Evaluation and Modelling of a Low Budget Hall Effect Based Flow-Rate Sensor using Adaptive Calibration Paradigm

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Abstract — The research work demonstrated the use of adaptive and comparative paradigm to calibrate and validate Hall Effect flowrate sensor’s related performance data. The experimental testbed used for the research work is composed of an IoT based platform integrated into a water pipe network. The use of IoT largely assisted in facilitating a well-coordinated and flexible paradigm for efficient data collections and analysis. Correlated and Associative analysis on data obtained shows a strong significant relationship (R²=89%) between the rate of Pulse count and rate of change in differential volume leading to the derivation of a model that is helpful in determining of volumetric rate and quantity of liquid dispense as function of pulse count generated from a Hall Effect flowrate sensor.

Index Terms — Hall Effect; Calibration; flowrate sensor; IoT.

I. INTRODUCTION

In water scarce regions, the need to manage scarce water resources and utilization can be a demanding. The YF201 Hall Effect flowrate sensor rates among the cheapest flowrate sensor that is commonly used in low budget applications requiring some form of water flowrate measurement and management. These applications span over gardening, fisheries, automating the flow measurements during milk production in milking of goats [1]. With milk flow data it is viable to characterize the dynamics of milk emission, an aspect of physiological significance which conventionally has been manually done [2].

Hall Effect sensors accuracy can be affected by aging and varied fabrication processes[1]. They are relatively cheap but lack high level of sensitivity, hence characterize by low accuracy. A study intended to address these limitations were proposed in[1]. The proposed approach entails linear positioning of a magnet that is independent of its modulus, and variation due to aging [1]. Calibrations information available for Hall Effect flowrate sensors suggest varied precision ratings and inconsistent scaling approach [3], [4].

The research work demonstrates the use of adaptive and comparative paradigm to calibrate and validate Hall Effect flowrate sensor’s related datasheet information. The experimental testbed used for the research work is composed of an IoT based Particle Photon development board, an array of Hall Effect flowrate sensors integrated into a water pipe network. The apparatus employs IoT technology to facilitate the collection, transmission, and storage of Flow rate sensor readings, differential dept readings, environmental temperature, and humidity readings from the arrays of flowrate sensors, Ultrasonic, Temperature and Humidity sensors. These data are subsequently analyzed to derive appropriate models that assist in accurate interpretation of readings obtained from the flowrate sensors.

II. EXPERIMENTAL SETUP

A. Conceptual Framework

Figure 1 depicts the conceptual framework upon which the testbed was developed. At the center of the testbed the Particle Photon development board [5]. The Particle Photon board is an IoT based Wi-Fi enabled development platform for developing connected devices. Particle Photon combines a powerful ARM Cortex M3 micro-controller with a Broadcom Wi-Fi chip in a tiny thumbnail-sized module. The ARM Cortex M3 micro-controller in used is the STM32F205RG [5].

![Fig. 1. Conceptual framework](image)

B. Theoretical Framework

From [6] it can be inferred that the flowrate (volume/second) from the tank is directly proportional to the differential dept as presented by the HR-SC40 sensor. Likewise, the number of pulses sensed and relayed from the...
flowrate sensor is also proportional to the quantity (volume) of fluid (water) flowing through the pipe. The assertions could be interrelated and expressed using Equation 1 ($V_T(t)$ – Tank volume (m$^3$), t – time (s), $P_{FR}(t)$ – pulse count obtain from the flowrate sensors)

$$\frac{dP_{FR}(t)}{dt} = K \frac{dV_T(t)}{dt}$$  \hspace{1cm} (1)

If the relationship is linear [7], then the constant of proportionality $K$ is obtainable from a plot of $\frac{dP_{FR}(t)}{dt}$ against $\frac{dV_T(t)}{dt}$. Reversing Equation 1, produces Equation 2 where $\frac{dV_T(t)}{dt}$ is equivalent to the flowrate sensor’s measure as a function of the proportionality constant and the Pulse count rate. Note that $V_T(t)$ is a product of the cross-sectional area of the tank $A_T$ and differential height $h_T(t)$ occasioned by water level depletion. Equation 2 suggests the possibility of deriving the flowrate readings from the number of pulses recorded from the flowrate sensor over time.

