Applied Mechanics and Materials Vols. 249-250 (2013) pp 1133-1138
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doi:10.4028/www.scientific.net/AMM.249-250.1133

Microcontroller System for Oil Refinery Parameters Measurements Based on Piezoresistive and Strain Gauge Pressure Sensors

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Keywords: Pressure measurement, Flow rate measurement, Level measurement, Piezoresistive DP sensor, strain gauge DP sensor, fuzzy logic.

Abstract. In oil refinery there is a variety of physical parameters such as pressure, flow rate and level that need to be measured. A microcontroller system is built based on PIC 16F877A, piezoresistive differential pressure DP sensor (24PC series) and strain gauge DP sensor (IDP-10) with ranges from 0 to 15psi. The results of the microcontroller system showed that; the percentage error for piezoresistive sensor in pressure from 0.43808% to 8.613 %, in flow rate from 0.21929% to 20.340%, and in level from 0.43808% to 2.5789%. While the percentage error for strain gauge sensor from 0.846% to 1.946% for pressure measurement, from 0.1% to 0.4% for flow rate measurement and from 0% to 0.64% for level measurement. The percentage error of the piezoresistive sensor is more than the percentage error of the strain gauge sensor: for pressure measurement by about 6.667%, for flow rate measurement by about 19.94% and for level measurement by about 1.9389%. Fuzzy logic is used to predict the output surface of pressure, flow rate, and level measurements.

Introduction

Measuring pressure, flow rate and level are the backbone of controlling oil refinery process. Pressure can be measured in vessels using Rayleigh waves and L_{CR} waves. The change in pressure induces a change in the stresses on the vessel's wall. According to variations in stress affect the wave velocity and propagation distance of the ultrasonic waves. The relationship between ultrasonic transit time delay and both pressure and temperature changes is established for measuring pressure [1].

Conventional flow meters produce a differential pressure in the flow, which is measured and suitably scaled to get the flow rate. Incidentally, a control valve uses the principle of restricting the area for flow control which in turn produces a differential pressure. So a method using a control valve for measurement and control of flow is established [2].Liquid level in tanks can be measured by using three capacitive sensors. This method eliminates the effect of air and gives the accurate reading of the liquid level in the tank. The main advantage of this method is that it can directly be applied to any kind of nonconductive liquid without calibration. The method is based on the measurements of capacitances of three parallel plate capacitive structures, which are designated as level, reference, and air sensors. The capacitance measurements are performed using a capacitance-to-digital converter integrated circuit, which can measure very small capacitances up to ±4 fF error [3].

In this paper a microcontroller circuit [4,5], piezoresistive and strain gauge DP sensors are used to measure pressure, flow rate and level in oil refinery. Flow rate can be detected by introducing a restrictor (Orifice plate, Venturi, Flow nozzle, Dall tube, Elbow) in the pipe which produces a differential pressure drop across it. This differential pressure is an input for the piezoresistive and strain gauge sensors. Whereas liquid level can be measured by the means of the hydrostatic pressure caused by a column of liquid, this pressure also is an input to the piezoresistive and strain gauge sensors. The outputs of the sensors are detected by the microcontroller and monitored on LCD, and then a proper intelligent processing using fuzzy logic has been chosen because it gives better results

and enhances discrimination techniques among sensed pressures. Fuzzy logic systems encode human reasoning to make decisions and control dynamical systems. Fuzzy logic comprises fuzzy sets which are methods of representing non-statistical uncertainty and approximate reasoning, including the operations used to make inferences. It is a tool for mapping the input features to the output, based on data in the form of "IF - Then" rules as in [6,7,8,9]. An implementation of a fuzzy expert system depends on Mamdani type fuzzy controller. The objective of the controller is to discriminate different pressure ranges and to detect the output pressure, flow rate and level according to the input variables.
There are five steps to construct a Mamdani type fuzzy controller:

Step 1. Identify and name the input linguistic variables and their numerical ranges [6,7,8,9]. There are two input variables for each measurement which are differential pressure and output voltage of the sensors. There are five ranges for each variable, which have been identified.
Pressure, flow rate and level measurement:

Differential pressure (psi)
Linguistic range
Low Low 0 < P < 5
Low 2.5 < P < 7.5
Medium 5 < P < 10
High 7.5 < P < 12.5
High High 10 < P < 15

Fig. 1 Presents the membership function for the input pressure.

Voltage (mv)
Linguistic range
Low Low 3.4 < V < 37
Low 20.2 < V < 53.8
Medium 37 < V < 70.6
High 53.8 < V < 87.4
High High 70.6 < V < 104.3

Fig. 2 Presents the membership function for the input voltage.

