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Design of Arduino Uno Electronic Module for Digital Measurement of Rotational Speed in Agricultural Machinery Actuator Systems*

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Many agricultural machines and equipment and their components depend on rotatory power. Measuring the rotational speed and properly controlling the rotating parts are necessary for enhanced machine operation. A module that is capable of accurately measuring the number and rate of revolutions of rotating parts of machines is an important instrument. This paper describes the design, assembly, and deployment of an Arduino digital speed meter. It is an excellent mechatronics instructional project for undergraduate students, and its application as an efficient and cost-effective method to measure rotational speed on agriculture machinery which provides the engineering student with experience in all stages of system development. This meter is a system-on-electronic-module (SOEM), and due to its simplicity and low development cost, it is an economical and easily deployed computerized unit. The basic circuit of the Arduino digital speed meter consists of an Arduino Uno board, an optical infrared accelerometer (IR) sensor based on the return of projected infrared light from the rotating part of the machine, and a digital display to show the speed of the rotating part in revolutions per minute (rpm). An experiment utilizing these components to evaluate the rotational speed of the PTO shaft provided highly accurate measurement results comparable to the accuracy of a commercial digital Tachometer. The average differential between the project developed module and a commercially available tachometer was only 4.47%. Considering the cost differential these results are very commendable. This innovative module is a cost-effective solution for hands-on instruction in mechanism design and development; it is a practical application for rapid on-site evaluation systems, while offering a simple economical method to measure agricultural power output.

Keywords: Arduino Uno; IR sensor; LCD digital display; relative error; revolution per minute; Tachometer

1. Introduction

1.1 Overview

Agricultural activity is one of the hardest professions and is considered the main source of food provisioning in the world. Agriculture is becoming a great concern in many countries as it is one of the most important areas on which their national economy depends. Agricultural machinery and equipment are major investments in agricultural activity that have made agriculture convenient and have simplified work in the agricultural environment by contributing to increased productivity, reducing demand for labor, and facilitating agricultural operations in general. Rotational power output is crucial as its efficiency significantly affects overall costs. Efficient rotational power impacts all aspects of agricultural operations from planting through harvest. Rotational power is required, from the pressing wheels and the geared cylinders of planting machines, to the self-combine harvester machine and all its rotating parts (e.g., the head pentagon reel and the threshing cylinder that are used to separate the grains from the spikes, and the augers to move clean grains into or out of the machine's tank). Rotational power is applied to the transmission on agricultural tractors and equipment, the tractor power take-off (PTO), the side driven pulley on the tractor, and obviously the gearbox and drive wheels.

Modern technology has contributed to advancement in all vital fields, and particularly in agricultural activity, by facilitating, simplifying, and reducing the time expended in many important operational processes. For example, the smart automation of irrigation operations makes it possible to determine the start and end time of irrigation periods, and specific devices such as the tensiometer, a device used to measure the level of moisture in soil, have provided the information that the farmer needs to complete the farming process directly and quickly. Another critical instrument for agriculture is the Tachometer, which can measure the rotatory power by measuring the rotational speed in revolutions per minute (rpm). Since the Tachometer requires direct contact with the rotating parts to measure rotational speed it requires adoption of stringent safety methods as a result of

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direct contact with a part whose rotational capacity may be high. A digital optical Tachometer (an optical sensor) gives the measurement results more efficiently and safely. In general, measuring rotational power is necessary in order to know the quality and capacity of the machine's engine, transmission system, and other devices that depend on the rotatory power output.

Engineering students interested in smart sensor systems must have a close understanding of many applications, and students must be familiar with smart circuit networks and connectivity concepts to effectively understand the direct application of engineering principles in general. Pines and Lovell [1] noted that it is often difficult when there is a need to demonstrate an engineering concept by experiment or direct construction. As an engineering student, agricultural engineering students meanwhile need to particularly understand engineering applications that are useful or necessary in the field. This current undertaking was developed to help undergraduate students apply their understanding of their program courses to design and build new ideas for their final undergraduate projects. Projects similar to this one can serve as excellent teaching enhancements for mechatronic (smart sensing) engineering students, particularly in the area of sensors and actuators, to provide them with practical interpretation of these subjects. The second objective of this project was to actually measure the rotational speed of certain parts of machines in general, but particularly agricultural equipment in the field while under the influence of rotatory power.

