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FUSION OF VENTURI AND ULTRASONIC FLOW METER FOR ENHANCED FLOW METER CHARACTERISTICS USING FUZZY LOGIC

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Abstract

This paper proposes a technique for measurement of liquid flow using venturi and ultrasonic flow meter(UFM) to have following objectives a) to design a multi-sensor data fusion (MSDF) architecture for using both the sensors, b) improve sensitivity and linearity of venturi and ultrasonic flow meter and c) detect and diagnosis of faults in sensor if any. Fuzzy logic algorithm is used to fuse outputs of both the sensor and train the fuzzy block to produces output which has an improved characteristics in terms of both sensitivity and linearity. For identification of sensor faults a comparative test algorithm is designed. Once trained proposed technique is tested in real life, results show successful implementation of proposed objectives.

Keywords:

MSDF, Fuzzy, Flow Measurement, Fault Identification

1. INTRODUCTION

Control of fluid flow is a very important process in any industry, as many processes are related with control of liquid flow rate. Like in case of temperature control it is done by controlling the flow of steam; pressure control in pneumatic or hydraulic driven instruments is done by flow of air or liquid, etc. Control of flow can be achieved only by accurate flow measurement. In other cases, inaccurate flow measurements or failure to take measurements can cause serious (or even disastrous) results. Many sensors are used for the purpose of measurement of flow. Sensors can be classified based on working principle like drag type flow meter, obstruction type flow meters, volumetric flow meter, radiation type flow meter, electromagnetic flow meters, etc. of which obstruction type and radiation type are most commonly used.

Several researchers have reported works on measurement of flow like use of thermistor anemometer for measurement of flow rate of liquid is reported in [1]. Measurement of Liquid flow using a disk type ultrasonic flow meter is reported in [2]. Calibration of ultrasonic flow sensor is reported in [3]. Ultrasonic Doppler type of flow meter is used for measuring flow rate of liquid with bubbles in [4]. In [5], an estimation method for sensing flow rate of feed water is reported. A discussion on use of capacitive sensor for measurement of flow rate is reported in [6]. Analog circuits are used for calibration of capacitive sensor for measurement of flow rate. In [7], a discussion on use of centrifugal force type flow sensor for measurement of flow rate is discussed, and calibration of reported work is carried on by using a bridge network to an inductive pickup. In [8], a technique for measurement of liquid flow using an elbow with oval cross section is reported. In [9], neural network algorithms are used to calibrate the venturi flow meters which are used in wet gas flow measurement. Characteristics study of ultrasonic flow meter is reported in [10], its calibration techniques are discussed in [11]. In [12], design of orifice flow meter for measurement of reciprocating gas flow is discussed. Wet gas flow rate is measured using venturi flowmeter in [13]. Design of adaptive measurement technique using venturi flow meter is reported in [14]. Volumetric flow rate is discussed using a vortex meter in [15]. In a similar work [16], use of venturi flow meter for measuring two phase flow of wet gases is reported.

From reported works it is obvious that venturi flow meter is a widely used obstruction type flow meter because of its ease in construction and ruggedness. However problem of offset, non-linear response characteristics, low sensitivity have restricted its use. Similarly, Ultrasonic Flow Meters are popular among radiation type flow meters, as they are also widely employed in process industries for flow measurement because of its advantages like high sensitivity, ease to place, and noncontact to medium of measurement. But problem like nonlinearity, offset have restricted its uses. To overcome above drawbacks a technique is proposed using multi-sensor data fusion.

Multi sensor data fusion is a science of combining data from multiple sensors, and related information from associated databases to achieve more specific inferences than could not be achieved by the use of single sensor [17 - 19]. MSDF has gained significant attention in recent years for both military and non-military applications. Several researchers have reported work on use of multi-sensor data fusion. Like in [20], a multi sensor system is used to measure the glucose content in human body using non-invasive methods. Presence of fire is detected by using a cluster of sensors using MSDF architecture in [21]. In [22], a cluster of optical sensor, tactile sensors and tomography sensors are used in the analysis of earth geology using sensor fusion in a similar ground, an attempt is made in the proposed paper to design a multi-sensor based flow rate measurement system with the use of fuzzy logic algorithms.

