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Nonintrusive Method for Liquid Level and Volume Measurement

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Abstract: **Liquid level is an important process parameter; it plays a key role in many industrial processes. Accurate gauging of liquid level is necessary when computing liquid volume in the process tanks. The accuracy of the measurement depends upon the measurement system used and the conditions in which these level measurement techniques are made. When the liquid in the tank is corrosive, it generally gets evaporated, and hence the contact type techniques are not recommended.**

In this paper an attempt has been made to develop a system which measures liquid level and volume using nonintrusive technique. We have proposed He-Ne laser based technique with ARM-7 controller. A prototype experimental set up has been developed and the measurement has been carried out. Results obtained are compared with conventional dipstick method; It has been found that that the proposed method shown accuracy of ±2. 5% with sensitivity of 7mv/ml for water and 10mV/ml for slurry. Repeatability of around 0. 3% is observed. Also volume is calculated and compared with obtained experimental results and shows accuracy of ±3% with sensitivity of 90mV/m^3 for water and 100mV/m^3 for slurry, with the dynamic range supported by the proposed method is up to 250mm. The proposed method is well suited for closed tank level measurement.

Keywords: **Liquid level, computing, nonintrusive method, dipstick method, Arm 7, and dynamic range.**

1. INTRODUCTION

Liquid level and volume measurement techniques are generally based on resistive, inductive, capacitive, piezoelectric, ultrasonic and fiber-optic transducers [1]. In recent times, many researchers have proposed and reported several liquid level sensing techniques based on fiber-optic sensors [2]-[6]. These techniques measure liquid levels in terms of discrete levels. At the same time, they are characterized by a very small dynamic range of measurement in spite of their good sensitivities. The ultrasound sensors are also used to measure liquid level [7]. In ultrasound measurement techniques, the system parts should have good acoustic reflection properties. Otherwise, the sound waves are scattered. This may be a problem for different container shapes. Furthermore, if there are gas bubbles in the liquid the waves are scattered through the bubbles.

Number of physical principles is in practice to measure liquid-level sensors [8-10]. Generally, the choice of the most suitable level sensor for a specific application is based on the requirements such as; Dynamic range of measurement, Resolution, Accuracy, Characteristics of the liquid and Environment [11].

The presented technique provides better resolution of liquid level. At the same time, this method can be used for measurement of liquid level in excess of 150 mm in depth, whereas [2–5] do have 5–100 mm. Further, this technique can be used for precise measurement of liquid levels and volumes in biochemical, pharmaceutical laboratories and field applications.

2. MATERIAL AND METHODOLOGY

2. 1 Laser source and detector.

In the proposed method the linearly polarized Helium-Neon laser is used. It operates at frequency 474Hz, having wavelength of 632. 99nm with speed of 2. 99x10^8 m/sec and wave time of 2. 1115E^{-15} sec with power output 5mv [Jain-laser, India make].

There are various sensors used for sensing laser beam, few sensors works on Photo resistive and photoconductive principles are commonly used for their various advantages [11]. Here photo resistive sensor (LDR) is used has; operating temperature range of -55˚C to +125˚ C, ¼ Watt power rating, temperature coefficient of resistance ±15 ppm/˚C, with tolerance in resistance of ± 0. 25%, dark resistance of 100KΩ, maximum operating voltage of 150V and with diameter of 2. 3cm.

The light-detecting resistor (LDR) works on the principle of change in the resistance for the change in the intensity of the incident light [12]. This property of the LDR is mainly used in proposed method where in the laser light beam is incident on the LDR and the output of the LDR is connected to the electronic circuitry for measurement and further processing the physical parameter.

2. 3 Principle of measurement

The principle of measurement used in the proposed technique is quite different from the already reported fibre-optic liquid level sensors techniques [2-6].

When a laser beam is incident on the surface of a liquid, part of the incident light is reflected from the liquid surface, part of it undergoes refraction at the air-liquid interface and the remaining light is scattered in the bulk of the liquid and also on the liquid surface. The beam of light that is reflected from the liquid surface is of interest in liquid level measurement.