An Arduino Uno system is also one of the recent applications of modern technology. It contains a programming language that can be employed in a variety of applications. It can be easily modified and customized to build new modules for measuring systems, sensors, and databases to work with various electrical devices. Also, Arduino Uno is an open-source board that receives and transmits data, and is designed to easily develop ideas and projects related to automatic control systems by using the programming language of the Arduino boards (Arduino C; i.e., the C programming language). Thus, the Arduino Uno, which is an electronic board, intended for programming control devices in order to facilitate their usages in innovations, engineering projects, and various electronic machines.

There are many practice trainings on using the Arduino Uno including: measurement tasks, such as measuring temperature, and humidity; controlling tasks of operation of the machines devices with displaying the results on a LCD screen; control of robots; design the control panels and automatic agricultural systems; animation and satellite communication devices, as well as learning electronics with Arduino at home, Arduino-powered games, companies in industries, and schools for which educational learning can be practical using Arduino in teaching and student projects [2], along with some readily available open source practical applications, Arduino Uno can also be used for numerous measuring and control devices. This research project directive was to design, build, and employ an electronic board-based system that includes diverse elements. The main stipulations were a sensor, a board to receive sensed data and analyze, a data/results output device, as well as an electric power source for the module circuits.

1.2 The Concept of Rotational Speed and Relative Power Efficiency

The development of modern agricultural practices and the introduction of modern technologies into field operations, such as control systems for many agricultural machines and equipment, so-called measurement and control in agricultural technology (Precision Agriculture) have resulted in important gains in crop yields, effective management of natural and applied resources, and ultimately reduced production costs. Many previous studies and research were carried out to discover the effect of measuring devices, especially regarding obtaining rotational speed in machines and equipment that depend on efficient application of rotatory power levels for optimal performance of all the components connected with that power. The studies also investigated safe operation limits, as well as various methods of connecting accurate measuring devices in different ways, to achieve the best practical solutions for field operations.

Mathematically, angular velocity is the timed rate of rotation around an axis (t), and it can also be known as the angular displacement (θ) between two axes, and it is usually denoted by the symbol (ω). Therefore, Jebouche and Gerd [3] assumed that when discussing a phonograph that rotates at 33 revolutions per minute, it actually means that its angular velocity is being indicated, i.e., describing its rotation speed. In general, gears are mechanical parts of machines that have a significant and noticeable effect on the transmission of rotational power. Gearing is an important component of all machines that have moving mechanical parts, and every machine has at least one gear that would be used to transmit rotational power. One of the most important mechanical parts affecting the rotation of the gears is the reduction gear (gearbox). The gearbox is typically used as a device that converts the incoming rotational speed and torque (inputs) to an external rotational speed and torque (outputs), i.e., it is a transmission appliance. The transmission process is achieved by increasing or decreasing the input rotational speed and the gear (reduction) ratio (*i*) is converted by the reduction (or amplification) ratio between the engagement gears. To calculate the reduction ratio for each interlocking set of gears, certain measurements are required, either the number of teeth of each of the input and output gears, or the basic diameter (or radius) of each of the input and output gears. With this information as input, mathematical equations can be used to calculate the rotational speed of the rotating parts of the machines (i.e., the idling gear ratios), thus the value of the rotational speed can be obtained mathematically [4].

