JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

PREDICTIVE ANALYSIS OF A CENTRIFUGAL PUMP USING DIGITAL TWIN

[1]Prashant K. Ambadekar, [2]Hariranga Vakati, [3]Aniruddh Iyer, [4]Gokulraj Anilkumar, [5]Eashan Bhatt
SIES Graduate School of Technology, Nerul, Navi Mumbai, India

Abstract : This research paper investigates the data acquisition of a centrifugal pump using three sensors: a flow sensor, an accelerometer MPU6050, and an ultrasonic sensor HC-SR-04. The proposed work aims to identify any discrepancies between the sensor data and physical measurements and provide insight into potential issues with the sensors or pump. The results of this study can be used to improve the design and operation of centrifugal pumps, and ensure its performance meets the required specifications. The study validates the data collected by the sensors through physical measurements, including pump head, vibration, and flow rate. By comparing the sensor data with physical measurements, the accuracy and reliability of the sensors can be evaluated. The results show a negligible error for the accelerometer and the flow sensor which is of 0.71% and 0.40% respectively, and a small error for the ultrasonic sensor of 4.20%.

IndexTerms **- Centrifugal pumps, data acquisition, flow sensor, accelerometer, ultrasonic sensor, validation, physical measurements, pump performance, Raspberry Pi Pico**

I. INTRODUCTION

In the fourth industrial revolution, along with technologies like artificial intelligence, cloud computing, additive manufacturing or internet of things, Industry 4.0 has been able to capture fair attention of industry. One of the paradigms of Industry 4.0, the digital twin, is finding its place in various sectors like shop floor [1], surface roughness prediction [2], anomaly detection [3] or client satisfaction in retail industry [4] to name a few. Due to its potential to provide augment service in health sector, construction industry, travel industry, manufacturing, quality control, process design, etc., digital twins model the physical world into real time simulation. Digital twin is a relatively new concept, that find its early applications in aerospace industry [5], but it has established itself in different sectors from aviation to google map. Digital twin aims to improve the performance of the physical system by simulating it in real time and monitoring the progress on virtual platform.

In the study on sensors for process industry, Püttmer [6] proposed that acoustic emission technique using ultrasonic sensor are better compared to the vibration technique, making it particularly attractive in noisy environments. Soylemezoglu et.al. [7] projected that in a normal operation case, a centrifugal pump should operate within a specified range of vibrations hence the amount of vibration experienced on the pump is an effective indicator of potential problems caused. In order to validate the data of flow sensors K. Arasu diverted water back to the collecting tank where manual measurement of flow rate was carried out. This has also been used to calibrate the flow sensor [8]. Lu et.al. [9] performed experimentation to find correct position to mount a accelerometer in order to detect cavitation early. Authors identified the location as surface of the volute which is close to the point where cavitation bubbles generate and collapse. Lalnunthari and Thanga [10] used Hall effect flow sensor YF-S201 to investigate how the attached pipe diameter affects the accuracy of flow sensor. The result showed that as the attached pipe size becomes smaller than the internal diameter of sensor, the velocity of liquid coming out of the pipe increases, resulting in lesser accuracy of flow sensor. Rocchi et.al. [11] focussed on the investigation of a level measurements system able to estimate the position of the water surface in order to determine the thickness and depth of the pollutant layer. It proposes that ultrasonic sensors are best for level measurement owing to its low cost and high precision. An efficient, low cost and precise device for monitoring the water level in tank using an ultrasonic sensor controlled by a micro controller was proposed by Saleem et.al. [12]. The maximum error of ultrasonic sensor for water level measurement was found out to be approximately 0.07 cm indicating its effectiveness and high precision. A research work for a non-contact, continuous measurement of water level using an ultrasonic sensor was carried out by Boral et.al. [13] who suggested that proposed sensor with continuous measurement is more precise and cheaply available. Bohn et. al. proposed that vibration monitoring with accelerometer has been proven as a useful technique for evaluating the characteristic vibrations that propagates through the pump’s mechanical structure. Authors mounted accelerometer on the axial face of pump volute casing to collect vibration data [14]. An analysis of the responses of two MEMS accelerometers, models ADXL345 and MPU6050, which was exposed to a low intensity random signal and standard operating frequency was carried out by Rodrigues [15] with an objective to verify the capacity of these devices to be used as mechanical vibration sensors for rotating machines. Wei et. al. [16] used smart sensors and digital Internet of Things (IOT) to monitor the real time operating status of pumps and predict potential failures. The data from sensors was stored into cloud servers. After all side testing the diagnostic accuracy was above 85% and the wireless sensors monitored progressive faults very well. The system was low cost and easy to implement.

