Proceedings of 15th IOE Graduate Conference
Peer Reviewed
Year: 2024 Month: May Volume: 15
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Development and Testing of Non-Contact and Wireless Tachometer

Sajan Bhujel [a], Prahar Basnet [b], Tirtha Bahadur Khadka [c],
Tulsi Ram Bhandari [d], Vikash Verma [e], Chiranjivi Dahal [f]

[a, b, c, d, e, f] *Department of Mechanical and Automobile Engineering, Pashchimanchal Campus, IOE, TU, Nepal*

[a] sajanbhujel8m@gmail.com, [b] praharbasnet2017@gmail.com, [c] sumankdk354@gmail.com,
[d] tulcbhandari32@gmail.com, [e] svvermavikash1234@gmail.com, [f] cdahal@tcioe.edu.np

Abstract

This paper mainly emphasis on developing a contactless and wireless digital tachometer for measuring the rotational speed in Revolution per Minute (RPM). The tachometer is constructed through the integration of a microcontroller, an infrared system, and a Bluetooth Module in which the infrared system senses the interruption in the beam of rays caused by rotating object and generates pulses which will be sent to the microcontroller. These pulses will be counted and displayed on the Bluetooth Serial Monitor Application via Bluetooth Module in RPM on every one second. Through comprehensive testing at various speeds, including 498 RPM, 995 RPM, 1992 RPM, 2989 RPM, 3992 RPM, 4996 RPM, 5993 RPM, and 6995 RPM, the highest accuracy was achieved at higher RPM, displaying the percentage error less than 0.3% and the lowest accuracy was at lower RPM, with an maximum percentage error of 15.4%. These findings underscore the precision and reliability of the tachometer at different speeds which provides valuable insights for its practical application.

Keywords

Pulse Width Modulation, Infrared, Microcontroller, Bluetooth

1. Introduction

Rotational speed measurement is a key issue in most industries, either for process control, characterization or fault diagnosis. In electric motor driven systems, it can be used to estimate the motor load level [1]. A tachometer is a measuring instrument made and designed to measure the speed of rotating objects. It can be broadly classified into two main categories based on their measuring techniques [2]: contact and non-contact tachometers. For measurement of RPM (Revolution per Minute) using the mechanical tachometers, direct contact between motor and the tachometer is needed. This kind of tachometers requires regular maintenance and is complicated to use. These instruments suffer from wear and tear. In addition to this, mechanical tachometer imposes the load in the shaft and absorbs the power. Hence, they cannot be used in application involving small power [3]. Therefore, there is a requirement for a contactless digital tachometer which can be easily used with monitoring system.

The procedure of a digital tachometer is shooting infrared light at the plane reflective, which will reflect infrared light received by a detector [4]. These interruption in the beam of light has to be counted and presented in the RPM for the rotational speed measurement. When it comes to the measurement of the rotational speed of the propeller of a drone during flight, both existing mechanical tachometers and digital tachometers face limitations because they do not provide the wireless data transmission of the RPM to the user at ground. Hence, for the measurement of the RPM of the propeller of the Unmanned Aerial Vehicle (UAV) contactless and wireless tachometer should be constructed. In this paper, contactless and wireless digital tachometer was developed and tested for measuring the rotational speed through the integration of a microcontroller, an infrared system, and a Bluetooth Module.

2. Related Works

The first mechanical tachometer was invented around 1817 by German engineer Dietrich Uhlhorn. It operates like a centrifugal governor and has since been widely used to measure the speed of machines, including locomotives, automobiles, trucks, tractors, and aircraft [5]. Some researchers have researched motor rotational speed measures such as Plante and Lane who investigated error detection and failure prediction using vibration analysis and current motor signature analysis to detect imbalanced motor resistance, respectively. The motor condition monitoring experiment was regulated, and the operational speed of the motor was controlled by the AC motor drive [6]. A tool made by Tunggal to measure the motor's rotational speed using the E18-D80NK sensor, microcontroller, and LCD has best performance at low to medium speeds, and it starts to decline at high speeds [7]. A motor rated 3000 RPM was tested using existing tachometer and the microcontroller based tachometer for four readings at different Pulse Width Modulation (PWM) and the percentage error of the microcontroller based tachometer is 1.02% and the percentage error of the existing tachometer is 2.41% [8].

