Intelligent Flow Meter Development Using Neural Network

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Abstract: Flow measurement is important in the process industry which is used to measure the flow of the liquid or gas. The flow meters which are used in industry are for local indication where the data cannot be processed directly from flow meter. Hence an intelligent flow meter is developed in which Hall effect sensor and rotameter are integrated to measure the flow rate. The Hall voltage measurement is affected by the temperature. Variation of hall voltage with respect to temperature are non linear in nature Hence neural network is used to compensate this non linearity. Levenberg Marquardt algorithm is used to train the neural network model. Improved flow measurement accuracy makes it possible to reduce the variability in the chemical process of the industry.

***Index Terms* – Hall effect sensor, Rotameter, Neural network.**

I. INTRODUCTION

In today's world all the systems are made smart. In industry many parameters will be controlled like flow, level, pressure, temperature, density, viscosity, etc. It is necessary to make the system error free and work safely. All these parameters has to be controlled at a time in the industry hence it is necessary to make the system smart. The designed system has to be accurate and reliable.

Flow measurement is important in the process industry. Flow meters are used to measure the flow of the liquid, steam or gas. Water flow meter measures the flow of the cold water, hot water, muddy water or any other liquid through it. In industry conventional flow meters are used namely orifice flow meter, venture tube flow meter, electromagnetic flow meter, ultrasonic flow meter, variable area flow meter, nozzle, Pitot tube, calorimetrics, turbine flow meter, vortex, ultrasonic flow meter, thermal flow meter etc.

In orifice flow meter the water is made to flow to the different pressure area so that differential pressure is taken for the flow measurement. It works on the differential pressure principle. Bernoulli's equation is used to calculate the flow rate. In venture tube flow meters the tube in which liquid flows is made by reducing the tube diameter to create the pressure. It creates less pressure drop compared to venture tube flow meters. Rotameters work on the variable area flow meters. It has a glass body along with measurement scale to indicate the flow rate. It has free moving float to indicate the flow rate. In electromagnetic flow meters the coil is wound on the pipe circularly. It works on the principle of Faraday's laws of electromagnetic induction. When the current is supplied to the coil it gets energized and the fluid inside the pipe acts as conductor. As water or any other liquid flow through the pipe, voltage gets induced in the coil which is directly proportional to the flow rate of the liquid in the pipe.

In ultrasonic flow meters volume of the liquid can be measured based on the velocity of the liquid along with ultrasound is used to calculate the flow rate of the liquid. These flow meters are affected by the different properties of the liquid like viscosity, temperature, density etc. Velocity is measured by taking difference between the pulse transit time to and fro direction of the liquid. Both speed and velocity can be measured by this method.

In this work a smart flow meter is developed by which the flow rate data can be processed directly unlike the existing system. Variable area flow meter called rotameter is used to measure the flow rate of the liquid. It can be used as a local indicator for flow measurement. For remote indication a Hall Effect sensor is used to convert the flow rate into voltage and process the data continuously. A flow sensor with integrated Hall Effect sensor along with the magnet is used. This Hall voltage measurement is affected by the different variables like viscosity, temperature, density of the liquid, pressure etc. As temperature is very slow process it is considered for this work. Hall voltage changes nonlinearly with the temperature. To make Hall voltage and temperature linear neural network is used. Levenberg Marquardt algorithm, Bayesian regularization algorithm and scaled conjugate gradient algorithm of back propagation algorithm is used to train the network. Comparing the three algorithms least error and regression one is obtained by Levenberg Marquardt algorithm hence that algorithm is used to train the network in MATLAB.

II. LITERATURE REVIEW

These are the papers referred to this work where different techniques of artificial neural network flow measurement are discussed.
Haizhuang Kang and Qingping Yang [1], discussed about the flow meter design for the recognition of the sensor to measure the flue gases in the pipes in the industry. Pitot tube is used to detect the flue gases in the pipe by which manual work is reduced. Artificial intelligence is used for this work and neural network is used for the simulation.
R.A. Hooshmand and M. Joorabian [2], reviewed about the electromagnetic induction principle is used in this work. Electromagnetic flow meters are used in which potential difference between the two electrical rods are considered to measure the flow rate. Neural network technique is used to compensate the non linearity of the liquid level and coefficient of conductivity. Simulation is done in MATLAB.