The application of digital twin in predictive maintenance is finding its suitability, applicability, and reliability **[17]** and is developing to prevent faults, accidents, breakdowns, downtime, and much more. Once such application for the predictive maintenance of centrifugal pump is proposed in this paper. Centrifugal pumps are one of the most used devices in various industries, including petrochemical, water treatment, and HVAC systems. The ability to measure the performance and behavior of these pumps is crucial in optimizing their operation and designing more efficient systems. In recent years, data acquisition systems have become an essential tool for collecting and analyzing data from these pumps. This paper focuses on data acquisition of a centrifugal pump using three different sensors: a flow sensor, an accelerometer MPU6050, and an ultrasonic sensor HC-SR-04. The flow sensor is a device that measures the rate of fluid flowing through the pump, providing essential data on the flow rate and pressure. The accelerometer MPU6050 detects the vibrations and movements of the pump, providing insights into the pump's performance and behaviour. The ultrasonic sensor HC-SR-04 measures the distance between the pump's impeller and the volute casing, providing information on the pump's internal components' behaviour.

II EXPERIMENTAL SETUP

The data collected by these sensors can be used to validate physical measurements, including pump head, vibration, and flow rate. By comparing the sensor data with physical measurements, the accuracy and reliability of the sensors can be evaluated.

To analyse the flow of water through a centrifugal pump a test rig, shown in Fig. 1, consisting of "MINI MAGIC Regenerative Self Priming Monoblock Pump" manufactured by Mangla Engineering Limited was selected. As discussed in earlier section, various sensors were selected to measure and analyse the basic aspects of the pump such as flow rate, vibration, water level etc. The pump was run to generates a constant speed of 2700 rpm.

Wired flow sensors that measure the flow rate of water were mounted on an inflow pipe of suction head 27 cm and outflow pipe of delivery head 56 cm. All pipes were selected with a constant diameter of $3/4^{th}$ of an inch. As the correct location of the flow sensor would result in more accurate output, it was mounted at the upper position of the pipe which was mounted horizontally. This position did not create any disturbance in the flow as it was located in between upstream and downstream flow of water flow. It was ensured that there were no fittings, pipe bends or valves in this minimum distance.