Further, detection of faults in a sensor is very vital, because when we use a faulty sensor we ended up with an erroneous system behavior however accurate is the control system. Many reported works have discussed the basic technique for detection of sensor faults like in [23], a method for fault detection using principal component analysis for sensors in chillers is discussed. A technique for detection of fault in sensors used for process parameter is carried on using estimation is reported in [24]. An online method for detection of faults is discussed in [25]. In context to the earlier discussed work, this paper proposes a technique to design a flow measuring technique involving two dissimilar flow meters like venturi flow meter and ultrasonic flow meter having improved characteristics in terms of sensitivity and linearity, with detection of sensor fault if any.

The paper is organized as follows: after a brief introduction about proposed work in first section, descriptions on venturi and ultrasonic flow meters and its associated circuits are discussed in second section. In the third section drawbacks of present measurement is discussed followed by solutions in fourth section. Analysis of results obtained from proposed work is carried on in fifth section and finally conclusion of the proposed work in section six.

2. AVAILABLE TECHNIQUE

2.1 MEASUREMENT USING VENTURI

The block diagram of available flow measurement technique using venturi is as shown in Fig.1.

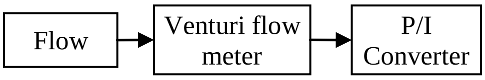

Fig.1. Available technique for flow measurement using venturi

A venturi flow meter (shown in Fig.2) is a device used for measuring the volumetric flow rate. It uses the Bernoulli's principle which gives a relationship between the pressure and the velocity of the fluid. The volumetric (Q) obtained from Bernoulli's equation by measuring the difference in fluid pressure between the normal pipe section and at the vena-contracta [26], [27] is given in Eq.(1).

$$\Delta P = kQ^2 \tag{1}$$

where,

$$k = \frac{\rho\left(1-\beta^4\right)}{2C_d^2 A_b^2}$$

C_d - Discharge coefficient

A_b - Area of the flowmeter cross section

β - Ratio of D_b to D_a

P_a - Pressure at study flow

P_b - Pressure at vena-contracta

ρ - Density of liquid

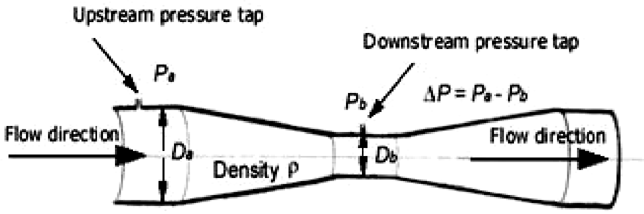

Fig.2. Venturi nozzle

This differential pressure is converted to current using a pressure sensor, and further converted to voltage using current to voltage converter.

2.2 MEASUREMENT USING UFM

The block diagram of available flow measurement technique using ultrasonic flow meter is as shown in Fig.3.

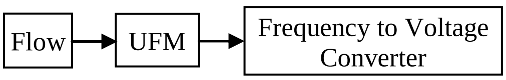

Fig.3. Available technique for flow measurement using UFM

Ultrasonic flow meters (UFM) are one of the most commonly used flow meters. Fig.4 shows the arrangement of one such UFM. Both sending and receiving transducers are mounted on either side of the flow meter, or pipe wall. The sending transducer sends an ultrasonic signal at an angle from one side of the pipe which is received by the receiving transducer. Flow meter measures time taken by ultrasonic signal to travel across the pipe in forward and reverse direction. When the signal travels along the direction of the flow, it travels more quickly compare to the condition of no flow. On the other hand, when the signal travels against the direction of flow, it slows down. The difference between the "transit times" of the two signals is proportional to flow rate [26], [27].

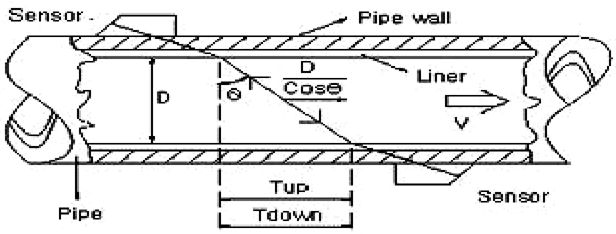

Fig.4. Arrangement of Ultrasonic flow meter

From Fig.4, we have

$$T_{up} = \frac{M * \dfrac{D}{\cos\theta}}{C_o + v\sin\theta} \tag{2}$$

$$T_{down} = \frac{M * \dfrac{D}{\cos\theta}}{C_o - v\sin\theta} \tag{3}$$

$$\Delta T = T_{up} - T_{down} \tag{4}$$

Frequency, $f_{IN} = 1/\Delta T$

where,

M - No of times ultrasonic signal travels in forward/ backward direction

C_o - Velocity of ultrasonic signal in static fluid

D - Pipe diameter

v - Velocity of fluid

Frequency is converted to voltage using a frequency to voltage converter.