Lei Shi *et al.* [3], concluded that back propagation algorithm can be used for the calibration of the pH sensor. pH sensor is kept in water, the glass acts as one electrode and another electrode is inside the sensor , the difference between two is converted into voltage and that voltage is non linear in nature.

Yan-xia Wang *et al.* [4], designed the ultrasonic flow meter to measure the flow of the liquid based on the sound which is affected by the external factors. The speed of the sound and temperature are non linear in nature hence neural network is used to make linear mapping of both the parameters.

K. Amri *et al.* [5], discussed about neural network technique for flow velocity measurement using ultrasonic flow meter. In conventional method the ultrasonic flow meters is assumed to be symmetrical and developed fully. Here two methods are compared, one is conventional weighing method which is covered area with new approach of the weighing method called artificial neural network by using the mean squared error analysis. The results of their research work shows that by this method least mean square value is obtained with cascade algorithm of ANN.

Huichao Zhao and Lihui Peng [6] has discussed about the four path ultrasonic flow meter is used to measure the flow which improve the performance of complex flow profiles. This work presents the computed fluid mechanics method in which the velocity difference of single elbow and double elbow pipeline. Each path of velocity is taken using artificial neural network. The results are given for the training the network and least error is obtained. It is concluded that neural network is used to interpret the data compared to other method.

Nirupama Mandal et al. [7], has discussed the flow measurement using inductance bridge method. Rotameter is used for the flow measurement and local indication. By this method the data cannot be processed directly hence for remote indication inductance bridge technique is used, in which inductance of the coil changes as the flow rate changes. It is observed that the flow rate and inductance are linear.

N. Mandal et al. [8], has discussed about the rotameter and LVDT sensor in which rotameter acts as primary sensor and LVDT as secondary. As water pass through the rotameter the float moves in the direction of the flow of the liquid hence the rod also moves the voltage value varies. The float movement and output of the LVDT has linearity. Experimental results and theoretical equations are compared.

Sunita Sinha et al. [9], has discussed the implementation of the flow meter in real time. Rotameter and hall effect sensor for local and remote indication respectively. As water flow through the rotameter the float moves near to hall effect sensor which sense the magnetic field of the magnet placed on the float of the rotameter. Lab tech pro software and DAS is used to design this flow meter. The system working is verified with real time experiments are compared.

S.C. Bera et al. [10], has discussed the neural network application in the calibration of the electrode polarization. The back propagation algorithm of artificial neural network is used for non linear calibration by mapping the input and the output. Electrode polarization of impedance flow meter calibration is discussed. From the testing results from the neural network is observed and the test results are linear.

All the above papers describe about the different flow measurement techniques. Back propagation algorithm is used to make error zero and get the required result. From these papers it can be concluded that neural network is best suitable technique for flow measurement.

III. PROPOSED METHODOLOGY

Rotameter is used to measure the flow rate of the liquid. As the water flow through the rotameter the float moves up in the direction of liquid. The measurement is done by the position of the float and scale on the rotameter. It is used for the local indication. During flow measurement it should placed in vertical position. By this it is not possible to process the data directly hence the intelligent sensor is developed using Hall Effect water flow sensor and DS18B20 temperature sensor.

3.1 YF-S201 Hall Effect water flow sensor

Rotobotix water flow sensor YF-S201 measure the amount of water flow through it. The range of flow meter is 1-30 LPM. The Hall Effect sensor is integrated with this, covered by the plastic body to keep safe and dry. This sensor should be kept in line with the water flow direction to measure the flow. It has three wires red (5-24V dc), yellow (pulse output) and black (GND). Connect the red and Black wires of the water flow sensor to the 5v and GND of Arduino respectively, and connect Pulse Output (Yellow) wire of the water flow sensor to Arduino digital pin number 2. As water pressure increases the Hall voltage increases. Hall voltage measurement is non linear with temperature. Hence voltage decreases with increase in temperature. The Hall voltage readings from arduino are noted at different temperature and flow rate.