Al Sharifi et al. [5] studied the effect of threshing machine operating speed on corn yield based on some of the technical indicators for operating the threshing machine. Two types of local corn sheller LCS-Irs1 and LCS-Irs2 were employed with three operational cycles of 200, 300, and 400 rpm for threshing corn. The results showed that the LCS-Irs1 machine was significantly better than the LCS-Irs2 machine in all studied conditions (Table 1). Results showed that the productivity of peeling cobs of corn was 1.12 t/h for LCS-Irs2 machine and 1.16 t/h for LCS-Irs1 machine, the energy consumption was 11.14 kilowatt for LCS-Irs1 machine and 11.91 kilowatt for LCS-Irs2 machine, the efficiency of grain shelling was 80.95% for LCS-Irs2 machine and 81.75% for LCS-Irs1 machine. These results also showed that the rotational speed of the thresher machine at 200 rpm was better than the other measured rotational speeds of 300 and 400 rpm, under all considered conditions. For example, 200 rpm provided a productivity of peeled corn cobs of 1.16 t/h, and energy consumption to operate the threshing machines at a rate of 11.14 kilowatt.

Khan et al. [6] studied the effect of the rotor speed of a rotary disc plow during the plowing process at different depths and different rotation speeds of the vertical axis rotary disc harrow on the total soil mass tilled and fuel consumption of the tractor. Several cutting depths of 8 cm, 10 cm, and 15 cm were used, and the rotation speeds of the rotary plow were 150 rpm, 200 rpm, and 300 rpm. They observed that the relationship between the rotation speed of the rotary disc harrow and the average mass of the soil aggregate decreased linearly with the increase of the vertical axis. This indicates that a higher speed of the vertical axis rotary disc harrow is desirable for precision tillage. Increased rotational speed provided a better digging rate which is desirable for good tillage operation. Similarly, the relationship between the rotation speed of the vertical axis rotating disc harrow and the fuel consumption of the tractor increases linearly (directly proportional) with the increase in the disc rotational speed. Wasilewski et al. [7] conducted a study to determine the best estimation of the efficiency of fuel consumption of an agricultural tractor engine and how to use it correctly in different environmental conditions. The experiment was conducted at engine rotation speeds ranging from 1600 rpm to 2200 rpm and the temperature value of fuel was taken at every 150 rpm. They found that the highest efficiency of the engine was between 1750 and 1900 rpm.

Table 1. Effect of the LCS-Irs1 and LCS-Irs2 threshing machines on corn yield [5]

Measurements	LCS-Irs1	LCS-Irs2
Productivity of peeling cobs (t/h)	1.16	1.12
Energy consumption (kilowatts)	11.14	11.91
Efficiency of grain shelling (%)	81.75	80.95
Unshelled grain (%)	3.43	3.88
Percentage of loose grains (%)	3.82	4.72
Corn seed damage ratio (%)	1.99	2.23
Grain cleanliness (%)	89.69	89.17

1.3 Challenges in Measuring the Rotational Speed

The Tachometer is a device that produces a signal expressing the level of rotational speed and shows the measured rotational speed in revolutions per minute (rpm) and can thus be defined as a revolution counter. There are many types of revolution counters. Some of these counters depend on measuring the repetition of pulses resulting from the rotation shaft, or the time interval between the measuring device and the body under the influence of rotation. Some Tachometers are similar to miniature actuators in that the Tachometer's shaft is driven by some mechanical means and a voltage is fully developed as a result. The faster the shaft rotation, the greater the magnitude of voltage (i.e., the signal amplitude is directly proportional to the speed). The output voltage shows polarity with a positive or negative sign depending on the direction of the shaft revolution [8].