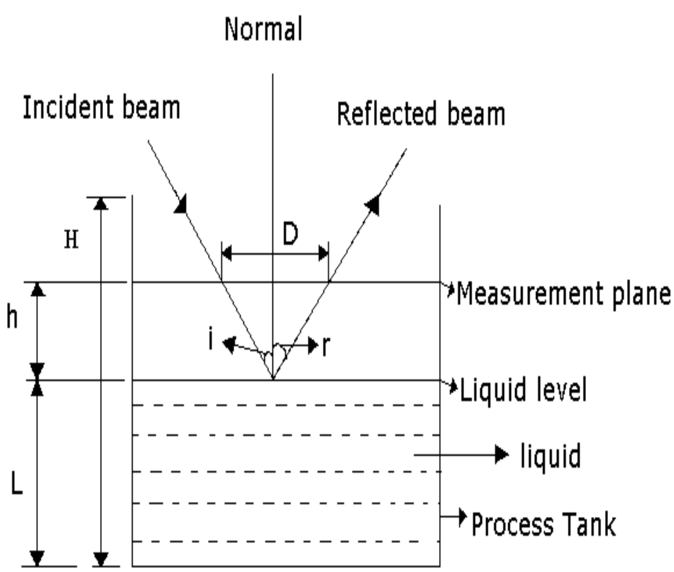

Fig. 1. Principle of measurement

The reflection coefficient of liquid level can be calculated from Fresnel reflection law.

$$\rho lq = [(n_1 - n_2)/(n_1 + n_2)]^{\wedge}{}_2 \quad (1)$$

Where
n_1= refractive index of medium in which incident beam is travelling.
n_2= refractive index of medium at the surface of which reflection occurs.

For air-water interface ρlq at 18° Celsius is 0. 02 [3]. When a 5Ww laser is used the optical intensity of the reflected beam is around 100μw.

The laser beam is incident on the liquid surface at an angle *'i'* as shown in Figure-1. A distance *'D'* on a measurement plane separates the incident beam position and reflected beam position. Two LDRs are moved at a constant velocity *'V'* on the measurement plane, at the position of incident beam the LDR1 triggers a timer ON and at the position of the reflected beam the LDR2 triggers the timer OFF, if *'t'* is the time indicated by the timer (i. e. time taken by the detector to move from incident beam position to reflected beam position) then distance *'D'* covered by the sensor head between the incident point and the reflected point of the laser beam on the liquid surface is deduced as;

$$D = Vx\, t \quad (2)$$

The liquid level (L) of the liquid in the process tank is determined using,

$$L = H - h \quad (3)$$

$where\ h = \frac{D}{2} x \tan r$
$H = height\ of\ the\ process\ tank$

The time taken by the moving sensor between the two beam points is measured and processed to calculate the liquid level using ARM-controller and displayed in 16 x 2 LCD display.

3. METHOD

3. 1. Process Tank Design

The measurement range and the angle of incidence of the incident beam primarily influence the design of tank. For a measurement range of 0-30cm and an angle of incidence of 30 degrees, the measurement range on the measurement plane is given by,

$$D = 2\ x\ h\ x \tan 29.5 \quad (4)$$

Where h = distance of measurement plane from maximum level of 30cm. With h = 40cm, D = 45. 26cm. The width of the tank is selected to be greater than 45. 26cm; it is taken as 60cm. The height of the tank is chosen to be greater than 40cm; it is taken as 60cm. For convenient machining the tank is designed with as 60cm x 60cm x 60cm cube. The prototype tank is fabricated using a 1. 3mm thick iron sheets. The mouth of the tank is closed using a 60cmx 60cm iron lid.

3. 2 Design of Measurement Head

The measurement head comprises of a lead screw, guide rod, with its housing bearing and D. C. motor to rotate the lead screw and slide element to hold detector. The mechanical system is fixed into the tank wall. The lead screw has square threading with a pitch of 6mm. It is fitted into a square block housing with bearings. The lead screw is coupled externally to a dc motor having 200 rotations per minute. Gears are used to reduce the rotation of the lead screw to 52 rotations per minute. The dc motor used is operated at 12Vdc, 3A and has a torque of 3kg. The slide element holding the LDR's is welded into a nut which passes through the lead screw and guide rod. The slide element travels with a velocity of 0. 47cm/sec. Schematic diagram of proposed prototype method showing various parts of measurement head are shown in Figure-3. 1.

