, Image processing, Data acquisition, Fuzzy logic, Neural networks etc.

The fuzzy logic tool box is used to simulate and design the fuzzy logic system and is hence a appropriate for our work.

As already known, fuzzy logic is an approach where the results are based on " degree of truth" and not on the " true or false" or Boolean logic as understood by the computers. Thus the fuzzy logic tool in MATLAB is used with an aim to develop the code for accurate level measurement.

II. PRELIMINARY REVIEW OF LITERATURE

This entire chapter gives an insight of the study carried out before conducting the proposed work. Many researchers have come up with different ideas and techniques to measure the level of liquid in any chemical/process industries. One among them is discussed in paper[1], which makes use of the lateral displacement effect principle where the level of liquid is estimated by the difference in refractive indices and thickness of it, by making use of an oblique light ray which is made to propagate through the medium.

Paper [2], illustrates how the level measurement can be done by making use of the capacitive level sensor, which determines its level based on the varying capacitance of the vessel, with and without liquid in it. The capacitive sensor here is calibrated with inkjet printing on to a kapton substrate, which is why it can be used with any shape of the vessel.

Another approach of using capacitive level sensor for liquid level measurement is to make use of the grounded cylindrical capacitive sensors by making use of the shielded cables. The inner one of the two cables is grounded, whereas the other is used to measure the level, which is discussed in paper [3].

Paper [4] says a novel method of detection of rainfall of botanical gardens, by calibrated liquid Level sensor transducers, where the output signal is a pulse, which is transmitted over various channels like package switch networks, radio, infrared, optical etc.

Further improvements are done in [5] by improved linierized networks for capacitance measurement, where the output is converted to corresponding electrical signals which can be transmitted to remote areas. An attempt is made to minimize the stray capacitance in the system by using dc control voltage and operational amplifiers with high input impedence.

[6] reports a prototype differential pressure sensor, which precisely measures the liquid level of the reservoirs by measuring its hydrostatic pressure exerted by the process liquid and correlating it to the liquid level.

As there are always some variations in the output level obtained by ultrasonic level sensors,[7] has come up with a new method, where they make use of multiple input multiple output ultrasonic transducer array, then applying synthetic aperture technology to realise many samples. The factors such as the wave size of the liquid, echo signal SNR, beam forming focus position etc have a impact on this method of level measurement.

The liquid level and its electrical properties such as permittivity are determined based on ultra-wide band pulse radar which use layer stripping algorithms, enabling its use in estimating liquid levels of liquids containing multiple layers. Paper [8] discusses this technique in detail and also compares it with the other antennas such as four antenna array, eight-element antenna array etc.

III. EXPERIMETAL SETUP

The experimental setup consists of a cylindrical tank of height 25cm which can be filled with liquid. The liquid level in this tank can be varied to study the various controllers like the P, PD, PID controllers. In this work, this tank is used to validate the liquid level measurement using two different sensors. The experimental setup is shown in figure 1.

The container used for the experiment is the one that comes attached with one of the sensors used, i.e. The Capacitive level sensor. The other sensor which we have used is the Ultrasonic sensor which was later interfaced with the Arduino board and used for the measurements.

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Figure 1: Experimental setup of Liquid level process

A. Capacitive Level Sensor

In a capacitive level sensor (CLS) there is a metal electrode as a part of the sensor which starts acting like a capacitor. The electrodes behave like the sides of the capacitors. Thus the varying liquid level in the probe will change the capacitance level of the system, as the space in between the probes is now replaced with liquids with varying dielectric constant, that was earlier filled with air. The capacitance level is generally given by the equation 1 as follows

$$C = \frac{2\Pi\epsilon H}{\ln(A/B)} \qquad (1)$$

Where, C = Output Capacitance
B = Diameter of the probe
A = Diameter of the vessel
H = Height of the probe

The capacitive level sensor readings are calibrated in a such a way that we get the corresponding liquid level in terms of electric voltage. The output capacitance is first converted to frequency using timer circuit and then converted to corresponding voltage. Figure 2 shows the Capacitive level sensor and its working which is used for the Level measurement.