3. PROBLEM STATEMENT

In this section, characteristic of venturi and UFM are analyzed to understand the difficulties associated with available measuring scheme. For this purpose, an experimental setup consisting of venturi/UFM is used for the purpose of measuring flow rate of the range 0 to 21 lpm. Outputs of measurement system using venturi flow and UFM for variations in input flow are noted and plotted in Fig.5 and Fig.6 respectively.

The Fig.5 and Fig.6 shows output characteristics for variation in input flow when tested with different flow meters like venturi and ultrasonic flow meter. It has been observed that relation between input flow rate and output voltages of two sensors have dissimilar characteristics. From the outputs one can conclude that flow measurement with venturi would have characteristics like offset, less sensitive output, and nonlinear response. Whereas output of UFM shows that it is highly sensitive, and highly nonlinear.

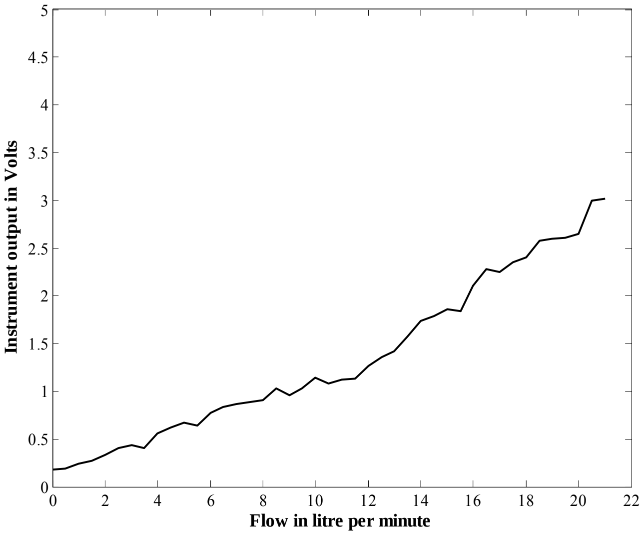

Fig.5. Characteristics of Venturi flow meter

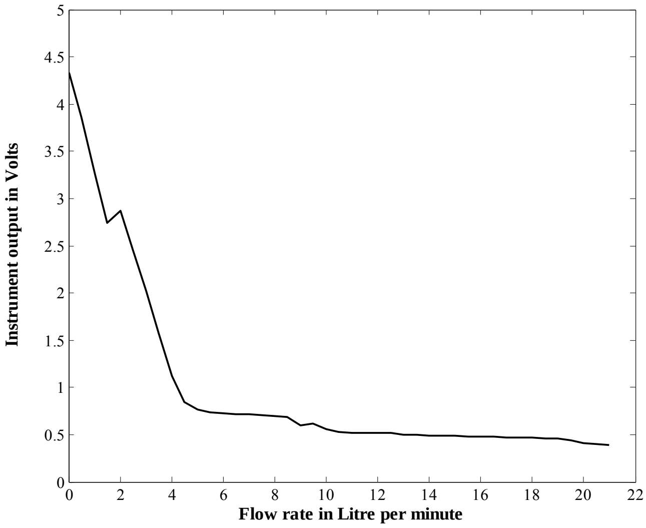

Fig.6. Characteristics of UFM

From above seen characteristics it is clear that designer will have to compromise any one of the characteristics (high sensitivity or linearity) while designing a flow measurement technique.

Thus to overcome these drawbacks, proposed paper makes an attempt to design an adaptive technique for measurement of liquid flow rate which is both linear and sensitive (i.e. without compromising any characteristics).

Problem statement: given a scheme of flow rate measurement consisting of venturi and UFM, design a flow measurement instrument having the following properties:

i. Sensitivity

ii. Linear

iii. Fault detection and identification

4. PROBLEM SOLUTION

The drawbacks existing in the available measurement technique is clearly shown in earlier section. It is clear that one has to compromise on either sensitivity or linearity for designing a measurement technique using a particular technique.

