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Development of a Locally-made Digital Tachometer

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Abstract
The exact measurement of rotational speed is an important parameter for monitoring and controlling mechanical systems such as motors, turbines, and automotive engines. This paper presents the design and evaluation of a low-cost digital tachometer that is locally produced using a Hall Effect sensor and an Arduino microcontroller. The tachometer was developed to accurately measure rotational speed for educational and industrial purposes while being less expensive than commercial tachometers. The fabricated device was evaluated using an electric motor, a mini hand fan, and an automobile radiator fan. The fabricated tachometer's measurements were then compared to Hall Effect-based commercial tachometers to evaluate their accuracy and reliability. Results showed that all tests had a very small difference between the fabricated tachometer and the commercial tachometers, showing that the measurements were accurate. The locally manufactured device had a shift of ±2.60 RPM, ±3.07 RPM, and ±2.57 RPM for the electric motor, mini hand fan, and automobile radiator fan, respectively. The overall efficiency is 97%. Therefore, the Hall Effect sensor and Arduino system could be used to monitor speed. One key idea of this research was to provide a low-cost option of a tachometer rather than one from a foreign country to enhance learning and use in industry. The instrument will provide an in-class mechanism for teaching engineering students instead of purchasing higher and probably unneeded foreign tachometers. Overall, the instrument will add a hands-on learning experience to engineering education while providing a low-cost option for an academic institution or small business.

Keywords: *Digital tachometer, hall effect sensor, Arduino microcontroller, speed monitoring, RPM Measurement consolidation.*

1.0 Introduction

Measurement of the speed of rotation is an important component in the monitoring and control of mechanical systems applied to a wide range of industries such as automotive, aerospace, manufacturing, and power generation. The tachometer is a key instrument used to measure the rotation velocity of a shaft or disk in revolutions per minute (RPM). Tachometers provide data on speed in real-time; as a result, engineers and operators can optimise performance, avert mechanical failure, and ensure safety, as stated by Randall (2021). The method of speed measurement has a history that dates back to the early nineteenth century when the first tachometer was invented in 1817 by German engineer Dietrich Uhlhorn. Early tachometers were the mechanical variety and based on centrifugal force. Initially, they were developed for direct usage on steam engines and locomotives to measure engine speed. Since then, advances in technology have led to the development of tachometers that are smaller, more accurate, and more efficient. There are both analog and digital versions, and tachometers can also be classified as contact or non-contact.

The recent tachometers employed a variety of sensing mechanisms for accurate speed measurement, including optical, magnetic, and Hall Effect sensors, according to Agarwal et al. (2022). Digital tachometers are often the most common due to their accuracy and ease of use; however, ready-made digital tachometers are prohibitively expensive for most students, small-scale industries, and research institutions in developing countries (Shnier et al., 2023). Hence, there is an existing need to manufacture digital tachometers that are locally made, cost-effective, and provide accurate speed measurement. This article details the manufacture of the digital tachometer as a cost-effective substitute for expensive imported digital tachometers. This digital tachometer utilizes a Hall Effect sensor, an Arduino microcontroller, and an LCD to provide measurements. This study examines the functioning of the tachometer in a similar manner to commercial digital tachometers, ensuring that it is accurate and reliable.

This paper proposes the development of a low-cost tachometer, utilising locally developed components to help support engineering education and industry needs for accurate measurement of speed at an affordable price, as reported by (Bello et al. 2023; Bello et al. 2022 and Bello et al. 2021). The application will not only

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serve as an effective learning tool for students, but will also be useful for small businesses with a reliable measurement tool for quality monitoring, maintenance of equipment, and operational efficiency. The goal of this study is to design a low-cost digital tachometer, using a Hall Effect sensor and Arduino microcontroller, to produce accurate measurements of rotational speed, for use in both industry and education. The project has significance in producing a suitable alternative to conventional tachometers at affordable, locally sourced prices. The potential use of inexpensive networked sensors in the future may be utilized to provide inexpensive measurements for both educational developments in engineering and industrial monitoring of equipment and tool quality. The possibility of future uses of the digital tachometer may enhance engineering education, monitoring equipment, and robots, and develop small-scale productivity in technology.