Singh and Tomar [9] stated that rotational measurement devices are very useful in monitoring and controlling equipment and pumps in many industrial fields, such as in chemical, pharmaceutical, and textile factories. Traditional Tachometers require direct contact between the measurement device and the rotating body. However, this method of direct measurement is not possible in some cases, so electronic measuring devices were developed that do not require direct contact between the measuring device and the object to be measured (contact-less). Digital rotational measurement devices are also used as calibration support devices to measure the speed of objects which are spinning at a certain number of revolutions per minute (e.g., a centrifuge machine). Also, some medical devices, such as the treadmill, are calibrated so the rotational speed (rpm) of the treadmill is converted to linear speed in kilometers per hour (km/h). Furthermore, Ehikhamenle and Omijeh [10] mentioned that the digital Tachometer can be classified into four types. Classification is initially based on the method of obtaining information or data. The first class is the digital Tachometer that needs direct communication; A second type is the "digital" Tachometer that does not require direct contact. This Tachometer uses a beam (rays) or an optical disc attached to the spindle shaft. The second major classification is based on measurement methods; one type measures time, and the second type measures frequency. Dwivedi et al. [11] pointed out that the speed measurement tool (Tachometer) can be easily applied to industrial purposes, industrial and laboratory process control systems and process. It is easily applied to the measurement of the speed of rotating objects such as a bicycle, a car, and an automatic transmission. In addition, it is important and economical in the applications of automotive and medical field.

1.4 Challenges in the Use of Arduino Applications

Gani and Salami [12] noted that effective instruction in mechatronics engineering requires experiments designed so that students can develop hands-on skills, so they are thoroughly drilled in the basics of mechatronics systems and their integration. They noted that since laboratories have limited assets for achieving these objectives, there is frequently a need to design and fabricate customized equipment that can improve students' knowledge and skills.

Implementers of innovations, engineering projects, along with various electronic machines have previously faced many difficulties and complications. With the development of the Arduino electronic board system, which is much easier than the old programming languages, and the associated microcontrollers, which are a set of programmable microcircuits (IC), those difficulties have been reduced. Also, the microcontroller is a small computer that contains the same components as a regular computer (PC), such as the processor and memory, so students are already familiar with the structures and concepts. Currently, one of the important things that contributed to the spread of the use of the Arduino Uno is its open source designation for users: all the design and programming details about the Arduino and all its projects have been published to the public. Therefore, there are many measurement practices on the use of the Arduino Uno, such as field and greenhouse measurements of environment variables; robot tasks; automatic machine control systems and GPS devices in agriculture, etc. These help the engineering student develop the hands-on basic skills with the device. Many applications and adaptation of the Arduino device are already documented, but in our particular case, the problem offered to the students did not specify the 'how' of obtaining the measurements, only that it had to be contactless and easily deployed in an agricultural setting. Student knowledge of the classroom concepts and the subsequent research on the project led to the Arduino.

An Arduino consists of an open hardware design using the Atmel AVR microcontroller. Several additional boards (shields) have been produced and these shields are able to extend the basic capabilities of the Arduino. The basic boards of the Arduino contain extensive capabilities, such as controlling DC motors, reading encoders, as well as wireless communication using the Xbee board, which allows the multiple Arduino boards to communicate. In addition, Arduino board producers have released new measuring tools with better specifications and lower prices which are based on the concept of Arduino boards and use Arduino C software [13]. In addition, the Arduino Uno board module is recognized as an operation and control board that contains 14 digital input and output ports, and 6 of these ports can be used as PWM or signal-width modulation (PWM) outputs. Furthermore, Arduino board has six analog inputs, a 16 MHz crystal oscillator, a USB connection, a power socket, and a connector for storing programming within the Arduino circuit assembly. The Arduino Uno can be powered via a USB port, an external power source (e.g., an external 9V battery), or via an external power supply from 6 to 20V. The Arduino Uno also contains the microcontroller called the Atmega328. The Atmega328 memory is comprised of 2kb SRAM and 1kb of EEPROM (i.e., an adjustable read-only memory that can be erased and reprogrammed repeatedly using EEPROM) [13, 14].