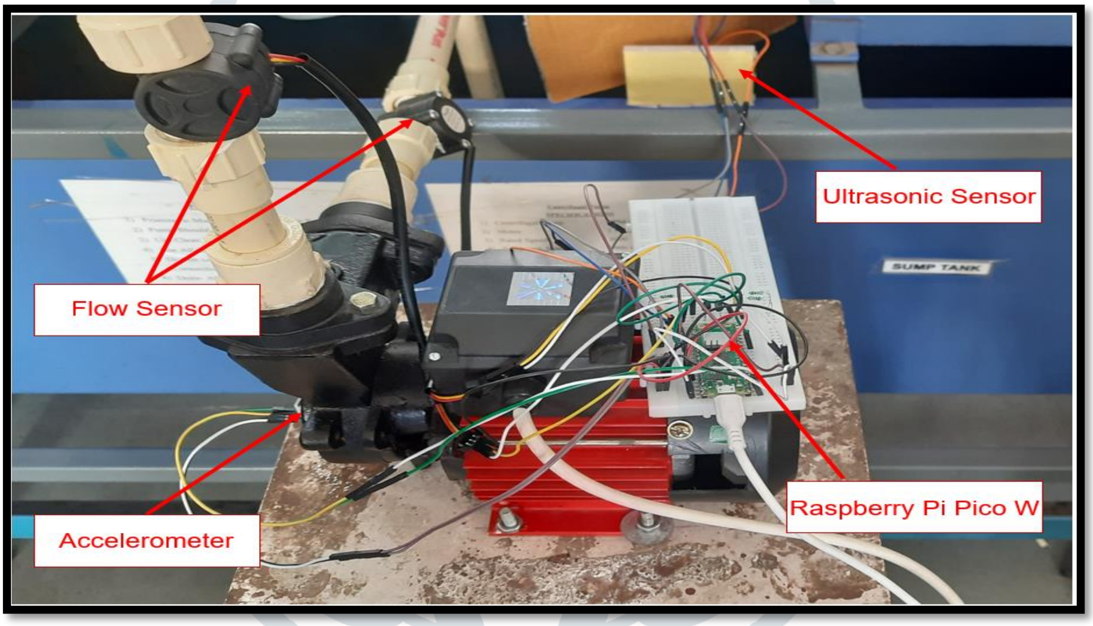

Fig 1: Experimental Setup

The acceleration sensor (MPU-6050) incorporates a run-time calibration firmware that eliminates costly and complex selection, qualification, and system level integration of discrete devices in motion-enabled products, guaranteeing that sensor fusion algorithms and calibration procedures deliver optimal performance. The MPU-6050 devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die, together with an onboard Digital Motion Processor, which processes complex 6-axis Motion Fusion algorithms. This sensor is mounted on the outer casing of the pump to obtain accurate data.

To keep track of the water level in the tank, an ultrasonic sensor (HC-SR04) was used to measure the height difference between the inlet level and the water level. Two ultrasonic transducers make up an HC-SR04 ultrasonic distance sensor. One functions as a transmitter, converting the electrical signal into pulses of ultrasonic sound at a frequency of 40 KHz. One operates as a receiver and searches for the pulses being transmitted. These pulses were received by the receiver, which then generated an output pulse whose width is related to the proximity of the object in front. With an accuracy of 3 mm, this sensor offered excellent non-contact range detection from 2 cm to 400 cm (about 13 feet). It may be immediately linked to a Raspberry Pi Pico W because it runs on 5 volts.

The Raspberry Pi Pico W is a small, fast and versatile board that is equipped with the RP2040 microcontroller chip developed by the Raspberry Pi Foundation. The sensors were connected to a raspberry Pi Pico W through wires and a breadboard. It was then connected to a computer, through which the sensors were programmed, and data was acquired. The data collection process was monitored over the computer screen. Figure 2 shows the circuit diagram with connections of all the sensors.