A tachometer is an important instrument for measuring the rotational speed of a shaft or disk, usually in revolutions per minute (RPM) (Xia, H., and Liu, Y. 2024; Bu et al. 2021). The use of a tachometer is central to tracking and regulating the operation of many mechanical systems, including engines, turbines, and various types of industrial equipment Al-Dosary et al., 2023). Historically, tachometers have developed significantly with technology, such that tachometers now continue to evolve to improve upon mechanical tachometers, to digital tachometers that show improvements in accuracy, longevity, and usability (Bhujel et al. 2024, Shahila et al. 2024, and Bello et al. 2024). In this study, tachometers literatures were reviewed, their types, and how they operate, and advancements in their conception and use. A number of studies on digital tachometers focus on sensor technology, accuracy, and cost-effectiveness, in addition to applications associated with tachometers. Different sensor technologies adopted in studies to conduct tachometers have included optical, magnetic, infrared, and Hall Effect sensors for educational and industrial implementation. Overall, findings from the literature indicate better data accuracy, integration of the sensor with a microcontroller, and now wireless. For example, Bhujel et al. (2024) developed a non-contact wireless tachometer that used an infrared sensor and Bluetooth module, which interfaced with an Arduino microcontroller. The results indicated good accuracy at ± 1.5 RPM baseline differences when compared to commercial tachometers, and an improved experience in real-time monitoring on a smartphone app.

Again, Sadaf et al. 2023 developed an optical tachometer based on a laser sensor and a photoelectric sensor for high-speed measurements, and the instrument had a low error of less than 1% on speed measurements, but it was difficult to detect rotation in the dark. Others have also developed an AI-enhanced Hall Effect tachometer with fault detection capabilities to meet Industry 4.0 needs. Shnier, A. (2023). Implemented a spin coater speed measurement system using an Arduino-controlled Hall Effect sensor. Speed measurements were accurate and could be monitored, but required frequent recalibration of the sensor. Li et al. 2023 implemented a tachometer-less synchronous sampling system for monitoring speed fluctuations in wind turbines. There has been a lot of literature documenting improvements to digital tachometer technology, but costs and accessibility are greater challenges. Many commercialized digital tachometers come at a high cost, making them inaccessible to students, small businesses, and researchers in developing countries. This study focuses on affordable, locally made tachometers using common materials.

The initial mechanical tachometers operated using centrifugal force measurement, a concept akin to the centrifugal governor Hasan, A., 2021). The earliest reported use of a tachometer was in 1817 when German engineer Dietrich Uhlhorn constructed a device that measured the speed of a machine. By the 1840s, tachometers were common in steam locomotives as a measure of an engine's output. As the innovations of the automobile and aviation industries advanced, tachometers became common fixtures on dashboards in order to assist the driver or pilot in measuring and optimising engine outputs. During the 1950s and 1960s, electrical tachometers were developed, utilising generators or sensors that would create an output signal proportionate to a measurement of the rotational speed. The contemporaneous digital revolution of the late 20th- and early 21st-centuries further enhanced tachometer technology in the introduction of non-contact and laser tachometers, which measured performance with greater accuracy and reliability.

Tachometers serve many roles across multiple fields:

i. Automotive: Tachometers measure RPM to optimise performance and avoid over-revved engines Murray, M., 2022).

ii. Industrial: Tachometers can be tasked with speed measurement on machines to improve safety, efficiency, and predictability of maintenance (Babayeju et al 2024 and Okirie et al 2024).

iii. Aviation: Tachometers measure RPM of engines on aircraft to reduce mechanical failures (Xu et al 2023 and Zhao et al 2023)

iv. Healthcare: Tachometers are employed in specialised equipment as a means to measure the blood flow rates in medical applications (Ray et al 2025 and Kulkarni, M. R. (2024)

v. Rail: Tachometers aid in speed regulation and safety systems on trains, Sengupta, M. (2024).

