

Real time level, temperature, Quantity and density measurements for petroleum storage tanks

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Abstract—This work presents a cheap ,standard (out of shelf) components real time system to measure the level, Quantity (Liter), Temperature and density of petroleum product in storage tanks based on measuring the Absolut pressure at two points with known distance . The system was designed and implemented based on one PLC , two pressure sensors and PT100 sensor per tank .the system could be used for monitoring N storage tanks simultaneously and reporting to a remote control center where a record is added to the database whenever there is a change in any parameters. The system is operational with accepted result.

Keywords— PLC, DP, GUI, IIR Filter, Web Based, PT100, ADC, RS485, 4-20ma

I. INTRODUCTION

A. Level measurement

Different methods have been used for measuring and monitoring liquid levels. Mechanical float-type depending on up / down movement of a float device placed in the vessel itself. An accurate readings could be obtained but requires frequent calibration and maintenance. An ultrasonic depending on measuring the time required for ultrasound pulses to make around from the sensor to the level although this method avoid direct contact with the fluid, but suffers from inaccuracies causes by varying temperatures and densities in the area above the fluid level and from potential confusion of echoes [1]. Microwave and radar uses low power high frequency impulses and the time difference between transmitted and received impulses to measure the level although more accurate result could be obtained as compared to ultrasound an inaccurate measurements are obtained in fluids with poor dielectric constants. Depending on the operation frequency, the antenna dimensions can limit the minimal distance to the liquid surface to be measured. Even more, all previous methods are electronic in nature so they suffer from intrinsic safety concerns. As with any electronic device, there are necessarily, heat generating Components that create, no matter how remote, the possibility of hazardous situations when used in areas where flammable materials are present. So an extra cost must be considered to make these techniques suitable for inflammable atmospheres with no risk. Optical technologies uses infrared transmitter and receiver with same principle although very good repeatability, hysteresis and response time it is used for transparent liquid and small vessels And wide bandwidth. Different laser and optical instrumentation devices have been already used in level measurement systems, such as

the patent described in [2]. But in any of them the laser, so the electronic driver, is in the sensor head. To avoid electronic presence in the measuring point, optical fibers should be used in the sensor head. This idea has been used in different optical sensors but for measuring short distances or just as simple control level devices [3-4]. A remote sensor head based on optical fibers for long distance is reported in [5] but using different lenses from transmitter and receiver fibers With the complexion related to this disposition, the measuring principle is different and none optical multiplexing is discussed. Differential pressure method based on measuring the pressure difference between two points the level could be obtained when the density is known. DP transmitters are subject to errors due to changes in liquid density. Density variations are caused by temperature changes or change of product. These variations must always be compensated for if accurate measurements are to be made [6].

B. Density Meters

Different methods have been used for measuring and monitoring liquid density. Pythagoras method based on measuring the mass of displaced liquid. Microwave method based on measuring the phase difference between the wave transmitted through drinking water and through the liquid for which the density have to measured Vibrating element method based on measuring the shift in resonance frequency of an element immersed in the liquid which depend on liquid density with temperature compensated method Mass measurement method based on accurate masse measurement for a known volume but none of these are continuous or on-line devices and cannot be considered densitometers. However, discrete measurements such as a pycnometer test are routinely used to prove a densitometer.[7,8].

II. THEORY

A. Level measurement

Using two pressure sensors fixed as shown in Fig. 1 with known distance between the two (D)

$$P = L * \rho * g \tag{1}$$

Where P=Pressure (Pascal) , ρ = Density (Kg/m³)
g = acceleration(m²/s), L = level (m)

$$P1 = L1 * \rho * g \tag{2}$$

$$P2 = L2 * \rho * g \tag{3}$$

$$\frac{P2}{P1} = \frac{L2}{L1} \tag{4}$$

$$L2 - L1 = D \tag{5}$$

So knowing P2 and P1 from sensor reading and D, L2 and L1 could be found .

B. Density measurement

Density could calculate by three ways

$$\rho_1 = \frac{P1}{L1 * g} \tag{6}$$

$$\rho_2 = \frac{P2}{L2 * g} \tag{7}$$

$$\rho_3 = \frac{(P2 - P1)}{(L2 - L1) * g} \tag{8}$$

The final value could be calculated

$$\rho = \frac{(\rho_1 + \rho_2 + \rho_3)}{3} \tag{9}$$

C. Quantity Measurement

- Theoretical calculation

Knowing the theoretical tank geometry (for example cylinder) the quantity Could be calculated as follow

$$Q1 = A * (L2 + D_d) \tag{10}$$

$$Q2 = A * (L1 + D + D_d) \tag{11}$$

The final value

$$Q = \frac{(Q1 + Q2)}{2} \tag{12}$$

Where A=Tank base area=distance between the two sensors , D_d = the distance from bottom to sensor P2 As shown in Fig.1