3.2 Temperature sensor

DS18B20 temperature sensor has 3 terminals, left pin is connected to VCC, middle pin is connected to GND and right pin is connected to arduino for temperature measurement. This sensor is powered with supply voltage from 3.3 to 5.5V and measure temperature range from -55°C to 127°C. A pull up resistor of 4.7KΩ is connected. Different temperature readings are noted from the arduino output.

3.3 Arduino uno

It is used to build the digital devices and control the objects in physical and digital world. It uses number of controllers and microprocessors. It has digital and analog input and output pins to interface with other circuits or breadboards. Communication is done using USB and also used to load the programs on the computer. C and C++ language is used for programming. Integrated development environment software is used to run the code in the system. Sensors and actuators are used for interfacing.

Arduino IDE software is downloaded to PC and code is written to read both temperature and flow sensors values. Using cable the arduino is connected to the system, then the written code to read the sensor values is uploaded and compiled in the arduino software. The readings of both temperature and water flow sensors are noted down at different flow rate

The Hall Effect voltage measurement is affected by the temperature hence to compensate the non linearity neural network is used. nntool and nftool of MATLAB are used to train the neural network model. The Hall Effect sensor and temperature sensor outputs are given to the neural network as shown in figure 3. The arduino uno board is used to read the sensor data and it is interfaced to the system. ATmega328p microcontroller is used. The experimental setup is as shown in fig 4.

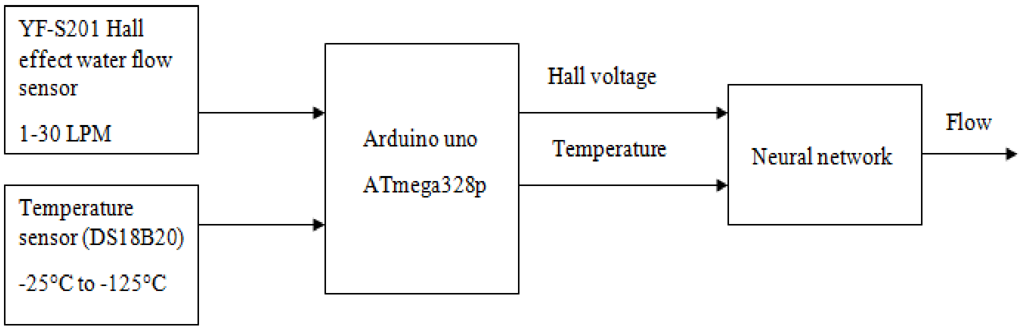

Fig 1: Block diagram of the proposed system

3.4 Neural Network

It is the imitation or mimic of the human brain. Dotted multiplication of input and output is described as neural network. It is the approach to predict, to classify and to recognize. Design of neural network is motivated by the human brain and the biological connections of that. Dendrites and axon connection is imitated to construct the neural network. The signal is transferred from one neuron to another neuron in the same way the data is transferred from one node to another. Here neuron is indicated by the node. It has huge application in pattern recognition.