An optical tachometer which can be operated with a supply of 3-15V has the range of maximum measured speed lower than the that of conventional tachometer and current drawn little bit higher but due to its simplicity and low manufacturing cost it will be better for industrial and laboratory application [9]. Ogunjirin [10] built the entire device around the ATmega328-p Arduino Micro-Controller Unit (MCU) which uses the embedded C++ programming language and after performance testing of the device against a commercial available tachometer a percentage error of 4.2% was observed, which is within an acceptable range.

Kolhe [11] uses a GS101201 speed sensor to measure the speed of one of the cars wheels in which the Arduino board receives signals from the sensor and calculates the rpm then converted into a speed, and send this information out to the LCD (Liquid Crystal Display) screen on the dashboard of the car. Ulanova [12] developed the instrumentation system to measure and present the data of real time motorcycle operating condition. This instrumentation system employs Arduino Mega as microcontroller and a number of sensors for measurements. Kumar [13] have implemented a BLDC (Brush Less Direct Current) motor speed control system to maintain the speed of the motor at the desired value under various conditions. The motor speed is sensed by an optical switch and converted to feedback voltage and the controller acts on the error signal detected by IR (Infrared) sensor and generates appropriate control voltage.

Based on the literature review, it becomes clear that there is a conspicuous gap in the tachometer technology. Hence, there is the need for such a technological advancement in tachometers that are capable of transmitting data directly to mobile phones. In this study, the wireless and contactless tachometer was developed and tested at various speed for the wireless data transmission of the RPM in the Bluetooth Serial Monitor Application.

3. Method and Methodology

3.1 Hardware Requirement:

The hardware components required for the above system is explained below:

3.1.1 Arduino Uno

Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB (Universal serial bus) connection, a power jack, an ICSP (In Circuit Serial Programming) header and a reset button [14].

3.1.2 IR Sensor

IR Sensor Module has built-in an IR transmitter and IR receiver that sends out infrared light and looks for reflected infrared light to detect the presence of any obstacle in front of the sensor module [15]. There is onboard a potentiometer to adjust the detection range. There is an Obstacle Detection LED indicator on the module board. IR sensor transmits digital data (logical 1 and 0) in the form of infrared light. When the sensor gets logical 1 means LED (Light Emitting Diode) ON and logical 0 means LED OFF.

3.1.3 Bluetooth Module

Bluetooth Module HC-05 is used to communicate between Arduino and Bluetooth Serial Monitor Application for displaying the RPM of the motor. HC-05 can be used in a Master or Slave configuration, making it a great solution for wireless communication [16].

3.1.4 9V Battery

This has polarized snap connector at the head and a rectangular prism shape with perfect edges. This 9-volt battery has a format which is generally obtainable in fundamental alkaline and carbon zinc chemistry. This format which is Mercury-oxide batteries in many years have not been made because of the content named mercury.

3.1.5 BLDC Motor

BLDC stands for Brushless Direct Current Motor. It has the rating of 1000kV means for every unit voltage applied, it's RPM increases by 1000 without any load. This compact and lightweight motor is ideal for applications such as drones, RC aircraft, electric bicycles and robotics.

3.2 Software requirement

The software required for the above system is explained below:

3.2.1 Arduino IDE (Integrated Development Environment)

Arduino IDE is an open-source software that is mainly used for writing and compiling the code into the Arduino Microcontroller. It is an official Arduino software, making code compilation too easy that even a common person with no prior technical knowledge can get their feet wet with the learning process. It is easily available for operating systems like MAC, Windows, and Linux and runs on the Java Platform that comes with inbuilt functions and commands that play a vital role for debugging, editing and compiling the code in the environment [17]

3.2.2 Bluetooth Serial Monitor

The Bluetooth Serial Monitor is an Android application designed to facilitate communication between Bluetooth modules and mobile devices [18]. It enables the display of RPM (Revolution Per Minute) data sent wirelessly from the Arduino to the Android device, providing a user-friendly interface for monitoring and analyzing the information.