Tachometers can be categorised into two types based on the principles of tachometer operations and measurement:

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Contact Tachometers - A contact tachometer must make physical contact with the rotating shaft to measure its speed. Optical encoders and magnetic sensors are used for detecting rotation. Non-Contact Tachometers - A non-contact tachometer uses lasers or infrared sensors to measure the speed of rotation without touching the moving part, making non-contact tachometers more durable and applicable to high-speed applications.

The tachometer measures the frequency of pulses over time, which is ideal for high-speed. Measurement tachometers measure speed by using clock time between subsequent pulses generated by the rotating shaft. This is more accurate in low-speed applications. Frequency Measurement: These devices typically use Hall Effect sensors or photo sensors to generate reliable readings Li et al (2023).

Digital tachometers have become increasingly popular because they are accurate, user-friendly, and can display more complex information compared to analog tachometers. They have features that allow them to:

Highly Accurate: Eliminate human error when taking measurements, even on smaller currents

Data Displayed in Real-Time: They can be paired with a microcontroller and perform data logging and analysis.

Improved Longevity: Digital tachometers have no moving parts, which serves to reduce stress over time.

Versatile: Digital tachometers let you read both contact and non-contact techniques, adding many more options to your toolbox.

User-Friendly Interface: LCD and LED displays provide clear numerical readings.

Despite these advantages, digital tachometers require power sources (batteries or external power) and are susceptible to electromagnetic interference, which can affect accuracy in industrial environments.

The literature review highlights the evolution, classification, and technological advancements of tachometers. Digital tachometers, particularly those utilising Hall Effect sensors, have revolutionised speed measurement by offering non-contact, highly accurate, and durable solutions for various industries. However, challenges such as electromagnetic interference, calibration needs, and power dependency remain. Future developments will likely focus on wireless connectivity, Artificial Intelligence (AI) driven predictive maintenance, and miniaturisation, ensuring greater efficiency and wider applicability in the industrial, automotive, and medical fields.

2.0 Materials and Methods

2.1 Materials

The construction of the digital tachometer required several key components, including:

Liquid Crystal Display (LCD) – Used to display the measured rotational speed in RPM.

Arduino Board – The microcontroller unit responsible for processing data from the Hall Effect sensor.

The tachometer system consists of several essential components that work together to measure rotational speed. The Hall Effect Sensor detects the presence of a magnetic field and generates pulses corresponding to the rotational speed. A push button serves as an input to start or reset the tachometer readings. Jumper wires are used to interconnect the components, while a 3D-printed case provides housing for the tachometer. A Duracell battery powers the device, and a converter adjusts the voltage levels as required by the system.

The digital tachometer operates based on the Hall Effect principle. When a rotating shaft embedded with a magnet passes in front of the Hall Effect sensor, it generates an electrical pulse. These pulses are counted by the Arduino microcontroller, which then calculates the RPM using a predefined time interval. The result is displayed on the LCD screen, providing real-time speed measurement.

Two push buttons are used for system control. The first button is connected to PIN 3 on the Arduino board, while the second button is connected to PIN 4. These buttons allow the user to interact with the tachometer, either starting or resetting the readings as needed

The LCD control lines are connected to A5 and A4 on the Arduino board, ensuring accurate data representation

The Hall Effect sensor is positioned near the rotating shaft, with a reference magnet attached to the shaft. As the shaft rotates, the sensor detects the passing magnet and generates a digital pulse. This pulse is sent to the Arduino's digital input pin for further processing and RPM calculation.