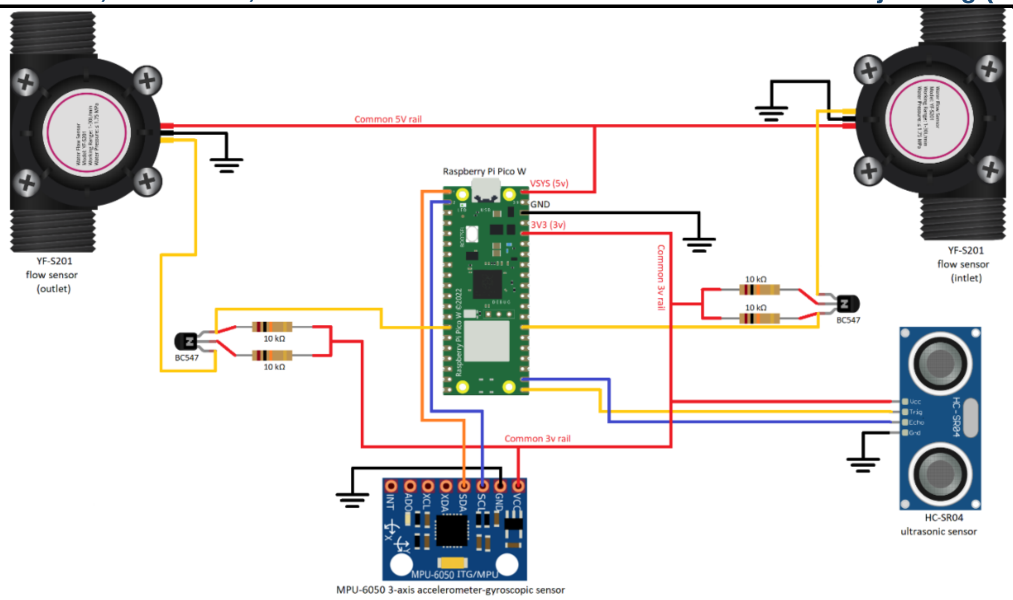

Fig 2: Circuit diagram with sensor connections

III METHODOLOGY

The problem addressed in this research is the need for accurate data acquisition from a centrifugal pump, which requires the use of several sensors to monitor various parameters such as flow rate, vibration, and liquid level. The three specific sensors (flow sensor, accelerometer MPU6050, and ultrasonic sensor HC-SR-04) were used in this experiment to monitor and collect data on different parameters of the centrifugal pump. The flow sensors were used to measure the flow rate (inflow and outflow) of the liquid passing through the pump, which is an important parameter for understanding the performance of the pump; Ultrasonic sensors were used to monitor the water level, whereas the accelerometer was used to measure the vibration. These sensors were then mounted on the pump to record data. Then, these sensors were connected to a Raspberry Pi Pico W, and were coded through an Integrated Development Environment (IDE) called Thonny using python. The complete methodology to conduct the experimentation in order to propose the solution to the research problem is shown in Fig. 3.

A pilot study was conducted to see whether the sensors were working according to the project requirements. Then, a data set of one hour was recorded using the sensors mentioned above. Over 13000 data points were recorded. Data was also recorded using conventional techniques. Both forms of data were compared to ascertain the validity of sensor data and the results were noted.

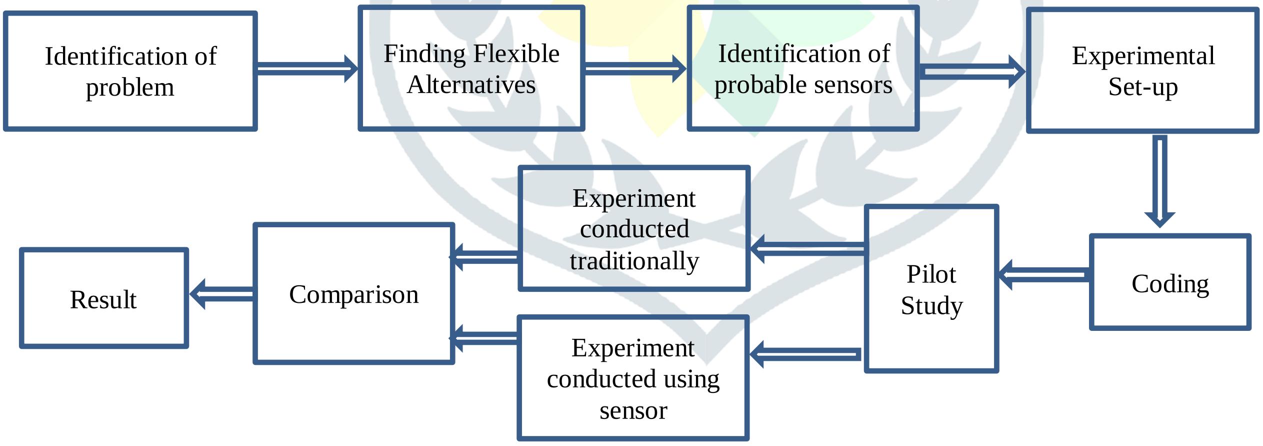

Fig 3: Methodology flowchart

IV RESULTS AND DISCUSSION:

The vibrations recorded by the accelerometer in the X, Y and Z direction over the period of one hour are shown in the Fig. 4. The orientation of Z axis is along gravity, hence its values range around 9.8 m/s^2. X axis of the graph represents the number of data points, while Y axis represents peak acceleration.

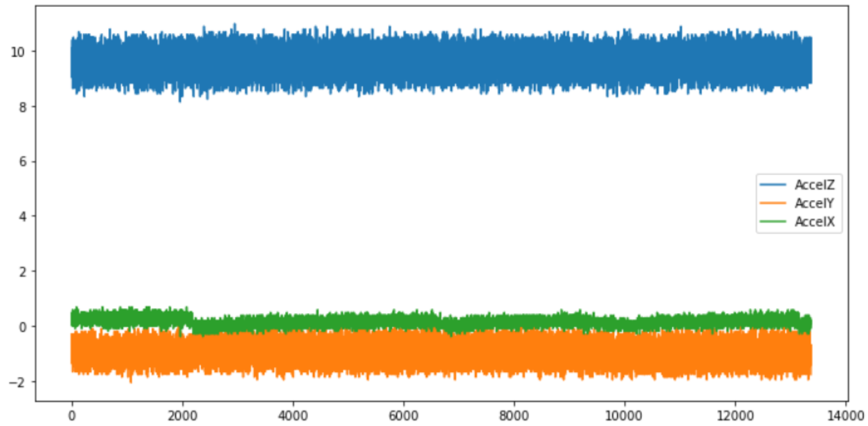

Fig 4: Accelerometer sensor readings plotted as a graph

Figure 5 represents the graph of flow rate recorded on the flow sensors over the period of one hour. There is negligible difference between the two sensors as there is no cavity for the water to be trapped or a sudden diametric change. The flow rate ranges from 16 to 18 LPM (Litres per minute). X axis of the graph represents the number of data points, while Y axis represents flow rate in LPM.