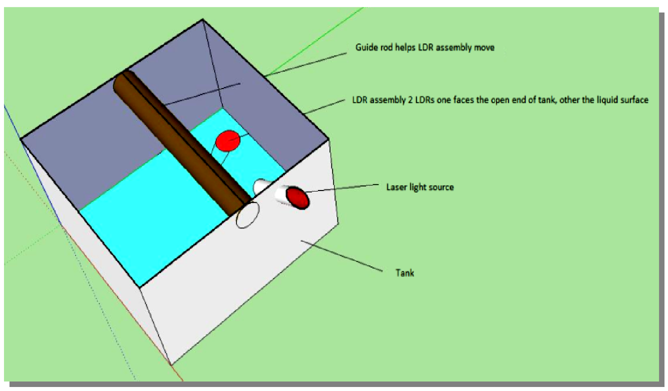

Fig. 3. 1. Proto type Model

3.3 Signal Conditioning Circuitry

The schematic diagram of signal conditioning circuit is shown in Figure-3. 2. It consists of voltage amplifier and comparator. The change in resistance of the LDR due to the incidence of laser beam (incident and reflected beam) is to be obtained as a voltage pulse. In order to realize this series combination of LDR's are connected as a feedback resistor in an inverting op-amp voltage amplifier with an input voltage of 0. 5Vdc. As the detector passes through the position of laser beam, the operational amplifier produces the output voltage between 0. 3V to 3. 5V. A comparator with a fixed reference voltage of 2V is fed along with the output of the operational amplifier. The output of the comparator is initially high (logical 1= 5V), when the op-amp output goes to 3. 5V the comparator output goes low (logical = OV).

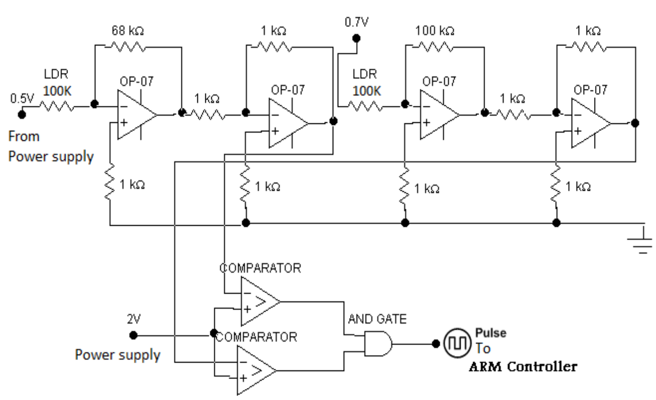

Fig. 3. 2. Signal conditioning circuit

Similarly, when the second LDR passes over the reflected beam, the operational amplifier output voltage changes from 0. 045V to 1. 3V. The comparator reference voltage given in this case is 0. 7V. So whenever output of the op-amp is more than 0. 7V the comparator output goes low. Thus a voltage pulse is produced whenever the detector system crosses the laser beam.

The output of the two comparators is feed to the AND gate. The output of the gate is high only when the output of the two comparators is high. Thus a voltage pulse is produced whenever the detector system crosses the laser beam. This voltage pulse is used as an external interrupt to drive the ARM controller as shown in circuit schematic diagram Figure 3. 3.