To overcome the drawbacks mentioned earlier, a fusion system using both the sensors is proposed in this technique. Proposed architecture is designed to produce an output which is better as compared to using individual sensors. Fusion based architecture is used consisting of both dissimilar sensors, using a fuzzy block in cascade to both the sensors. Block diagram of the proposed technique is shown in Fig.7 and experimental model used for demonstration of proposed technique is shown in Fig.8.

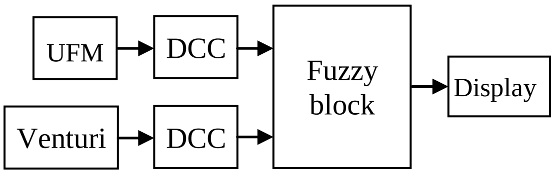

Fig.7. Block diagram of the proposed technique

Fig.8. Experimental setup of proposed system

Proposed fuzzy block is created using MATLAB Simulink tool box with fuzzy function designed using Mamdani function. The first step in fuzzification is to normalize data of both the sensor's to range 0 to 1 using the Eq.(5).

$$x_{norm} = \frac{(x_{\max} - x)}{(x_{\max} - x_{\min})} \quad (5)$$

Once normalized it is fed to fuzzy block to achieve desired objective. For this purpose fuzzy block needs to be trained. Training of fuzzy block starts with initialization of membership function, usually sets of membership function are chosen based on the characteristics of system [28-30]. There exists two different class of membership functions called as input and output functions. Input function is used to classify the data set of input whereas output is used for classification of output data. Input function is classified into five sets of membership functions for individual sensors output namely UFVL, UFL, UFM, UFH, and UFVH for ultrasonic flow sensor output and VFVL, VFL, VFM, VFH, for venturi flow meter. Output of the fuzzy block is mapped to a set of five membership functions namely FVH, FH, FM, FL, and FVL. Simulink model of the proposed technique is shown in Fig.9.

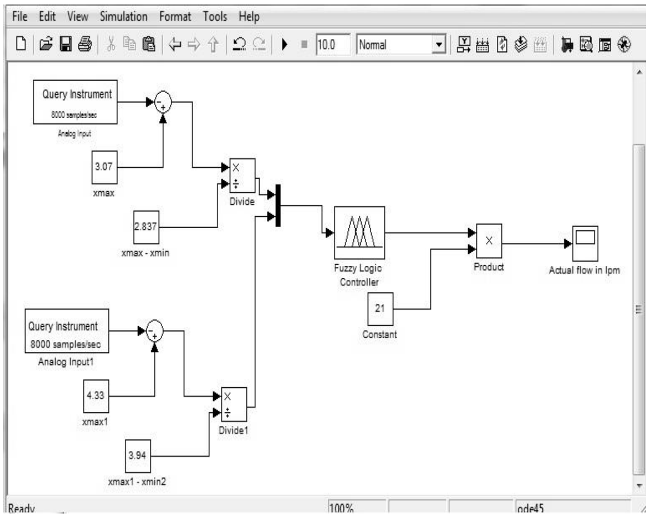

Fig.9. Input membership function for UFM output (Simulink Model)