To validate the performance of the fabricated tachometer, it was tested using various rotating devices. The tested devices included an electric motor rated at 2905 RPM, 380/415V, 50Hz, a mini hand fan with a maximum speed of 1800 RPM, and an automobile radiator fan with a maximum speed of 3000 RPM. These tests helped assess the effectiveness of the tachometer across different rotational speeds, and average efficiency was found to be 97%.

Each device was used to measure the RPM of the rotating equipment, and the results were recorded. The accuracy of the fabricated tachometer was determined by calculating the mean value of the commercial tachometers and comparing it to the readings from the locally developed model. This evaluation ensured that the device performed within acceptable accuracy limits. Table 1 describes the digital tachometer components.

Table 1: Parts of Digital Tachometer

S/N	Tachometer Parts	Description
1	LCD	The liquid crystal display (LCD) is the output screen used to display the angular speed value.
2	Arduino board	The Arduino board is an open-source microcontroller platform that enables users to program, prototype, and control electronic systems easily using sensors, actuators, and simple software tools worldwide.
3	Hall Effect sensor	A Hall Effect sensor detects magnetic fields, converting the field strength into electrical signals for use in position, speed, and current sensing applications in automotive, industrial, and consumer electronics.
4	Push button	A push button is a momentary switch that completes or interrupts an electrical circuit when pressed, enabling the user to turn on or turn off the Tachometer
5	Jumper wires	Jumper wires are flexible electrical connectors used to temporarily link the Arduino components without soldering during prototyping experiments.
6	3D Case	A 3D tachometer case is a custom-printed enclosure that houses and protects tachometer electronics, ensuring alignment, durability, mounting support, and professional appearance during operation.
7	Duracell battery	A Duracell battery is a long-lasting, reliable power source providing consistent energy for the digital tachometer device
8	Converter	A converter is an electronic device that changes the digital tachometer's electrical energy from one form, voltage, or signal type into another for compatibility.

2.2 Design Methodology

A digital tachometer can be designed through various methodologies; however, we have opted for a specific approach that incorporates a microcontroller as the primary control unit. This design utilises an infrared transmission technique for detection, an alphanumeric LCD module for output display, and a proximity sensor to monitor the rotation of the shaft whose speed is being assessed. In this configuration, the proximity sensor generates counted pulses by detecting any reflective object that passes in its vicinity, producing an output pulse for each complete rotation of the shaft. These pulses are subsequently transmitted to the microcontroller for counting, and the resulting data is displayed on the LCD module. The methodology implemented in this study is illustrated in Figure 1.