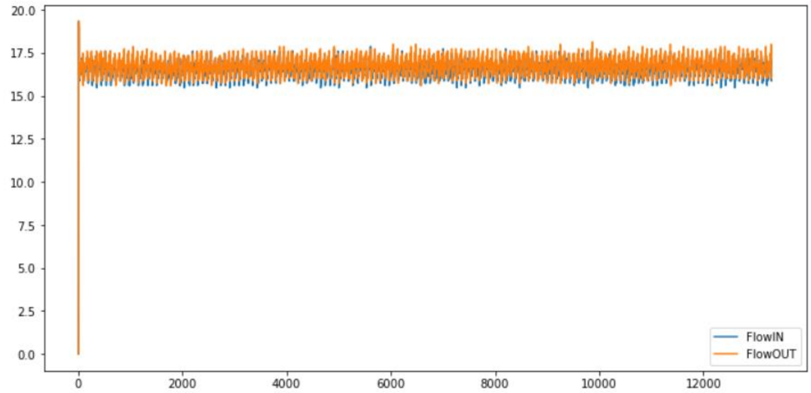

Fig 5: Flow sensors readings plotted as a graph

Figure 6 shows the water level recorded by the ultrasonic sensor over the period of one hour. The water level recorded for the tank was 35 centimeters. The spikes resulting in between as shown in the graph are due to the distortion of the sensor which is caused by the splashing of water and the creation of ripples. X axis of the graph represents the number of data points, while Y axis represents water level.

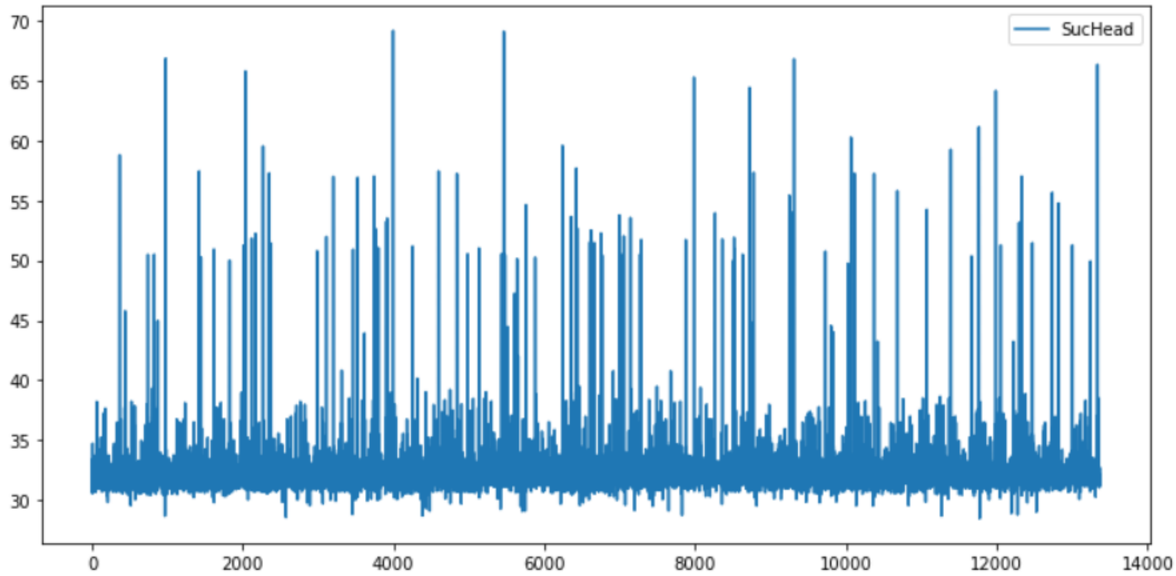

Fig 6: Ultrasonic sensor readings plotted as a graph

Data points were gathered from ten minute batches from the sensor data and compared to the data recorded using traditional methods. The comparison between both the techniques is discussed in the following paragraphs for all the three sensors.

a) <u>Acceleration Sensor</u>

Figure 7 shows the comparison between the acceleration sensor and vibrometer. The average error is 0.71%. This signifies a very negligible difference between both forms of recorded data.