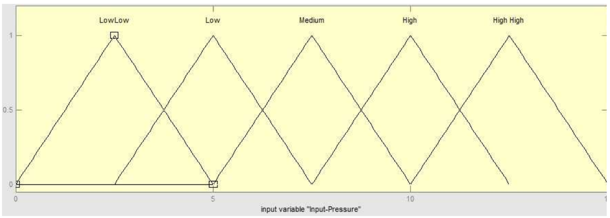

Fig. 1 The membership function of the input pressure

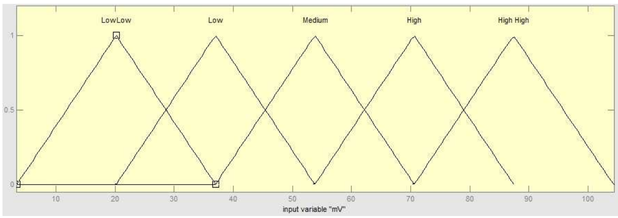

Fig. 2 The membership function of the input voltage

Step 2. Identify and name the linguistic output variable and its numerical ranges [6,7,8,9]. There is one output variable for each measurement.

For pressure measurement (psi)
Linguistic range
Low Low 0 < P < 5
Low 2.5 < P < 7.5
Medium 5 < P < 10
High 7.5 < P < 12.5
High High 10 < P < 15

Fig. 3 Presents the membership function for the output pressure.

For flow rate measurement (% flow)
Linguistic range
Low Low 0 < F < 33.3
Low 16.6 < F < 49.9
Medium 33.3 < F < 66.5
High 49.9 < F < 83.1
High High 66.5 < F < 100

Fig. 4 Presents the membership function for the output flow rate.

For level measurement (% level)
Linguistic range
Low Low 0 < L < 33.3
Low 16.6 < L < 49.9
Medium 33.3 < L < 66.5
High 49.9 < L < 83.1
High High 66.5 < L < 100

Fig. 5 Presents the membership function for the output level.

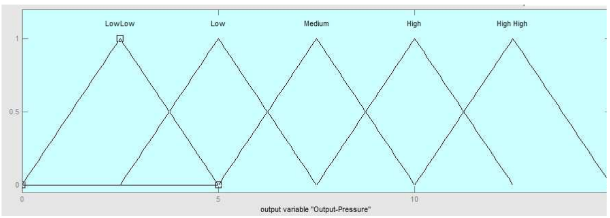

Fig. 3 The membership function of the output pressure

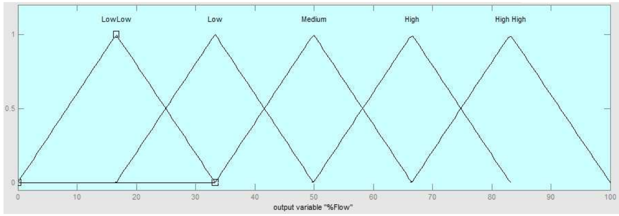

Fig. 4 The membership function of the output flow rate

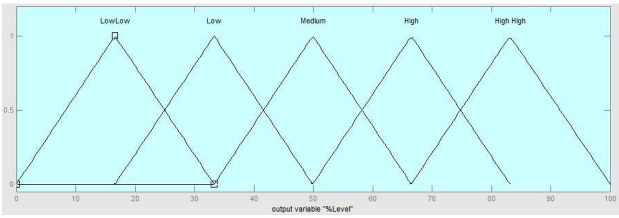

Fig. 5 The membership function of the output level

Step 3. Define a set of fuzzy membership functions for each of the inputs and the output, variables. The low and high values are used to define a triangular membership functions. The height of each function is one and the function bounds do not exceed the high and low ranges listed above for each range.

The membership functions must cover the dynamic ranges, related to the minimum and maximum values of inputs and output that represents the universe of discourse [6,7,8,9].

Step 4. Construct the rule base that will govern the controller's operation. The rule base is represented as a matrix of inputs and output variables. At each matrix row different input variable ranges with one of the output variable range. All rules were activated and fired in parallel whether they were relevant or not and the duplicate ones are removed to conserve computing time. Each rule base is defined by AND together with the inputs to produce each individual output response, for example: If pressure is low AND, if voltage is low THEN flow rate is low [6,7,8,9].

Step 5. The control actions will be combined to form the excited interface. The most common rules combination method is the centroid defuzzification to get the crisp output value. This step is a repeated process, after all adjustments are made, which allows the fuzzy expert system to be able to discriminate and classify the data set patterns pressure, flow rate and level [6,7,8,9].

The organization of this paper is as follows, materials and method, results and analysis then conclusion.