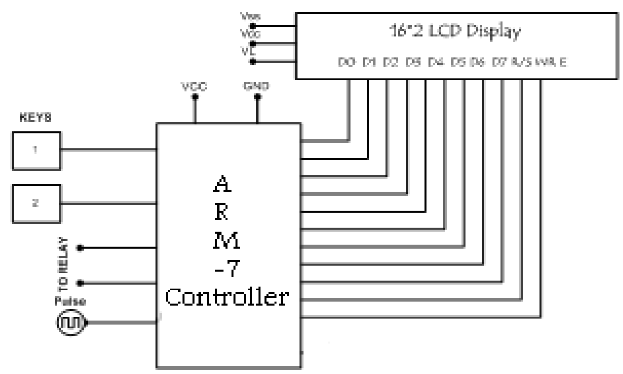

Fig. 3. 3. Circuit Schematic diagram

The relay driver circuit is used to drive and control the position of LDR mounted on slide. The control voltage of either zero volts or five volts is taken out from the microcontroller ports for driving the relay through the driver IC 74LS244. The output of this is connected to pair of relays. One is used to switch ON/OFF the DC motor and other is used to change the polarity if the shaft movement. And also the direction motors controlled through the software. When the moving head reaches one extreme part of the tank, the motor is directed in reverse direction. The measured physical quantity calibrated and displayed in 16 x 2 display

4. RESULTS AND DISCUSSION

To validate the proposed work using non-intrusive method, real time experiments were carried out with developed prototype tank of dimensions 60cm x 60cm x 60cm. The experimental results obtained are plotted in Figure 4a-4c.

Experimental result shows the accuracy of ±3% with sensitivity of 7mv/ml for water was produced and calibrated. The table, 4-1 and 4-2 shows the actual reading, obtained readings and error for two liquid containers of water and slurry.

Experimental plots shown in the Figure, 4a-4c has also confirmed sensitivity degradation with a decrease in the transparency of liquids. At the same time, it is also found to be higher for liquids having higher refractive indices. The results obtained by the proposed method shows highly linear with resolution of 10mV/ml approximately.

TABLE 4-1: Results comparison of level and volume for water

Liquid Type	Dipstick value in mm	Level measured in mm	Level Error in mm	Actual volume of liquid in m^3	Volume measured in m^3	Error in in m^3
water	10	9. 78	. 22	0. 0036	0. 00352	$0.08 * 10^{-3}$
	25	24. 72	. 28	0. 009	0. 00889	$0.10 * 10^{-3}$
	50	49. 39	. 61	0. 018	0. 01778	$0.220 * 10^{-3}$
	75	74. 20	. 8	0. 027	0. 02671	$0.3 * 10^{-3}$
	100	98. 68	1. 32	0. 036	0. 03552	$0.475 * 10^{-3}$
	150	146. 20	3. 8	0. 054	0. 05263	$1.36 * 10^{-3}$
	200	195. 30	4. 7	0. 072	0. 07030	$1.7 * 10^{-3}$

TABLE 4-2: Results comparison of level and volume of slurry

Liquid Type	Dipstick value in mm	Level measured in mm	Level Error in mm	Actual volume of liquid in m3	Volume measured in m3	Error in in m3
Slurry	10	9. 2	0. 8	0. 0036	0. 00331	$0.29 * 10^{-3}$
	25	23. 8	1. 2	0. 009	0. 00856	$0.432 * 10^{-3}$
	50	48. 4	1. 6	0. 018	0. 01742	$0.576 * 10^{-3}$
	75	72. 9	2. 1	0. 027	0. 02624	$0.756 * 10^{-3}$
	100	97. 41	2. 59	0. 036	0. 03506	$0.933 * 10^{-3}$
	150	145. 2	4. 8	0. 054	0. 05227	$1.73 * 10^{-3}$
	200	194. 6	5. 4	0. 072	0. 07005	$1.944 * 10^{-3}$

The measurement technique presented in this paper is a very simple, low cost, and innovative technique. The performance of the system can be improved by further optimization and fine-tuning in certain key aspects related to the laser light focusing arrangement and the sensitivity of the detector.

5. CONCLUSION

The proposed work has the following advantage; it provides continuous measurement of liquid level with wide measurement dynamic range up to 250mm with liquid level sensitivity of approximately 10mV/ml. It is non-intrusive technique helps measure the level and volume of corrosive and other highly acidic liquids.