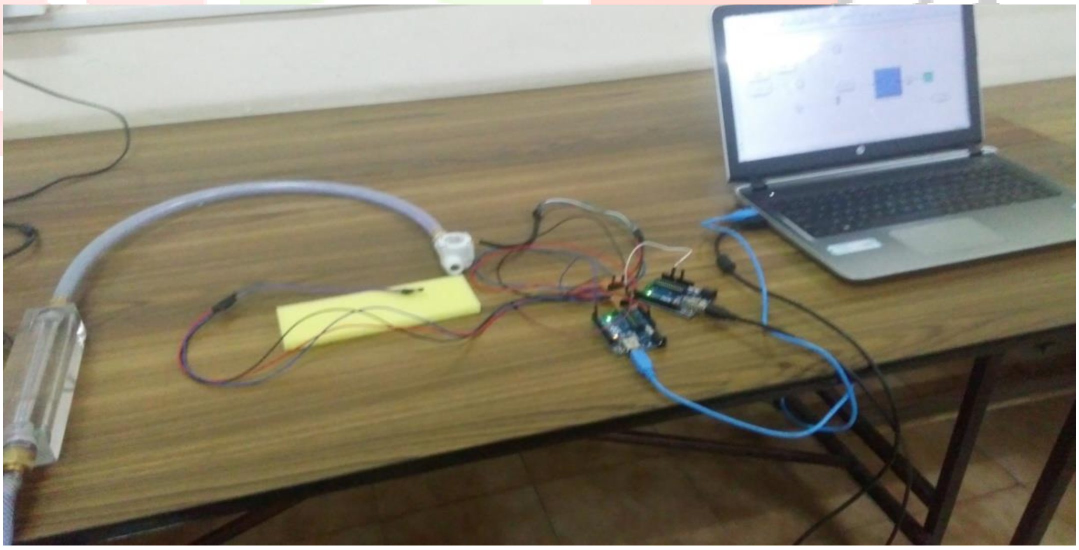

Fig 2: Experimental setup

3.4.1 Network Architecture

Neural network consists of three layers namely input, hidden and output layer. The data is transferred from one layer to another along with weight and bias value. Initially weight and bias values will be zero. In this many inputs are given and one output is obtained. Each node of one layer is connected to all the nodes of the next layer. The neural network architecture is shown in figure 3 below. Sigmoidal activation function is used in most of the cases. The network can create any number of hidden layers. W indicates the weight and b indicates the bias value in the network below.

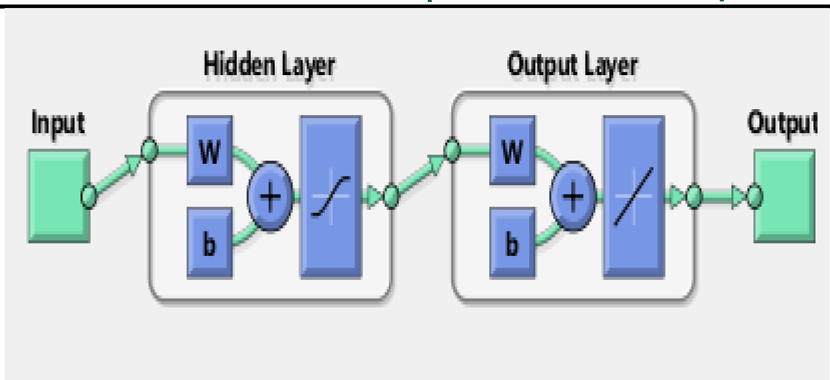

Fig 3: Architecture of neural network

3.4.2 Development of neural network

Hall voltage and temperature values are given to neural network and flow output is taken. The neural network is created using MATLAB. nnstart is used in MATLAB and by fitting app the input and output data are selected for training, 25% samples are taken for training and 6% samples for testing and 6% for validation. Best suited algorithm is chosen among the three algorithms namely Levenberg-Marquardt, Bayesian regularization, Scaled Conjugate gradient. The comparison of three algorithms is given in table 1.

3.4.3 Training method

In neural network trial and error method is used. Based on the output requirement the training method is chosen. For this system Levenberg Marquardt algorithm of back propagation is used. In this method the output is fed back to the input till the error is zero. The Levenberg Marquardt algorithm architecture is shown in figure 4 below.