- Practical approach

A tank calibration table which give the quantity/level step have to be supplied For each tank by an authorized authority. having this table the quantity could be found by using the measured level as an Index in the table to extract the quantity

D. Temperature Measurement

For each PT100 sensor a circuit as shown in Fig.5 Where R-PT100 sensor resistance as a function of temperature, R_{in} =input resistance for ADC card (250 Ohms in this design) , r=cable resistance from sensor to input of ADC,I = current measured by PLC

$$R - PT100 = \frac{5}{I} - r - R_{in} \tag{13}$$

Using a lookup table where the address is the measured resistance and The content is the temperature corresponding to this resistance as given for PT-100 sensor as shown in Fig. 6, the temperature Could be measured with 1C⁰ accuracy

E. Resolution

Level resolution measurement correspond to level calculated when the Output from ADC change by 1 . (for the sensor used in this design the maximum Measured pressure = 2.5 Bar and the maximum digital value for ADC = 16000)

Level Accuracy = [2.5 *100000]/ [16000*9.81*D]

For water the accuracy D= 1000 kg/m³

Level accuracy = 1.5625 mm

Level accuracy = 2.14 mm

Which is comparable to current expensive level meters (radar, ultrasound...)

F. Filter

All measure parameters P2, P1 and temperature are filtered by IIR filter implemented in the PC

$$Y(n) + (1 - \alpha) * X(n) + \alpha * Y(n - 1) \tag{14}$$

A good and stable measurements are obtained using $\alpha \leq 0.1$ with sampling frequency = 10 Hz

III. IMPLEMENTATION

The system implementation as shown in Fig. 2

- modular PLC type with floating point instruction for filters calculation
- ADC (14 Bits (0-16000), 16 channels ADC, 0.5ms conversion time)
- RS485 communication module
- Pressure sensors (2.5 Bar Maximum and 4-20 ma output)
- PC GUI as shown in Fig 3 and for a single tank as shown in Fig 4.
- C# 2010 is used for software for GUI where for each tank Temp, Density, Quantity and Level are displayed
- Three modes of operation are used
 - P2-P1 mode in this mode all the parameters (L2, L1, and Density) are calculated
 - P2-D mode in this mode the density is calculated OFF line and the density Have to be entered as input to the system
 - P1-Mode the same as P2_D using P1 and Density
- SQL Database is used to store the records for each tank containing date,time,L2,L1,Temp and Density Whenever there is a change

IV. CONCLUSION

1. Better resolution could be obtained using more than 14 Bits ADC and pressure sensors with less than 2.5 Bar (1.5 Bar) as explained in resolution calculation
2. Better accuracy and resolution could be obtained using intelligent pressure sensors with build in processor and compensations to be connected to PC directly through standard protocol(ModBus,Can,RS485,..)
3. A web based software could be used to remotely monitoring the system from any browser
4. Control and monitoring on the petroleum products in each tank could be easily done based on database
5. A more accurate result could be obtained using multi sensors for temperature and density at different tank levels.



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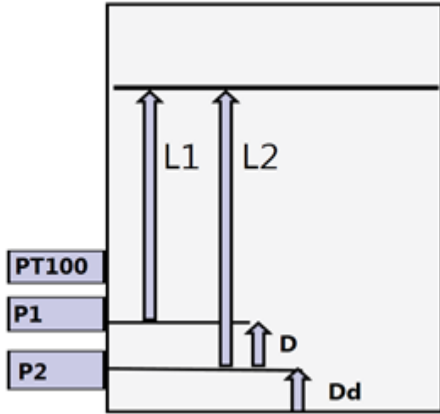