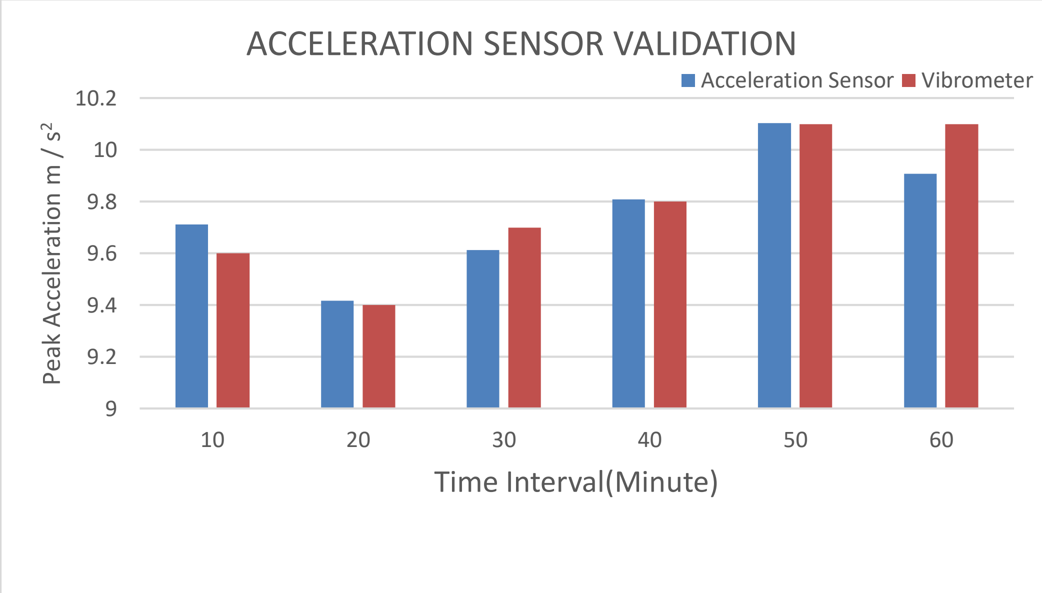

Fig 7: Comparison between acceleration sensor and vibrometer readings plotted as a graph

b) **Flow Sensor**

Figure 8 shows the graphical comparison between the flow sensor and the readings from the measuring tank. The flow rate is measured in Litres per Minute (LPM). The average error is 0.40%.

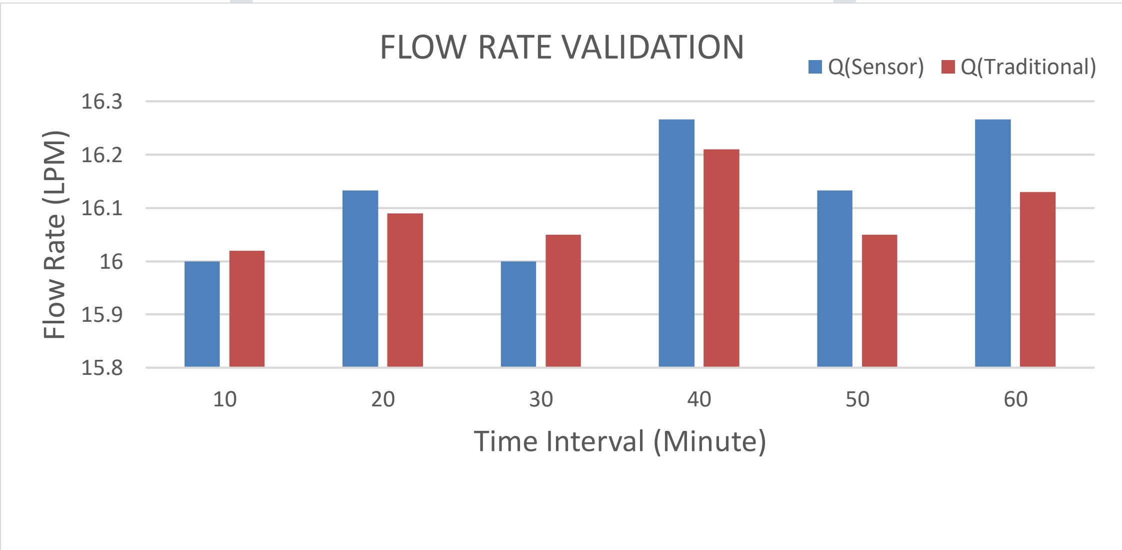

Fig 8: Comparison between flow rate sensor and conventional method for readings plotted as a graph