Materials and method

The microcontroller circuit consists of:

1. Microcontroller PIC16F877A with embedded (A/D) converter. It is chosen for the implementation of this task due to the on-chip memory resources, as well as its high speed and its analog pin input. The output data is monitored on LCD. The software is developed in C language and then is compiled, assembled, and down-loaded to the IC.
2. 4 MHz crystal oscillator (X1).
3. Two ceramic capacitors 18pF for reducing noise (C1 & C2).
4. 10k ohm resistance (R1).
5. Push button for reset (SW1).
6. Piezoresistive (24PC series) and strain gauge (IDP-10) differential pressure sensors with two pressure ports high and low.
7. LCD alphabetical 16*4.

All this components are connected as shown in Fig. 6 simulated by PROTEUS ISIS 7.7 professional suite.

For measuring gauge pressure: the process pressure is an input for the DP sensors at the high side and the low side vents to ambient pressure.
In measuring flow rate and level: the high process pressure is applied to the high side and the low process pressure is applied to the low side.
The outputs of the sensors are monitored by a microcontroller and showed on the LCD as a function of pressure, percentage flow and percentage level. The output voltage of the sensors was measured by digital AVO meter.

Results and Analysis

After the experiment has been setup and data have been collected, data analysis has been done by using two methods.

The first method. Depends on the relation between the monitored reading by microcontroller with the input differential pressure ranges for each measurement; pressure, flow rate and level.
The output pressure readings of the designed microcontroller system are plotted with the input pressure refers to Fig. 7.

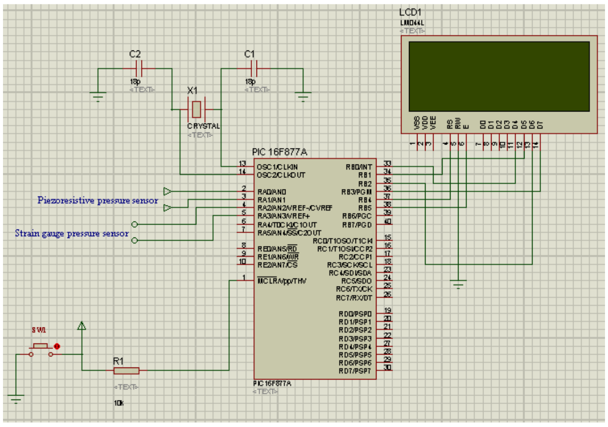

Fig. 6 The circuit diagram built by PROTEUS

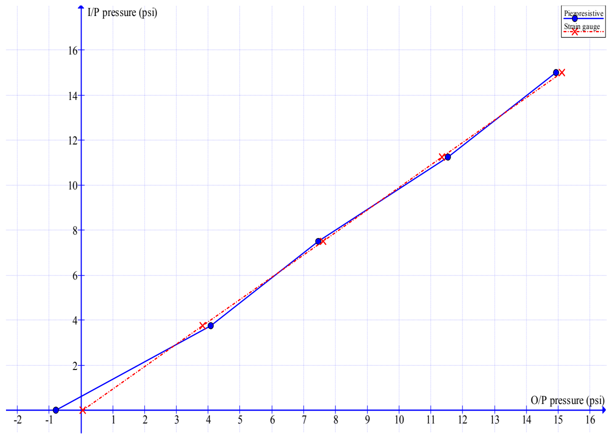

Fig. 7 The relation between the output pressure and the input pressure

DP flow rate is calculated refer to Eq. (1) [10]

$$Q = K\sqrt{\Delta P} \quad (1)$$

Q = the volumetric flow rate.
K = a constant for the pipe cross sectional area and liquid density.
ΔP = the differential pressure drop across the restriction.
The output flow rates readings of the designed microcontroller system are plotted with the input DP refer to Fig. 8.
From Eq. (1) it is noticed that the relation between flow rate and DP is square root which is similar to the plotted relation of Fig.8.

DP level is calculated refer to Eq. (2) [11].

$$\Delta P = \gamma \Delta h \quad (2)$$

ΔP= change in pressure.
γ = specific weight.
Δh = depth.
The output level readings of the designed microcontroller system are plotted with the input DP refers to Fig.9.

From Eq. (2) it is noticed that the relation between level and DP is linear which is similar to the plotted relation of Fig. 9.

The second method. Via fuzzy controller depending on the input differential pressure to the sensors and the output mV from the sensors as inputs to give online prediction of different pressure, flow rate and level measurements. The feature of each measurement is detected, based on the fuzzy system. The input and output surface of the fuzzy inference system is illustrated in Fig. 10-12 for the three parameters.