Fig. 1. Pressure and Temperature Sensors

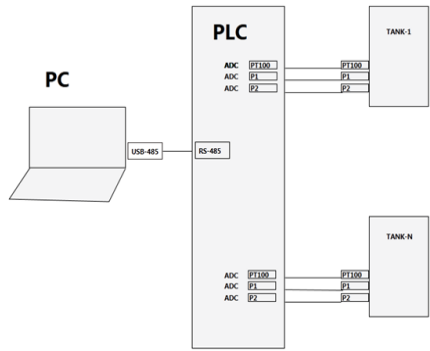


Fig. 2. System Block Diagram

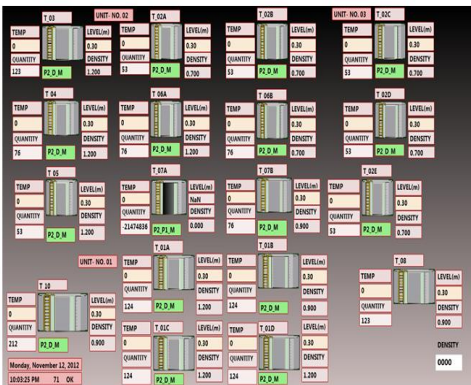


Fig. 3. Graphic User Interface

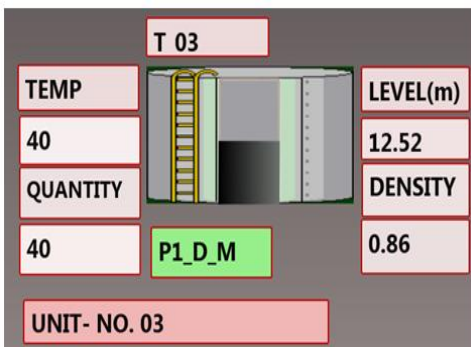


Fig. 4. Single Tank GUI

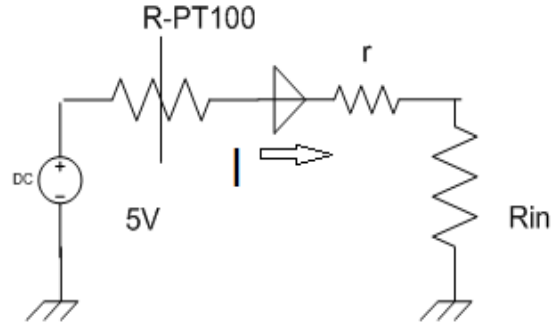


Fig. 5. Temperature Model Calculation

PT100 TEMPERATURE / RESISTANCE TABLE

°C	0	1	2	3	4	5	6	7	8	9	°C
-200	18.8423										18.8423
-190	22.9031	22.3737	21.9439	21.5139	21.0834	20.6526	20.2215	19.7909	19.3598	18.9292	-190
-180	27.0779	26.6280	26.1781	25.7281	25.2781	24.8281	24.3781	23.9281	23.4781	23.0281	-180
-170	31.2527	30.7827	30.3127	29.8427	29.3727	28.9027	28.4327	27.9627	27.4927	27.0227	-170
-160	35.4275	34.9375	34.4475	33.9575	33.4675	32.9775	32.4875	31.9975	31.5075	31.0175	-160
-150	39.6023	39.0923	38.5823	38.0723	37.5623	37.0523	36.5423	36.0323	35.5223	35.0123	-150
-140	43.7771	43.2471	42.7171	42.1871	41.6571	41.1271	40.5971	40.0671	39.5371	39.0071	-140
-130	47.9519	47.4019	46.8519	46.3019	45.7519	45.2019	44.6519	44.1019	43.5519	43.0019	-130
-120	52.1267	51.5567	50.9867	50.4167	49.8467	49.2767	48.7067	48.1367	47.5667	47.0067	-120
-110	56.3015	55.7115	55.1215	54.5315	53.9415	53.3515	52.7615	52.1715	51.5815	51.0015	-110
-100	60.4763	59.8663	59.2563	58.6463	58.0363	57.4263	56.8163	56.2063	55.5963	55.0063	-100
-90	64.6511	63.9911	63.3311	62.6711	62.0111	61.3511	60.6911	60.0311	59.3711	58.7211	-90
-80	68.8259	68.0459	67.2659	66.4859	65.7059	64.9259	64.1459	63.3659	62.5859	61.8159	-80
-70	72.9997	72.0997	71.1997	70.2997	69.3997	68.4997	67.5997	66.6997	65.7997	64.8997	-70
-60	77.1735	76.1435	75.1135	74.0835	73.0535	72.0235	70.9935	69.9635	68.9335	67.9035	-60
-50	81.3473	80.1973	79.0473	77.8973	76.7473	75.5973	74.4473	73.2973	72.1473	71.0073	-50
-40	85.5211	84.2511	82.9811	81.7111	80.4411	79.1711	77.9011	76.6311	75.3611	74.1011	-40
-30	89.6949	88.3049	86.9149	85.5249	84.1349	82.7449	81.3549	79.9649	78.5749	77.1849	-30
-20	93.8687	92.3587	90.8487	89.3387	87.8287	86.3187	84.8087	83.2987	81.7887	80.2787	-20
-10	98.0425	96.4125	94.7825	93.1525	91.5225	89.8925	88.2625	86.6325	85.0025	83.3725	-10
0	102.2163	100.4763	98.7363	96.9963	95.2563	93.5163	91.7763	90.0363	88.2963	86.5563	0
10	106.3901	104.5401	102.6901	100.8401	98.9901	97.1401	95.2901	93.4401	91.5901	89.7401	10
20	110.5639	108.6039	106.6439	104.6839	102.7239	100.7639	98.8039	96.8439	94.8839	92.9239	20
30	114.7377	112.6577	110.5777	108.4977	106.4177	104.3377	102.2577	100.1777	98.0977	96.0177	30
40	118.9115	116.7215	114.5315	112.3415	110.1515	107.9615	105.7715	103.5815	101.3915	99.2015	40
50	123.0853	120.7853	118.4853	116.1853	113.8853	111.5853	109.2853	106.9853	104.6853	102.3853	50
60	127.2591	124.8491	122.4391	119.9291	117.4191	114.9091	112.3991	109.8891	107.3791	104.8691	60
70	131.4329	128.9129	126.3929	123.8729	121.3529	118.8329	116.3129	113.7929	111.2729	108.7529	70