3.3 Block diagram

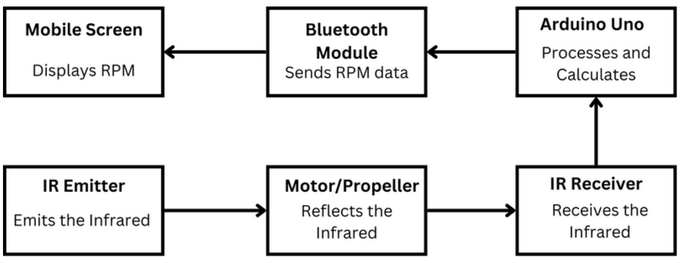

Figure 1: Block diagram

This part introduces the required approach towards making of digital speedometer. The tachometer system consists of several components to measure the rotation speed of an object and present the data through a Bluetooth-enabled interface. An infrared (IR) sensor is used to detect the rotational movement which generates the pulses as the object interrupts the infrared beam. These pulses are conditioned for reliability before being fed into an Arduino microcontroller, which serves as the central processing unit of the system. The Arduino calculates the RPM (Revolutions per Minute) based on the number of pulses generated by interruption and the time between the total pulses. To enable wireless communication, a Bluetooth module is connected to the Arduino which facilitates the transmission of RPM data. The Bluetooth module coordinates with a Bluetooth Serial Monitor application running on an external device, such as a smartphone and displays the real-time RPM values. The overall system includes power supply considerations to ensure the proper functioning of all components. This integrated approach allows for a wirelessly accessible tachometer system suitable for various applications.

3.4 Circuit diagram

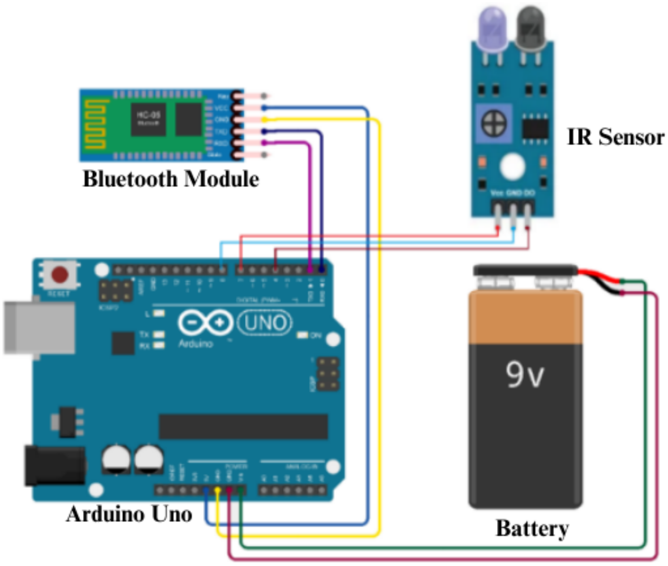

Figure 2: Circuit diagram

As shown in Figure 2, it contains Arduino Uno, IR sensor module and Bluetooth Module. Arduino controls the whole process like reading pulse that IR sensor module generate according to object detection, calculating RPM and sending RPM value to Bluetooth Serial Monitor through Bluetooth Module. IR sensor is used for sensing object. We can set sensitivity of this sensor module by inbuilt potentiometer situated on IR module. IR sensor module consist an IR transmitter and a photo diode which detects or receives infrared rays. IR transmitter transmits infrared rays, when these rays fall on any surface, they reflect back and sensed by photo diode. The output of photo diode is connected to a comparator, which compare photo diode output with reference voltage and result is given as output to Arduino.

3.5 Circuit connection

The circuit connection involves connecting the output pin of the IR sensor module directly to pin 4 of the Arduino Uno and the Vcc and ground pins of the IR sensor module are connected to pins 7 and 8, respectively. In the same way, the Bluetooth module's Rx (Receive) and Tx (Transmit) pins are connected to the Tx and Rx pins of the Arduino Uno. The Vcc and ground pins of the Bluetooth module are connected to the +5V and ground pins of the Arduino. A 9V battery powers the system through the VIN and ground pins of the Arduino. To initiate the Arduino Tachometer and begin counting RPM, a button is pressed. The calculated RPM values are then wirelessly transmitted and displayed in real-time on the Bluetooth serial monitor application on a mobile device.