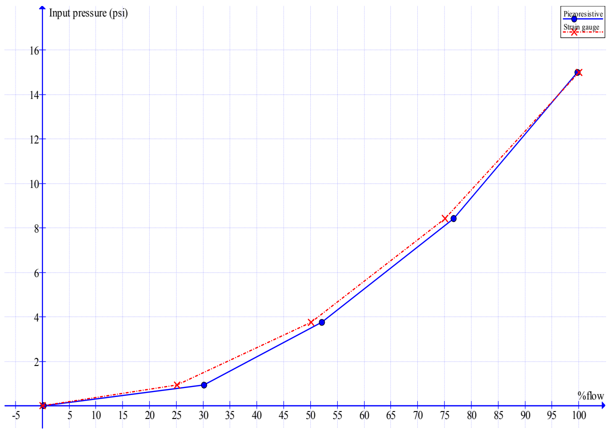

Fig. 8 The relation between the percentage flow and the differential input pressure (psi)

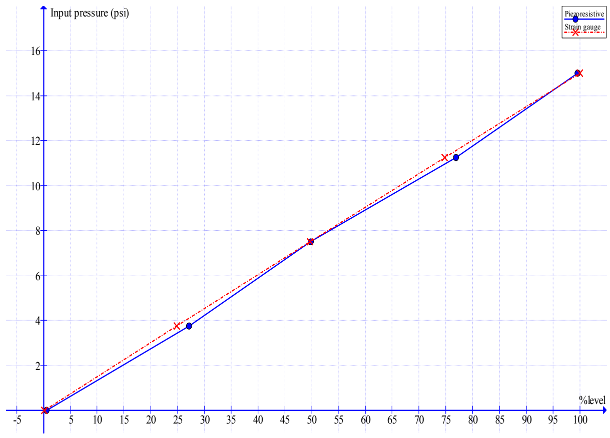

Fig. 9 The relation between the percentage level and the differential input pressure (psi)

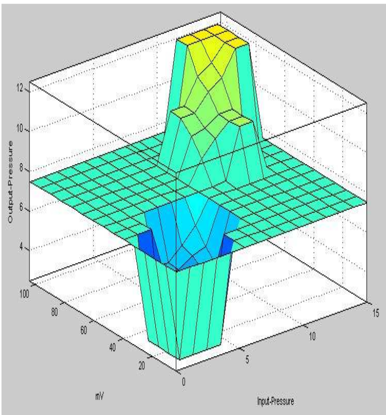

Fig. 10 The fuzzy surface of pressure measurements

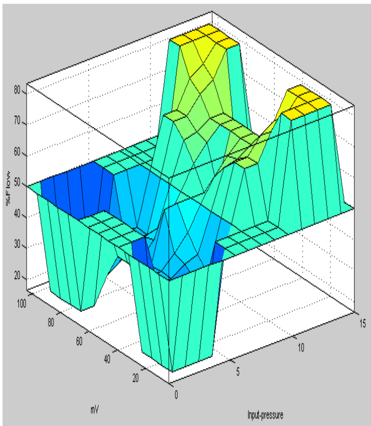

Fig. 11 The fuzzy surface of flow measurement

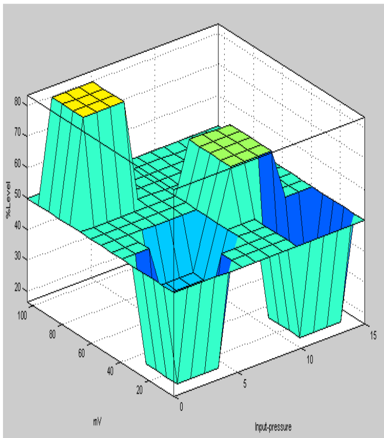

Fig. 12 The fuzzy surface of level measurements

Conclusion

A microcontroller system is built based on PIC 16F877A, piezoresistive DP sensor (24PC series) and strain gauge DP sensor (IDP-10) for measuring pressure, flow rate and level in oil refinery. The percentage error is calculated for each parameter at different set points. The percentage error depends on the output reading of the microcontroller system and the actual theoretical value. The output readings of the microcontroller system for pressure, flow rate and level measurements are plotted as in Fig. 7-9 simultaneously. The actual theoretical value for flow rate is calculated from Eq. (1) and for level is calculated from Eq. (2). For the piezoresistive sensor; the percentage error in pressure from 0.43808% to 8.613 %, in flow rate from 0.21929% to 20.340%, and in level from 0.43808% to 2.5789%. These values are compared with the percentage errors of the strain gauge sensor which are from 0.846% to 1.946% for pressure measurement, from 0.1% to 0.4% for flow rate measurement and from 0% to 0.64% for level measurement The comparison showed that The percentage error of the piezoresistive sensor is more than the percentage error of the strain gauge sensor: for pressure measurement by about 6.667%, for flow rate measurement by about 19.94% and for level measurement by about 1.9389%.

Mamdani type fuzzy controller is used to construct the rules, which are extracted from the data driven from the microcontroller system. It is used to illustrate measurements surfaces which give online prediction of pressure, flow rate and level that are extracted from the experiments.

The microcontroller system is simple and can be used as a portable device for measuring parameters at different test points in hazards area in oil refinery.

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