c) **Ultrasonic Sensor:**

Figure 9 represents the comparison between the ultrasonic sensor and physical measurement. The average error is 4.2%. This error was due to the splashing of water and the creation of ripples, which leads to sensor distortion.

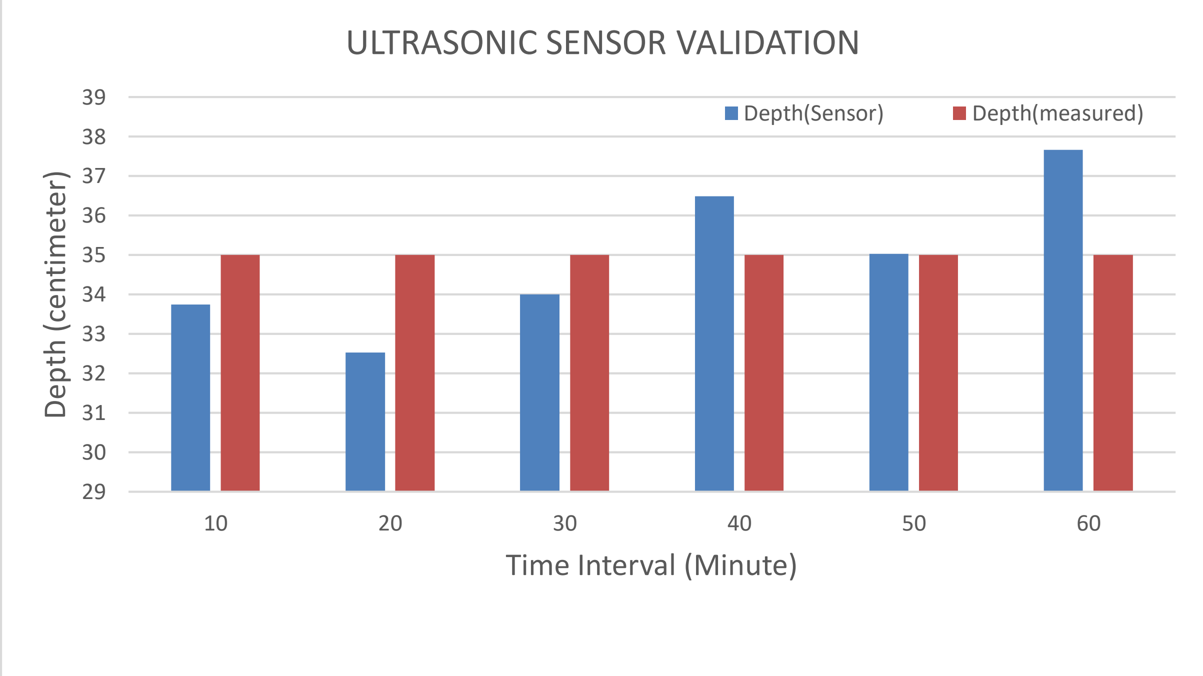

Fig 9: Comparison between Ultrasonic sensor and conventional readings plotted as a graph

CONCLUSION

The investigation of data acquisition for a centrifugal pump using a flow sensor, an accelerometer MPU6050, and an ultrasonic sensor HC-SR-04 is presented in this paper. The study validates the collected data from the sensors through physical measurements, such as water level, vibration, and flow rate. The accuracy of sensors was evaluated by comparing them to traditional forms of data acquisition. The accelerometer and flow sensor demonstrated a negligible error of 0.71% and 0.40% respectively, while the ultrasonic sensor displayed a slightly higher error of 4.24%. The higher error in the ultrasonic sensor is due to the distortion of the sensor which is caused by the splashing of water and the creation of ripples, resulting in the observed error.