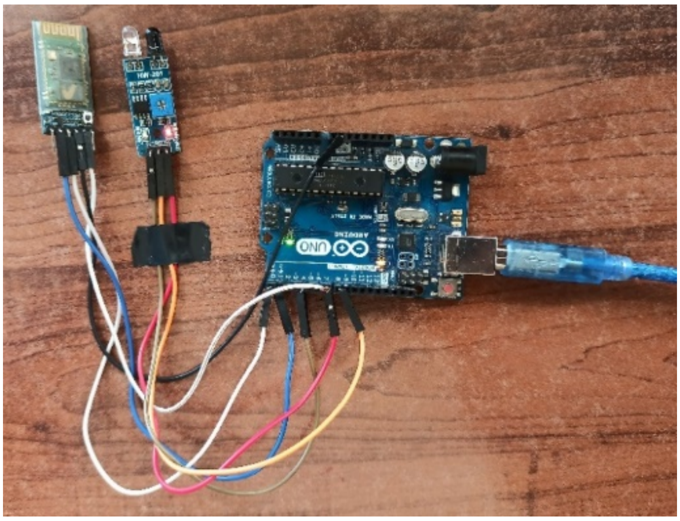

Figure 3: Experimental Setup

3.6 Working Principle of IR Obstacle Sensor

IR sensor is built in two components. IR LED is one of them and another one is IR Photodiode. They are also called in the name of photo coupler. Transmitter and receiver are the main components which built the IR obstacle sensor. The definition of IR Transmitter is a LED that can emits radiation which is infrared in nature [19]. The human cannot observe IR radiation which is emitted in open eyes. When the transmitter transmits an IR energy or infra-red radiation the IR receiver receives the signal. The receivers are consisting in the form of a transistor which is known as phototransistors and light emitting diode known as photo-diodes. IR Photodiode performed their work by emitting infrared radiation to the receiver. IR receiver receives the reflected signal from an obstacle which is emitted by a transmitter.

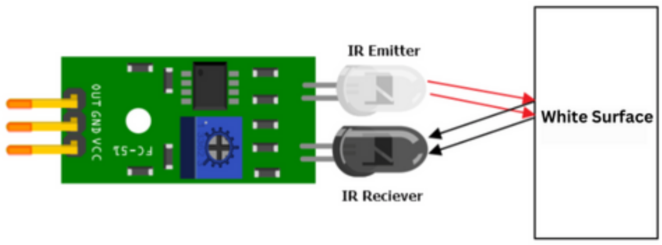

Figure 4: IR Sensor

3.7 Tachometer Formula

For counting the RPM of the Propeller, an IR break-beam that counts every interruption has been utilized. At first, the IR transmitter transmits the IR ray and when the IR rays strikes on the white surface of the tape, it comes back and the IR receiver receives the rays.

$$\text{RPM} = \frac{60000}{\text{current time} - \text{last time}} \times \text{pulse count} \quad (1)$$

Where,
RPM: Revolutions per Minute
60000: A constant to convert milliseconds to minutes
Current Time: The current time in milliseconds when the RPM calculation is performed.
Last Time: The time in milliseconds from the previous RPM calculation.
Pulse Count: The count of pulses received during the time interval.

This formula calculates the RPM based on the time elapsed between the current and last time the RPM was calculated, and the number of pulses received during that time. The interrupt is used to Count pulses, and the formula is then applied in the loop function. The Percentage Error between the RPM measured from standard tachometer and RPM measured from Self Made Tachometer is calculated using the formula [20] :

$$\text{Percentage Error} = \frac{\text{error}}{\text{RPM from standard tachometer}} \times 100\% \quad (2)$$

Where,
Error = RPM from Self Made Tachometer - RPM from standard tachometer

Figure 5: RPM on mobile screen

Figure 5 clearly demonstrates the tracked RPM of 180, which ultimately confirms the functionality of the IR system and successful transmission to the Bluetooth serial application for visual output.

4. Results and Discussion

4.1 RPM comparison of Commercial Tachometer and Self-Made Tachometer

During the initial circuit phase, the Bluetooth serial monitor application shows exactly zero RPM reading when there is no movement detected, confirming proper circuit initialization and zero-point calibration. With the multiple iteration of restarts and power cycles the Bluetooth serial monitor consistently shows zero-RPM readings, validating the effectiveness of the circuit connection. The tachometer transmits data every second making it more precise and reliable for the real time utilization. When the tachometer was operated, it demonstrated overall accuracy, percentage error in a notable pattern.