80	135.6067	132.9767	130.3467	127.7167	125.0867	122.4567	119.8267	117.1967	114.5667	111.9367	80
90	139.7805	137.0405	134.2905	131.5405	128.7905	126.0405	123.2905	120.5405	117.7905	115.0405	90
100	143.9543	141.1043	138.2543	135.4043	132.5543	129.7043	126.8543	123.9043	121.0543	118.2043	100
110	148.1281	145.1681	142.2181	139.2681	136.3181	133.3681	130.4181	127.4681	124.5181	121.5681	110
120	152.3019	149.2419	146.1919	143.1419	140.0919	137.0419	133.9919	130.9419	127.8919	124.8419	120
130	156.4757	153.3157	150.1657	147.0157	143.8657	140.7157	137.5657	134.4157	131.2657	128.1157	130
140	160.6495	157.3895	154.2395	151.0895	147.9395	144.7895	141.6395	138.4895	135.3395	132.1895	140
150	164.8233	161.5733	158.4233	155.2733	152.1233	148.9733	145.8233	142.6733	139.5233	136.3733	150
160	168.9971	165.6471	162.4971	159.3471	156.1971	153.0471	149.8971	146.7471	143.5971	140.4471	160
170	173.1709	169.7209	166.5709	163.4209	160.2709	157.1209	153.9709	150.8209	147.6709	144.5209	170
180	177.3447	173.7947	170.6447	167.4947	164.3447	161.1947	158.0447	154.8947	151.7447	148.5947	180
190	181.5185	177.8685	174.6185	171.4685	168.3185	165.1685	162.0185	158.8685	155.7185	152.5685	190
200	185.6923	181.9423	178.5923	175.4423	172.2923	169.1423	165.9923	162.8423	159.6923	156.5423	200
210	189.8661	186.0161	182.7661	179.6161	176.4661	173.3161	170.1661	167.0161	163.8661	160.7161	210
220	194.0399	190.0899	186.8399	183.6899	180.5399	177.3899	174.2399	171.0899	167.9399	164.7899	220
230	198.2137	194.1637	190.9137	187.7637	184.6137	181.4637	178.3137	175.1637	172.0137	168.8637	230
240	202.3875	198.2375	194.9875	191.8375	188.6875	185.5375	182.3875	179.2375	176.0875	172.9375	240
250	206.5613	202.4113	199.1613	196.0113	192.8613	189.7113	186.5613	183.4113	180.2613	177.1113	250
260	210.7351	206.5851	203.3351	200.1851	197.0351	193.8851	190.7351	187.5851	184.4351	181.2851	260
270	214.9089	210.7729	207.5229	204.3729	201.2229	198.0729	194.9229	191.7729	188.6229	185.4729	270
280	219.0827	214.9467	211.6967	208.5467	205.3967	202.2467	199.0967	195.9467	192.7967	189.6467	280
290	223.2565	219.1205	215.8705	212.7205	209.5705	206.4205	203.2705	200.1205	196.9705	193.8205	290
300	227.4303	223.2943	220.1443	217.0943	213.9443	210.7943	207.6443	204.4943	201.3443	198.1943	300
310	231.6041	227.4581	224.3081	221.2581	218.1081	215.0581	211.9081	208.7581	205.6081	202.4581	310
320	235.7779	231.6219	228.4719	225.4219	222.2719	219.1219	215.9719	212.8219	209.6719	206.5219	320
330	239.9517	235.8957	232.7457	229.6957	226.5457	223.3957	220.2457	217.0957	213.9457	210.7957	330
340	244.1255	240.0695	236.9195	233.8695	230.7195	227.5695	224.4195	221.2695	218.1195	214.9695	340
350	248.2993	244.2533	241.1033	238.0533	234.9033	231.7533	228.6033	225.4533	222.3033	219.1533	350

Fig.6 PT-100 Temperature/Resistance Table