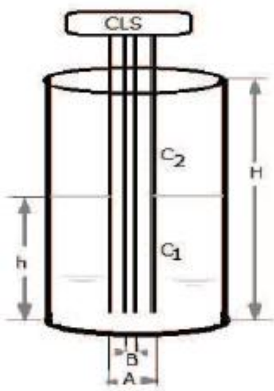

Figure 2: The Capacitive Level Sensor

Here, h = Height of the liquid being measured
H = Height of the tank
ϵ_o = Permittivity of Air
ϵ_r = Permittivity of Liquid
Ce = Effective capacitance

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Thus on varying the liquid level, there will be changes in the capacitances C_1 and C_2, which will vary the effective capacitance of the system Ce. The equations supporting this are given below.

$$Ce = (C_1 + C_2)\ F \qquad (2)$$

where,

$$C1 = \frac{2\Pi \epsilon_o \epsilon_r H}{\ln(A/B)} \qquad (3)$$

$$C2 = \frac{2\Pi \epsilon_o \epsilon_r H}{\ln(A/B)} \qquad (4)$$

B. Ultrasonic Level Sensor

Ultrasonic Level Sensor (ULS) is a non-contacting type of sensor that work by the "time of flight" principle using the speed of sound. This sensor is fit at the top of the container in which the liquid measurement is to be carried out. The setup of this sensor is shown in figure 3.Bottom of the tank is taken as the reference level for the sensor measurement. The level marked 'C' is the amount of liquid to be measured, 'B' is the distance of the sensor from that liquid level. Ultrasonic pulses are transmitted from the sensor and reflected back from the target. Level 'C' can be tabulated by multiplying half of the time with the speed of the sound in air. Here we have taken time as the parameter for all the level measurements.

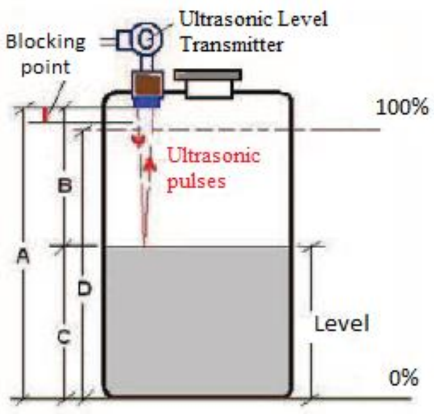

Figure 3: The Ultrasonic Sensor Setup

The time taken by the Ultrasonic sensor to transmit and reflect back is given by equation 5.

$$\Delta T = 2 * B/C_o \qquad (5)$$

where B= A-C

C_o= Velocity of Ultrasonic signal in Air

IV. METHODOLOGY

To achieve the desired functionality, an multi sensor data fusion algorithm is created in the Fuzzy logic in MATLAB using both of these sensors used earlier. This will now fuse the data obtained from both the sensors and hence the new liquid level obtained from the algorithm will be the result of the fused readings of both the individual sensors. Block diagram of the proposed framework is given in figure 4.

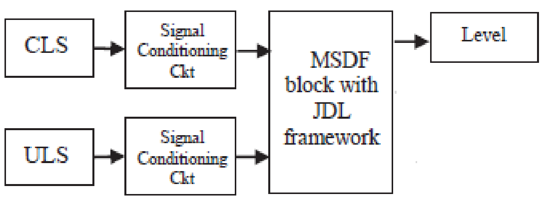

Figure 4: Block Diagram of the proposed technique

The liquid level readings are taken from the capacitive level sensor in terms of voltage, and the ultrasonic level sensor readings are taken in terms of the time period. Now the algorithm is written by properly defining the membership functions for each sensor and the level is obtained by feeding the values to it.

V. RESULTS AND ANALYSIS

Once the proposed framework is designed to get the liquid level, testing has to be done with liquid of different levels and checked for accuracy. Table 1 shows the result obtained from the proposed multi sensor data fusion algorithm for liquid level.

Table 1: Results obtained on testing the proposed work

Actual Height in cm	CLS readings in vtg	ULS readings in seconds	Measured liquid level in cm	% Error
3.55	0.57	85.8	3.492	1.6
4.04	0.68	84.2	4.00	0.99
5.01	0.83	80.6	4.98	0.59
9.55	1.58	69.9	9.404	1.05
10.48	1.74	66.2	10.30	1.7
11.68	1.95	61.9	11.52	1.366
13.16	2.20	57.8	13.12	0.30
15.67	2.62	50.2	15.59	0.51
19.77	3.29	39.4	19.65	0.60
21	3.50	36	20.9	0.48
22.43	3.76	30.3	22.47	-0.17

As can be analysed from the table, we get approximately correct level measurements. The percentage errors obtained are also in the allowable range which may be due to the low sensitivity of the sensors.

VI. RESULT AND DISCUSSION

Liquid level measurement is very crucial in industries dealing with liquids. Hence accurate measurement becomes an important task in such processes. In the proposed work a multi sensor data fusion framework was designed to obtain the objective of liquid level measurement using Ultrasonic sensor and the Capacitive level sensor. JDL framework was used to form the algorithm in the fuzzy logic tool. Results obtained validated correctly and showed accurate results with a little amount of error due to sensor sensitivities. The same work can be carried out for other liquids with different permittivity's.

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