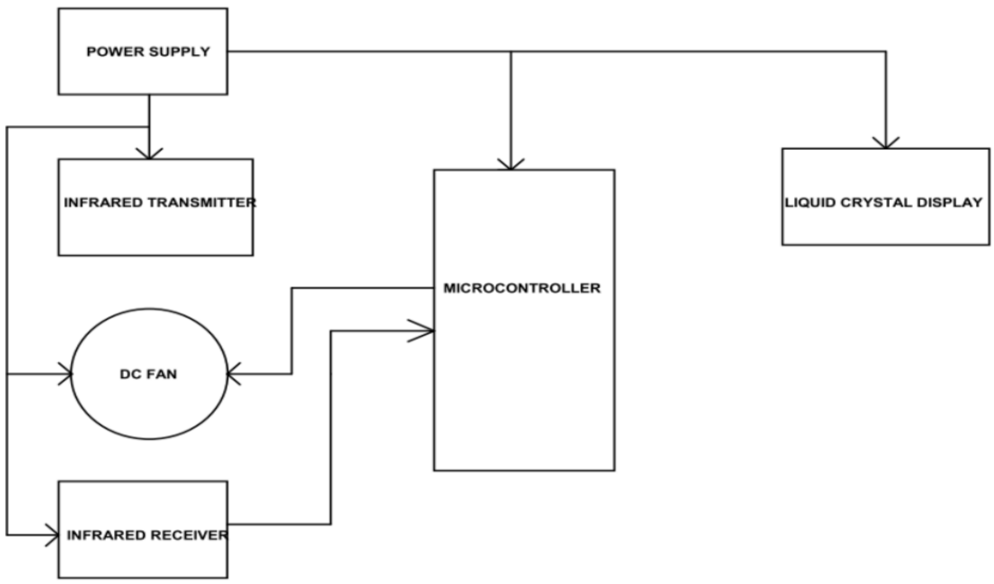

Figure 1: Block diagram of a digital tachometer

The power supply functions as the primary source of electrical energy for the system. It operates at a supply voltage of 220Vac, which is reduced by a transformer rated at 220Vac/24Vac and 500mA. The resulting 24VAC voltage undergoes rectification through a bridge rectifier, producing a direct current (DC) output. Following the rectification, any residual alternating current (AC) ripples are eliminated using a bypass

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capacitor. The output from this capacitor remains unregulated, leading to a significant voltage drop when a load is applied. To address this issue, an integrated circuit (IC) voltage regulator is employed to achieve a stable output. Figure 2 depicts a Schematic Representation of the Power Supply Unit.

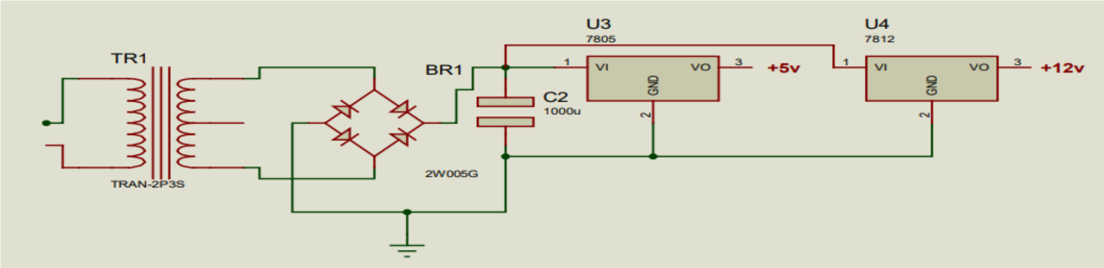

Figure 2: Schematic Representation of the Power Supply Unit.

2.3 Data Analysis

The RPM measurements obtained from the fabricated tachometer were compared with the commercial tachometers to determine any deviation. The outcomes were analysed statistically to assess the reliability and accuracy of the locally developed device.

2.4 Limitations and Future Improvements

The current design is limited to rotational speed measurement and does not include data logging or wireless transmission.

Future progresses may involve integrating miniaturised electronic components for enhanced portability.

Packaging improvements can enhance durability and ease of use in industrial environments.

This methodology ensures a systematic approach to developing a cost-effective digital tachometer and maintaining accuracy and reliability.

3.0 Results and Discussions

3.1 Devices Used for Measurement

To evaluate the performance of the fabricated digital tachometer, different rotating devices were used as test subjects. These devices included:

i. Electric Motor
ii. Full load speed: 2905 RPM
iii. Rated voltage: 380/415V
iv. Rated frequency: 50Hz
v. Power: 7.5 HP (5.5 kW)
vi. Mini Hand Fan
vii. Maximum speed: 1800 RPM
viii. Automobile Radiator Fan
ix. Maximum speed: 3000 RPM

Figures 3 and 4 present the interior and exterior of the digital tachometer.