The hardware and software strategies chosen assure the following:

High static performance; the accuracy and repeatability being contained within the transducer resolution; Acceptable dynamic performance; it strongly depends on the liquid viscosity but could be improved by either increasing the ADC conversion rate or changing the software strategy; High reliability; a further improvement could be obtained by increasing the number of lasers.

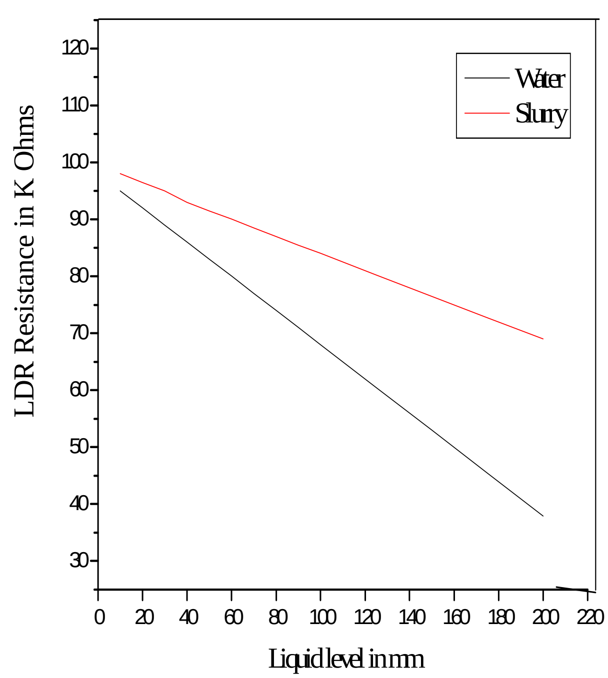

Fig. 4a. Experimental plots for two liquid containers: (a) LDR resistance variation with water and slurry level;

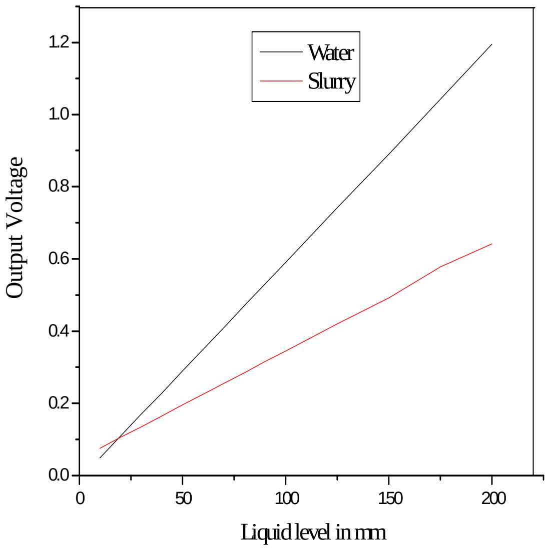

Fig. 4b. Experimental plots for two liquid containers: (a) proportional DC voltage with water and slurry level;

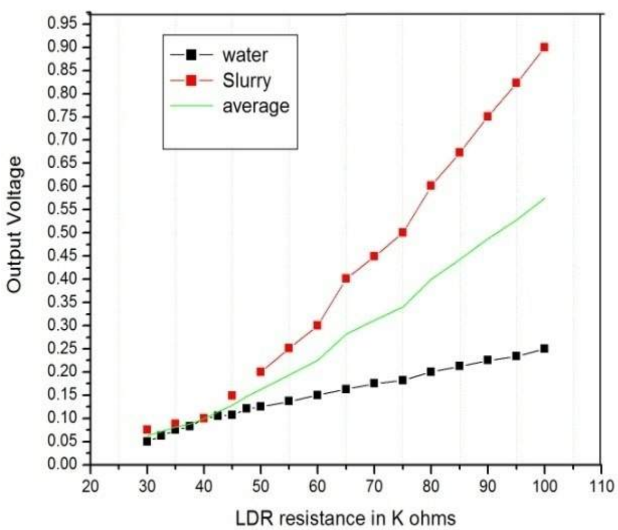

Fig. 4c. Experimental plots of sensitivity forliquids;.

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