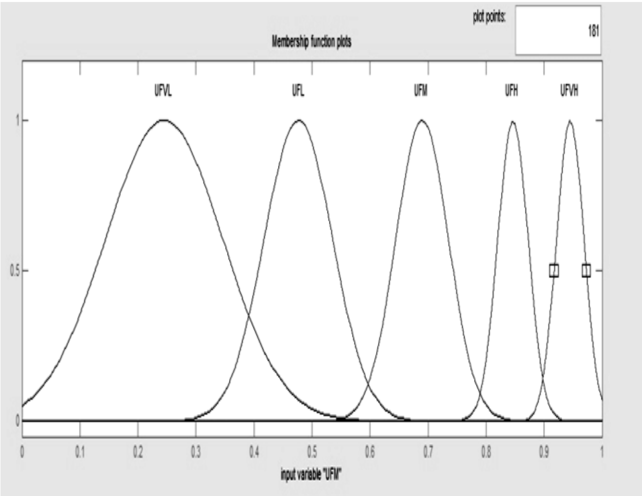

Fig.10. Input membership function for UFM output

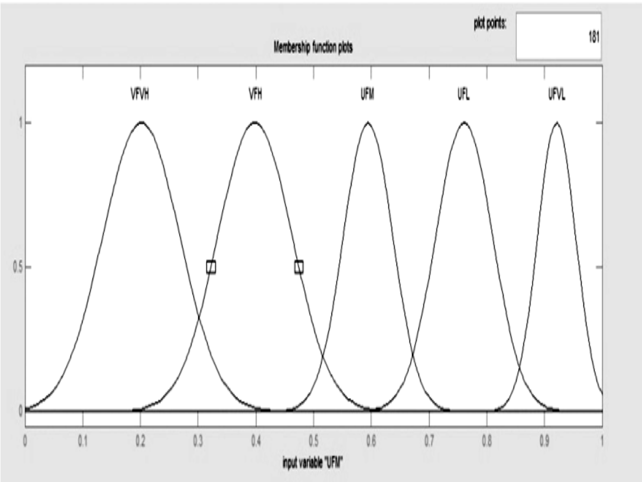

Fig.11. Input membership function for VFM output

The Fig.10 and Fig.11 shows input membership function of ultrasonic and venturi flow meter output. Similarly Fig.12 shows output membership function of proposed flow meter. The data sets, range and function shown are obtained after training with several combinations. Obtained results are optimized set of several combinations. Input output characteristics obtained for the class of function is shown in Fig.13. Output of fuzzy set will be a normalized value. So, de-normalization is carried on for obtaining the results in flow rate.

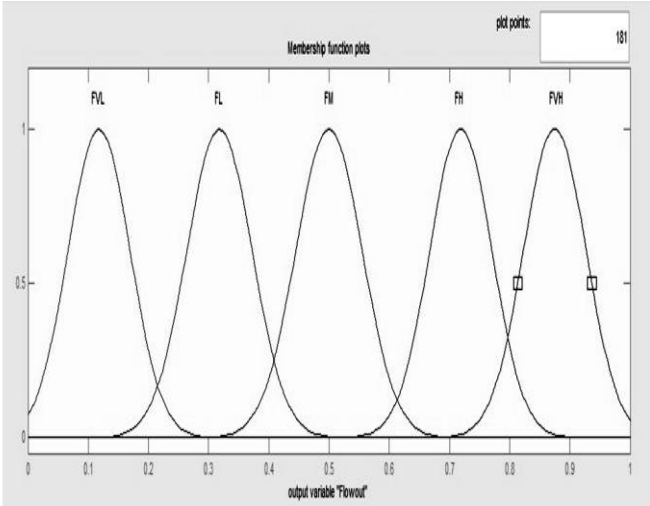

Fig.12.Output membership function

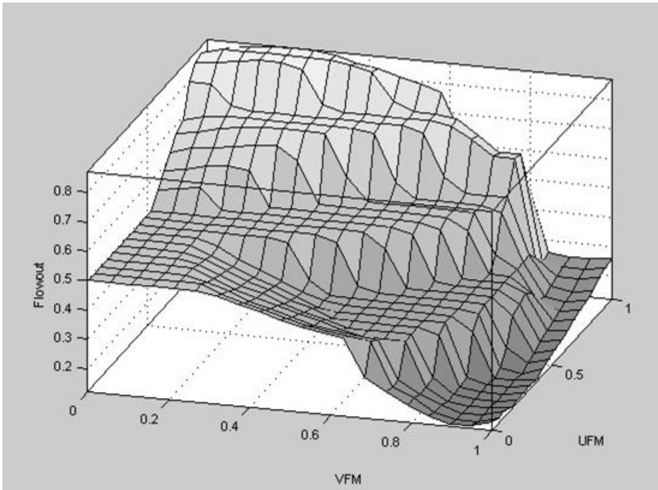

Fig.13. I/O characteristics of trained fuzzy model

4.1 FAULT DETECTION

Faults in sensors may lead to improper measurement, it is essential to identify them before it is carried on to next stage. Proposed work designs a methodology to check and identify the faulty sensors. To identify sensors fault a block diagram is designed consisting of a lookup table with outputs of both sensors for a particular input flow. Faulty sensors have characteristics which is different from the regular one. Sensors outputs are compared for two machine cycles every time. If it is found that output remains static while the other is varying then it can be concluded there is a sensor fault. Table.1 shows the logic used to build the proposed technique.