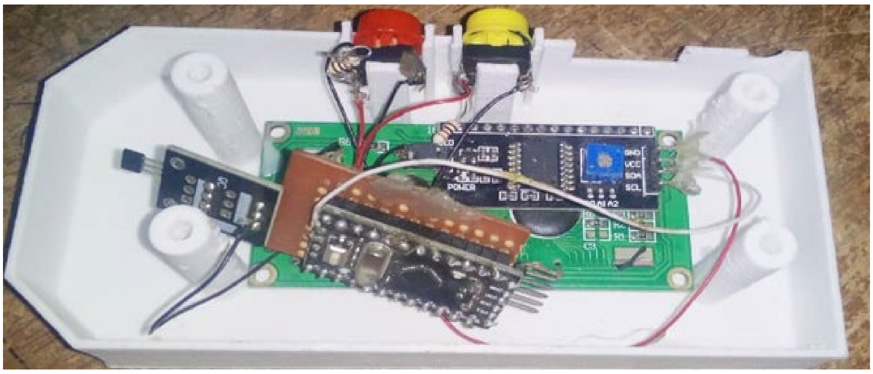

Figure 3: The interior of the digital tachometer

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Figure 4: The exterior of the digital tachometer

3.2 List of Digital Tachometers Used for Measurement

The fabricated tachometer was compared with commercially available models to verify its accuracy. The devices used for comparison included:

i. Tachometer 1 – The locally developed Hall Effect digital tachometer.
ii. Tachometer 2 – An optical digital tachometer.
iii. Tachometer 3 – A commercially available Hall Effect digital tachometer.
iv. Tachometer 4 – Another commercial Hall Effect digital tachometer.

The performance of each tachometer was tested by measuring the RPM of the selected rotating devices, and the results were recorded for analysis.

3.3 Results of Speed Measurement

The speed values obtained from each tachometer for different devices are presented in Table 2

Table 2: RPM Measurement of Different Devices Using Various Tachometers

Devices	Tachometer 1 (Fabricated)	Tachometer 2 (Optical)	Tachometer 3 (Hall Effect)	Tachometer 4 (Hall Effect)
Electric motor	1351.00	1348.20	1349.00	1348.00
Mini hand fan	854.00	851.80	851.00	850.00
Automobile radiator fan	2950.00	2948.30	2949.00	2945.00

3.4 Performance Comparison and Accuracy Analysis

The testing of the manufactured tachometer was carried out by comparing its readings with the average values recorded by commercial tachometers. The results revealed excellent accuracy for different rotating devices. For the electric motor the average commercial tachometer speed was 1348.40 RPM while the manufactured tachometer speed was 1351.00 RP resulting in a deviation of ±2.60 RPM. For the mini hand fan, the average commercial tachometer speed was 850.93 RP while the manufactured tachometer speed was 854.00 RPM, leading to a deviation of ±3.07 RPM. For the automobile radiator fan the average commercial tachometer speed was 2947.43 RPM while the manufactured tachometer speed was 2950.00 RPM, a deviation of ±2.57 RPM. The relatively low deviations in each case shows that the manufactured tachometer applied highly accurate speed. The performance of various tachometers indicated that the manufactured tachometer provided performance similar to that of commercial tachometers and confirmed it could be used reliably to obtain speed measurements.

3.5 Discussion

The performance evaluation results show that the digital tachometer that is constructed locally is an accurate and reliable method for measuring speed in comparison to commercial tachometers. The very small differences in the measured RPM values confirms that the Hall Effect sensor and Arduino based system are working in capturing and processing rotational speed measurements.

The constructed tachometer displayed a great level of accuracy through a variety of rotating mechanisms. The testing of electric motors had an average RPM deviation of only 2.60, and when the mini hand fan and the car radiator fan were tested, the deviations were 3.07 and 2.57 relative to each device's RPM rate,

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respectively. These deviations are negligible when you consider this tachometer was developed locally, thus giving this design equal status with commercially made tachometers, and in studies similar to the results obtain by (Arif et al 2013, Ferreira et al 2020, and Tunggal et al 2023). Overall, these results are certainly indicative of the tachometer's utility as an alternative tachometer at a lower-cost option. One of the great benefits of the tachometer that has been fabricated relates to the cost of materials. By using locally produced/available materials the cost of production is significantly lower than sales price of imported tachometers. Cost is very important when considering the application of this tachometer for educational purposes, small companies, or the application in and for research in developing countries/regions. Lastly, this tachometer is a reliable and accurate device, where the deviations of the tachometer were well within acceptable limits. In summary, the tachometer is easy to use, accurate and has a relatively inexpensive apparatus to achieve desired RPM speed that is visually displayed in a LCD readout.