$$\frac{dV_T(t)}{dt} = \frac{1}{K} \frac{dP_{FR}(t)}{dt}$$  \hspace{1cm} (2)

Further work on Equation 2 can assist in obtaining the quantity of water collected over a duration $t$ as shown in Equations 3 and Equations 4.

$$V_T(t) = \frac{1}{K} \int_{t_0}^{t} dP_{FR}(t)$$  \hspace{1cm} (3)

$$V_T(t) = \frac{P_{FR}(t_0-t_0)}{K}$$  \hspace{1cm} (4)

The degree of relationship between pulse count and differential volume as express in equation 1 is shown using correlation and regression square tools.

III. METHODOLOGY

A. Testbed Composition and Operation

The testbed consists of two subsections: the first subsection (Calibration unit) handles the calibration process while the second subsection (Validation unit) is intended for validation purpose. The Calibration unit consist of a water flow piping network, four flowrate sensors, a remote controllable valve, a tap control and a 1000 L capacity water tank (Fig. 2). Two of the flowrate sensors are connected in series and aligned horizontally while the other second set of two were aligned in a vertical orientation. The tap control is intended to allow for manual regulation of the water outflow while the valve allows for the remote switching of water outflow to the flowrate sensors.

The Validation unit is made of three set of sensors interfaced to a separate particle photon platform. The sensors are HC-SR40 meant to provide water displacement related information and the DHT22 which provides Temperature and Humidity related information, respectively.

At the Centre of the two subsections is the particle photon platform which performs sensors’ data collection, processing, control coordination, reception, and transmission of data to a remote online database via the use particle IoT cloud platform’s webhooks.

B. Software Architecture and Realization

Fig. 3 depicts the sequence of operations and inner workings of the software design [5]. The illustrations cover how objects within the modules in the Calibration and Validation units work together. The operations management and data collection procedures were implemented using IoT utility functions provided by Particle’s edge-to-cloud IoT platform [5]. Starting from the Calibration unit, the inflow of water through the flowrate sensors is controlled remotely via the valve. Activating the valve marks the beginning of the calibration – validation cycle. Summarily, the pulse rate counts are capture every second and transmitted via the cloud and stored in a table in the database. At the end of the sixtieth count, the Validation unit captures dept differentials, humidity, and temperature readings within the tank as the water level decreases with the outflow of water. These data are subsequently store in a second table in the database. The content of both tables serves as a source of data for the purpose of analysis and modelling.
IV. RESULTS AND DISCUSSION

Fig. 4 and Fig. 5 are graphs indicating the relationship between time of data capture against aggregated pulse count and dept differentials respectively. As earlier anticipated, the relationships are near linear in nature. The step nature of the graph (Fig. 4) reflect changes resulting from increase in the outflow of water as the tap is incrementally adjusted in a clockwise direction. The adjustment translates to increase in quantity of water flowing through the flowrate sensor.

The data captured via the Calibration and Validation units were used in the determining the overall relationship between the Pulse rate generated by the Hall Effect sensor and the Volumetric Depletion rate derived from the dept differential values (Fig. 6). Using the Microsoft Excel tool, Correlat and Associative analysis on data obtained shows a strong significant relationship ($R^2$=89%) between the rate of Pulse count and rate of change in differential volume. Hence, with reference to Equation 4, and using the constant of proportionality as indicated in Figure 6 the derived model is further expressed as shown in Equation 5.

$$V_T(t) = \frac{P_{FR}(t_n - t_0)}{90.10}$$

Initial readings of pulse count obtained at the onset when the level of water in the tank is at its peak (full Tank) were very erratic. However, an improvement in the consistency of the readings were observed when the water out flow rate and pressure were reduced via the use of the manual Tap.

Further work will be needed to determine the exact boundaries of water flow rate as function of pressure that will further guarantee improved accurate readings.
V. CONCLUSION

The research work has demonstrated the use of adaptative and comparative paradigm to calibrate and validate Hall Effect flowrate sensor's related datasheet information. Correlated and Associative analysis on data obtained shows a strong significant relationship between the rate of Pulse count and rate of change in differential volume.

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