The proposed work demonstrates the potential of the data acquisition system using flow sensor, accelerometer, and ultrasonic sensor for other types of pumps and industrial applications. The future research could explore the application of this system to different types of pumps, real-time monitoring of pump performance, and development of predictive maintenance algorithms to identify potential issues with the pump. The implementation of such algorithms could increase the reliability of pumps, reduce downtime, and result in significant cost savings for industries. The future study will be based on development of digital twin which could further optimize pump operation, reduce maintenance costs, and lead to research in machine learning and artificial intelligence to enhance pump performance.

REFERENCES

[1] J. Liu, J. Liu, C. Zhuang, Z. Liu, and T. Miao. 2021. Construction method of shop-floor digital twin based on MBSE. Journal of Manufacturing Systems, 60, 93-118.

[2] L. Liu, X. Zhang, X. Wan, S. Zhou, and Z. Gao. 2022. Digital twin-driven surface roughness prediction and process parameter adaptive optimization. Advanced Engineering Informatics, 51:101470.

[3] Q. Lu, X. Xie, A. K. Parlikad, and J. M. Schooling. 2020. Digital twin-enabled anomaly detection for built asset monitoring in operation and maintenance. Automation in Construction, 118: 103277.

[4] Maïzi, Y., & Bendavid, Y. 2021. Building a digital twin for IoT smart stores: A case in retail and apparel industry. International Journal of Simulation and Process Modelling, 16(2), 147-160.

[5] Augustine, P. 2020. The industry use cases for the digital twin idea. Advances in Computers, Vol. 117, No. 1, 79-105.

[6] Alf Puttmer. 2006. New applications for ultrasonic sensors in process industries, Ultrasonics, 44, e1379-e1383.

[7] Ahmet Soylemezoglu, Sarangapani Jagannathan, and Can Saygin. 2011. Mahalanobis-Taguchi System as a Multi-Sensor Based Decision Making Prognostics Tool for Centrifugal Pump Failures. IEEE Transactions on Reliability, Vol. 60, no. 4.

[8] K. Arasu. 2017. Automated experimental procedure using sensors and Arduino. International Conference on Inventive Computing and Informatics.

[9] Jiaxing Lu, Shouqi Yuan , Siva Parameswaran, Jianping Yuan , Xudong Ren, and Qiaorui Si, 2017. Investigation on the vibration and flow instabilities induced by cavitation in a centrifugal pump. Advances in Mechanical Engineering, Vol. 9(4) 1–11.

[10] J. Lalnunthari, and H.H. Thanga. 2017. Dependence of Hall Effect flow sensor frequency on the attached inlet and outlet pipe size. IEEE International Conference on Consumer Electronics-Asia.

[11] A. Rocchi, E. Santecchia, F.Ciciulla, P. Mengucci, and G. Barucca. 2018. Characterization and optimization of level measurement by an ultrasonic sensor system. IEEE.

[12] Saleem Latteef Mohammed, Ali Al-Naji, Mashael M. Farjo and Javaan Chahl. 2019. Highly Accurate Water Level Measurement System Using a Microcontroller and an Ultrasonic Sensor. International Conference on Sustainable Engineering Techniques.

[13] Surjay Boral, Abhishek Sardar, Analprabha Roy, and Rajatsubhra Maiti. 2020. Non Contact Water Level Monitoring For Rain Water Storage System Using Labview With Arduino & Ultrasonic Sensor. Project Report. RCC Institute of Information Technology.

[14] Bryan Bohn, James Olson, Bhushan Gopaluni, and Boris Stoeber. 2020. Sensing Concept for Practical Performance Monitoring of Centrifugal Pumps. IEEE.

[15] João Victor Oliveira Rodrigues, João Victor Oliveira Rodrigues, Flávio Fernandes Barbosa Silva,and Reginaldo Gonçalves Leão Junior. 2021. Performance evaluation of accelerometers ADXL345 and MPU6050 exposed to random vibrational input. Research, Society and Development, v. 10, n. 15, e286101523082.

[16] Lei Chen, Lijun Wei, Yu Wang, Junshuo Wang and Wenlong Li. 2020. Monitoring and Predictive Maintenance of Centrifugal Pumps Based on Smart Sensors. Sensors, 22(6).

[17] W. Luo, T. Hu, Y. Ye, C. Zhang, and Y. Wei. 2020. A hybrid predictive maintenance approach for CNC machine tool driven by digital twin. Robotics and Computer-Integrated Manufacturing, 65: 101974.