The fabricated tachometer achieved its intended purpose, though it has some restrictions in functionality. The design only measures rotational speed, and there are no additional features such as wireless data transmission, data storage, or multi-sensor integration. Future revisions could consider Bluetooth or Wi-Fi capabilities for monitoring data remotely, a smaller device for portability, and improving the durability of the shell for industrial use. Lastly, developing a rechargeable battery system would improve energy efficiency and usability. In practice, the locally sourced manufactured tachometer can be used in the automotive industry for measuring engine RPM, by manufacturing plants for measuring machine speed, and by educational institutions or programs for hands-on design experience training related to engineering and the design process. It could also be used to monitor the rotation speed of wind turbines or other rotating components in the renewable energy systems field.

The Advantages of the Fabricated Tachometer are: The use of locally sourced materials significantly reduces production costs, making it an affordable alternative to imported tachometers; the measured deviations were minimal, confirming the precision of the Hall Effect sensor and Arduino-based system; the digital LCD provides a clear and real-time RPM reading, improving usability for engineering students and industry professionals. The fabricated tachometer successfully measured the RPM of different rotating devices with minimal deviations from commercial tachometers.

The results confirm that the locally developed tachometer is a viable alternative to expensive commercial models. It provides high accuracy, affordability, and ease of use, making it suitable for educational, automotive, and industrial applications. Future research should focus on improving design features to enhance its efficiency, reliability, and practical applicability in diverse engineering fields.

4.0 Conclusion

The design and evaluation of the locally constructed digital tachometer indicated that it was an inexpensive and reliable alternative to a commercially available equivalent. The device was built using a Hall Effect sensor and an Arduino microcontroller, which provided highly accurate rotational speeds with very little error compared to standard measuring tachometers and was easy to use. Affordability and ease of use make it suitable for educational and industrial applications where a real-time tachometer would be appropriate for engineering students and small businesses. The results showed that the tachometer was a valid instrument to measure RPM in different rotating devices and can be easily adapted to be a great tool for use in the automotive field or manufacturing environments, where more advanced tachometers can cost substantially more. This study, however, does not end here; there is room for consideration of more advanced modifications such as making the components smaller, incorporating wireless data transfer capabilities, and improving the robustness of the digital tachometer for practical use in more demanding industrial settings. To sum, this study demonstrates it is possible to have both affordability and accuracy in tachometry; furthermore, locally made devices can compete with high-end imported devices.

4.1 Recommendations

Taking into consideration the results achieved from this investigation, these suggestions are made to improve the operability, usability, and functionality of the locally made tachometer: Improvements of the original design should consider:

i. designing a Bluetooth or Wi-Fi connection to make communication easier to report and log data to a personnel laptop or mobile device remotely.

ii. improving the materials that encase the device to a plastic or more durable material, and work tolerably in worse environments for an industrial field application.

iii. include a memory module to store RPM data over time on a per-second basis, so trends in speed can be recorded over time

iv. charged batteries with a mode that has power saver and energy savings, and improvements to lessen costs and provide energy efficiency

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v. more performance testing in more industrial settings (including renewable energy systems, heavy machinery, precision makeover), others to test the versatility and robustness of use cases in other reliable settings

vi. provide standardization of tachometer and validated tachometer so that it corresponds to accuracy (i.e., standards, range, tests) with industry standard (a guide for storing data tested prior), which is a sustainable market value, and those tests become part of learning practice,

vii. have an engineering tradition to contribute to the local tachometer as a teaching tool for hands-on training in sensor technology, microcontroller programming, and industrial instrumentation.

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