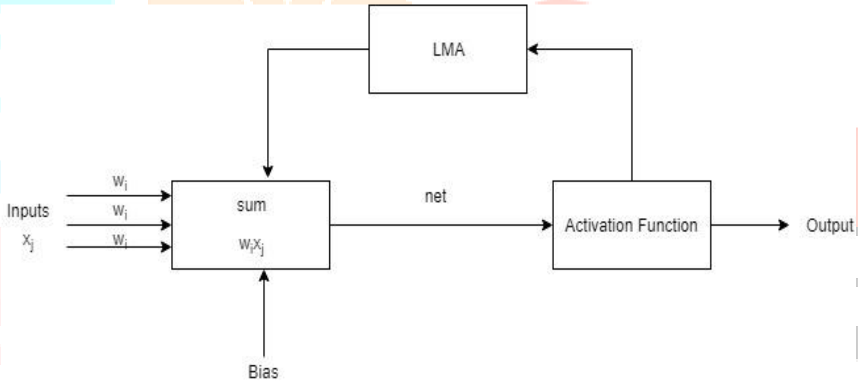

Fig 4: Architecture of Levenberg Marquardt algorithm

X is the input and j is the number of inputs. W is weight and i is the number of weight. The weight and input value product is summed with the bias value as shown in figure and given to next layer. Sigmoidal activation function is used in most of the cases. It varies between 0 and 1 value. It gives S shaped curve hence the name sigmoidal. It uses the iteration method for the minimization. The output is feedback to input till the required output is obtained. For every iteration the weight and bias values will be updated. Again with the updated weight the input is multiplied and added with the new bias value and given to next layer. From actual output and measured output the error is calculated. In this method the output is fed back to the input hence the name back propagation algorithm. By this method required result is obtained.

Table 1: Comparison of three algorithms

Algorithms		Mean squared error(MSE)	Regression
Levenberg-Marquardt	Training	0.102	0.9797
	Validation	0.1335	0.9758
	Testing	0.174	0.9818
Bayesian regularization	Training	0.102	0.9813
	Validation	0.0000	0.0000
	Testing	0.2567	0.8727
Scaled Conjugate Gradient	Training	0.186	0.9878
	Validation	0.194	0.9845
	Testing	0.235	0.8902

From above table it can be observed that Levenberg Marquardt algorithm meets the requirement hence it is used to train the network. The network model is trained again and again to get error zero and regression value equal to one. The trained neural network block is taken for simulation. The data from arduino uno is interfaced through serial communication. The Experimental setup readings are tabulated in table 2.

Table 2: Experimental setup readings

Actual flow rate (LPM)	Temperature (°C)	Hall voltage(mV)	Measured flow rate (LPM)
2	28	78.75	2.0025
2	37	50	2
3	29	136	2.994
3	41	72.9	2.999
4	29	157.14	3.9985
4	40	80.2	3.991
5	31	221.42	5.3
5	38	112.1	5.101
6	28	278.57	6.01
6	42	111.2	6
7	29	314.28	7
7	37	238.9	7

V RESULTS

Temperature and Hall voltage readings are taken from the experimental setup. Both temperature and Hall voltage and temperature are non linear in nature as tabulated in table 2, which is compensated by the neural network. The results obtained by the neural network and hardware set up are compared. The temperature compensation is done by neural network as shown in figure 5. The actual flow rate and measured flow rate are compared as shown in graph.

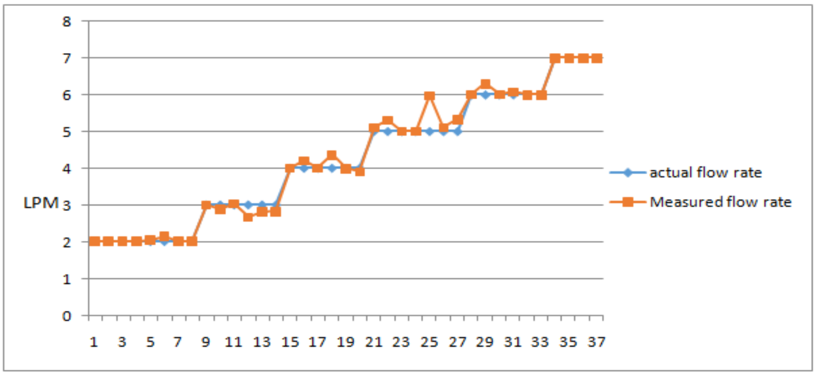

Fig 5: Linear input and output flow rate at different temperature

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