Table.1. Fuzzy table

	UFVL	UFL	UFM	UFH	UFVH
VFVL	FVL	FVL	Fault	Fault	Fault
VFL	FVL	FL	FL	Fault	Fault
VFM	Fault	FL	FM	FM	Fault
VFH	Fault	Fault	FM	FH	FH
VFVH	Fault	Fault	Fault	FVH	FVH

5. RESULTS AND ANALYSIS

Proposed system once trained using fuzzy logic algorithm is tested with different test cases for variations in input flow. For testing the proposed technique flow is tested in the ranges to 0 to 21 lpm.

For analyzing performance of the proposed setup around 47 reading are tabulated. Flow is considered in ranges of 0 to 21 lpm, with a step size of around 0.3 lpm. Measured value of proposed technique is compared with the output of standard measuring instrument. Results obtained are also plotted in terms of input output graph and percentage error graphs in Fig.14 and Fig.15 respectively. From the graph it could be seen that output of proposed system is linear and sensitive as comparison to the output when individual sensor are used as flow meter. Root mean square of percentage error of system is found to be 0.769%. Performance of proposed system shows that it can be used in many applications. For testing its performance for fault identification a particular sensor was made faulty. Proposed system was able to identify the fault accurately.

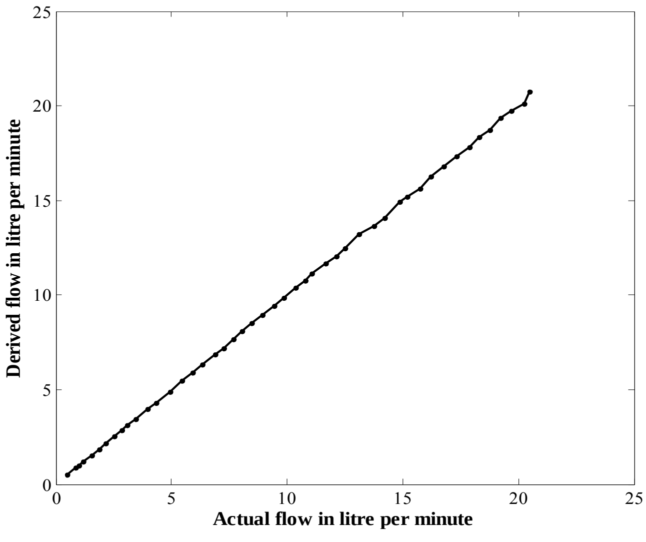

Fig.14. I/O characteristics of proposed flow measurement system

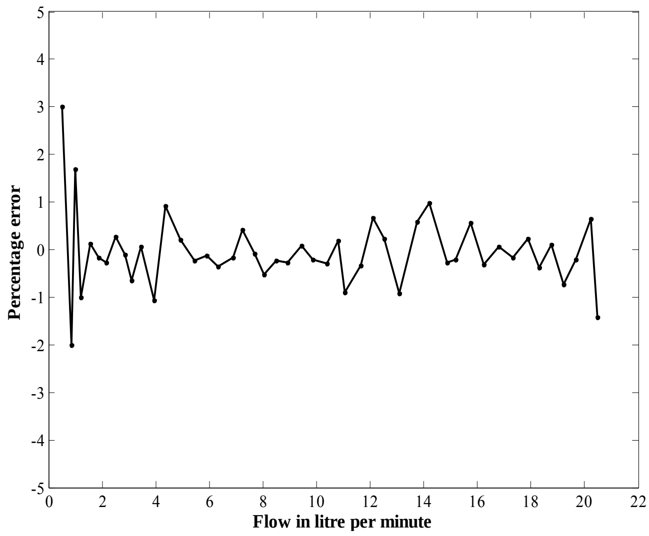

Fig.15. Variation in percentage of error

6. CONCLUSION

Flow measurement is one of the important process parameters to be carried out in many process industries. Flow is measured using a particular sensor based on application. But it's often found that while choosing the sensor one has to tradeoff between some characteristics. The reported work thus uses two different sensors each having different characteristics to measure the single parameters using the techniques of multisensory data fusion using fuzzy logic algorithms. For the purpose of demonstration venturi and ultrasonic flow meters were considered, and implementation of the proposed technique was carried on to test its efficiency. Results obtained over the entire range of measurement shows improved linear and sensitive characteristics as compared to instruments with single sensor. Percentage of error also shows that the proposed technique can be implemented in industries.

Extension of proposed work will be to implement a system for on-chip applications with improvement in many more characteristics.

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