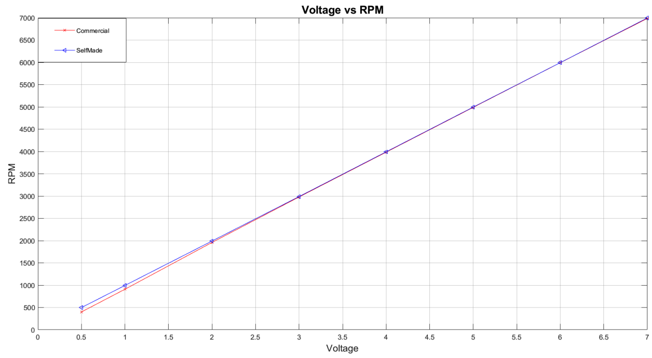

Figure 6: Voltage vs RPM

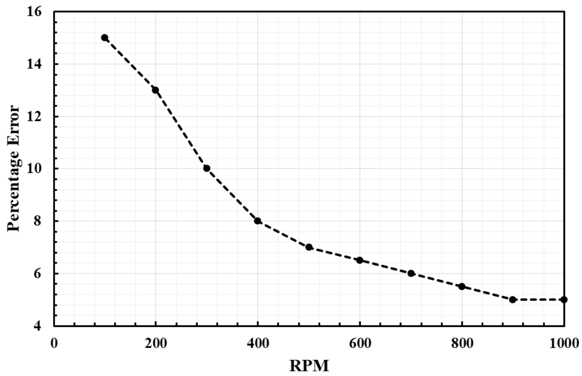

Figure 7: % Error vs RPM (0 RPM to 1000 RPM)

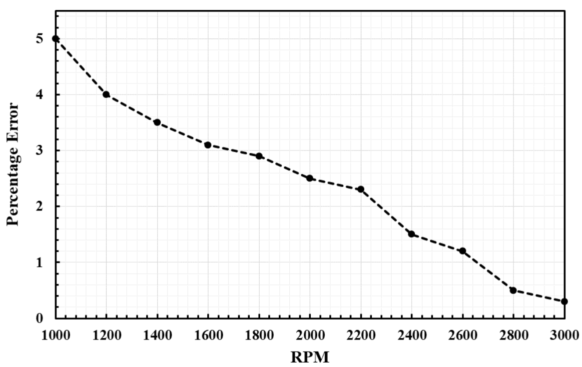

Figure 8: % Error vs RPM (1000 RPM to 3000 RPM)

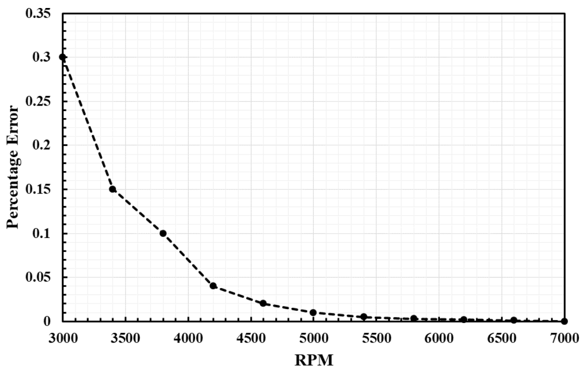

Figure 9: % Error vs RPM (3000 RPM to 7000 RPM)

The data obtained during its testing and comparison with commercially available tachometer are plotted in the graph and the readings were superimposed on one another, which can be seen in the figure (6), validating the tachometer. However, it shows the absolute errors were comparatively higher at lower RPM ranges which can be seen in figures (7) and (8), suggesting a potential room for further optimization. Moving on the error values were less significant at higher RPMs shown in the figure (9), indicating a higher degree of precision. The high errors in the low RPM region can be a result of external noise and sensors resolution.

To enhance the tachometer's performance, the errors obtained mainly during the low RPMs operations must be omitted. The possible factors for the errors could be sensors limitations, signal processing delays, or inherent inaccuracies in RPM calculation algorithms.

At low RPM, weaker signal strength and longer intervals between target detections may amplify the impact of noise and interference which leads to higher measurement error. Conversely, at high RPM, stronger, more consistent signals and shorter detection intervals may result in lower error rates.

4.2 Cost Comparison

The Cost Comparison was made between the Self-Made tachometer and the commercially available tachometer. The table below shows the total cost for making the self-made tachometer which is around Rs. 2270. DT-2234A Digital Laser Photo Tachometer costs Rs. 5550.

Table 1: Cost of the Component of Self-Made tachometer

S.N.	Components	Price
1	Arduino	Rs. 860
2	IR Sensor	Rs. 160
3	HC 05 Bluetooth Module	Rs. 1000
4	9V battery	Rs. 150
5	Total Price	Rs. 2270

5. Conclusion

Based on the testing and data retrieval at speeds of 498 RPM, 995 RPM, 1992 RPM, 2989 RPM, 3992 RPM, 4996 RPM, 5993 RPM, and 6995 RPM, the highest accuracy was achieved at higher RPM, displaying the percentage error less than 0.3% and the lowest accuracy was at lower RPM, with an maximum percentage error of 15.4%. In the project, satisfactory results were accomplished as per the motive to create an experimental setup that can be used to calculate the RPM of the machine. The contactless nature of the tachometer makes it suitable for situations where physical contact with rotating machinery is impractical. Even the Bluetooth connectivity facilities with remote RPM monitoring and data collection enabling for real-time analysis in various fields. Future work will be focusing on minimizing errors, testing different conditions and integrating with UAV, ultimately advancing in the field of RPM sensing and wireless data transmission in different sectors. For decreasing the percentage error at low RPM, advanced signal processing techniques such as digital filtering and adaptive algorithms must be employed to mitigate errors, where signal noise tends to be more prominent.

References

[1] Fernando JTE Ferreira and Aníbal T de Almeida. Considerations on in-field induction motor load estimation methods. In *2008 18th International Conference on Electrical Machines*, pages 1–8. IEEE, 2008.

[2] Roman Malarić. *Instrumenation and measurement in electrical engineering*. BrownWalker Press, Boca Raton, Florida, 2011.

[3] Thomas A. Weedon, Philip Kirk, and Franklyn W. Kirk. *Instrumentation and process control*. American Technical Publishers, Orland Park, Illinois, seventh edition edition, 2019.

[4] E Galvan, A Torralba, and LG Franquelo. A simple digital tachometer with high precision in a wide speed range. In *Proceedings of IECON'94-20th Annual Conference of IEEE Industrial Electronics*, volume 2, pages 920–923. IEEE, 1994.

[5] William G. Hurley and Werner H. Wölfle. *Transformers and inductors for power electronics: theory, design and applications*. Wiley, Chichester, reprinted with corrections edition, 2014.

[6] Tristan Plante, Ashkan Nejadpak, and Cai Xia Yang. Faults detection and failures prediction using vibration analysis. In *2015 IEEE AUTOTESTCON*, pages 227–231. IEEE, 2015.

[7] Tatiya Padang Tunggal, Lailicia Anggi Kirana, Afif Zuhri Arfianto, Elsayed T Helmy, and Farhad Waseel. The design of tachometer contact and non-contact using microcontroller. *Journal of Robotics and Control (JRC)*, 1(3):65–69, 2020.

[8] M Ehikhamenle and BO Omijeh. Design and development of a smart digital tachometer using at89c52 microcontroller. *American Journal of Electrical and Electronic Engineering*, 5(1):1–9, 2017.

[9] ASM Bakibillah, Muhammad Athar Uddin, and Shah Ahsanul Haque. Design, implementation and performance analysis of a low-cost optical tachometer. 2010.

[10] Olusola Ogunjirin, O Ojo, Olalekan Ola, and Nwaobilor Promise. Design, construction and performance evaluation details of a low cost contactless-digital, 08 2020.

[11] Kshitij Kolhe and Omkar Taru. Digital speedometer using arduino board for formula student cars. *International Journal of Engineering Research And*, 9:805–811, 2020.

[12] Agus Ulinuha, Almas Ghulam Riza, et al. Design and implementation of data acquisition device and instrumentation based on microcontroller for electric motorcycle. In *2nd Borobudur International Symposium on Science and Technology (BIS-STE 2020)*, pages 17–24. Atlantis Press, 2021.

[13] Vimal Kumar, Ravi Agarwal, Sanjiv Kumar, and P G Student. Closed Loop Speed Control of BLDC Motor using Microcontroller and LABVIEW Interface Monitoring. 7(6), 2018.

[14] Leo Louis. working principle of arduino and u sing it. *International Journal of Control, Automation, Communication and Systems (IJCACS)*, 1(2):21–29, 2016.

[15] Pooja Ajmera. A review paper on infrared sensor. *International Journal of Engineering Research & Technology (IJERT)*, 5(23):1–3, 2017.

[16] Rajesh Shrestha. Study And Control Of Bluetooth Module Hc-05 Using Arduino Uno. January 2016.

[17] Mohamed Fezari and Ali Al Dahoud. Integrated development environment “ide” for arduino. *WSN applications*, 11:1–12, 2018.

[18] Akhilesh Chawla, Tejas Bangera, Chinmay Kolwalkar, and Mahalaxmi Bhat. Bluetooth based weather station. *International Journal of Engineering Trends and Technology (IJETT)*, 28(2):98–101, 2015.

[19] R Ismail, Z Omar, and S Suaibun. Obstacle-avoiding robot with ir and pir motion sensors. In *IOP Conference Series: Materials Science and Engineering*, volume 152, page 012064. IOP Publishing, 2016.

[20] David Halliday, Robert Resnick, and Jearl Walker. *Fundamentals of physics.* John Wiley & Sons, 2013.