The importance of this study, especially for students, engineers, and technicians in general, is developing an understanding of the importance of accurate measurement devices, recognizing the importance of rotational power and its impact on agricultural operations and its multiple uses in the agricultural mechanisms, and appreciating the numerous and varied ways to measure the rotational speed by different devices and programs. Deciding on an efficient and quick solution was an integral part of the exercise. Additionally, the resulting solution and its application to the real-time contactless challenge describes the design and use of the Arduino Uno board application and its programs and capabilities for deployment in measuring devices such as measuring the rotational speed of the power take-off shaft of an agricultural tractor (PTO).

Consequently, this project commenced by investigating the reasons for knowing the tractor PTO power output (costs, efficiency, yield, etc.). This was followed by some basic concepts about the old argic-tractors that are still working, such as how these tractors work, field operation, measuring tools required, and the apparent instrumentation on the dashboard. It was observed that some tractors do not have rev-speed measuring devices for the PTO rotational speed, which is specified at the rear of the tractor, so the main objective at that point was to investigate and design an instructional low-cost apparatus to measure the rotational speed of agricultural machines and equipment, especially the older agricultural tractors that do not contain the necessary tractor dashboard components. Thus, the application of classroom engineering concepts, research, development, and the final application confirm the educational perspective of this study design.

2. Presentation

2.1 Design Considerations

The digital rotational speed measurement module is based on Arduino Uno. It can be considered within the scope of systems-on-electronic-modules (SOEMs) which could be used for the accurate measurement and monitoring of all operational variables related to time periods. The rotational variables of the tractor PTO can be converted into a measured frequency using reflective optical sensors (photoelectric sensor) to measure the rotational speed. The optical device uses an infrared sensor that converts the angular velocity of rotating objects into a frequency, and this frequency, which is equivalent to the angular velocity of the rotating objects, can be used to calculate the rotational speed in units of revolutions per minute (rpm).

The main steps of this study consisted of:

- Obtain knowledge of the design of a digital device for measuring rotational speed by applying Arduino Uno boards and the Arduino software.
- Build the prototype to accurately measure the rotational speed of agricultural machinery normally used in numerous agricultural applications.
- Confirm the functionality of the design.
- Analyze the codes of those optical measuring devices through the Arduino board and its programming.
- On-site-real-time analysis of the rotational speed of the agricultural equipment and compare the results obtained by the developed device to those obtained by using a commercially available optical measuring device.

The materials required to complete the laboratory measurement experiments include the following electrical instruments (as shown in Fig. 1). The list of materials for the digital measuring module can be detailed as follows: rechargeable 9V DC battery, an Arduino Uno SMD main controller board (Arduino Uno R3 interface CH340G & microcontroller SMD ATmega328p development board with 6 analog input pins, 14 digital input/output pins include 6 PWM outputs, and USB cable), 3 pin IR sensor module (i.e., IR infrared obstacle avoidance sensor module for arduino/3-Pin reflective photoelectric), LCD digital display with I2C display module (i.e., 1602 16x2 LCD for arduino characters/I2C serial interface 5V adapter module), electrical jumper wires with connecting metal pins (male/female connectors), and precise Arduino programing code (Arduino IDE 1.8.10).

2.2 Designing the Module of Measurement

Arduino boards in certain operating systems play important roles, including measuring the operating parameters of those systems. The operating measurement methods vary according to several factors: what is being measured, such as temperature, rotational speed, voltage measurement, wind speed, and humidity; the precise measuring devices (sensors) used with those boards and their programming; the Arduino Uno board which communicates with all elements in the measuring module and gives them the command to complete the measurement process.

Fundamentally, the functioning of this measurement system is mainly based on systematically synchronized modules, and the measurement system basically includes a control unit (i.e., Arduino Uno), a digital display unit (screen), an optical sensor (IR sensor), and an electrical power source for the measuring system (DC source). Obviously, the system requires an intended object which is under the influence of an external rotational power and whose rotational speed (rpm) must be measured (Fig. 1).

The device in this case uses the Arduino Uno as the master control. Other important components are the infrared sensor diode that monitors the rotation by measuring the reflected infrared rays (detects the wavelength of light in the received infrared rays), and the I2C display unit/LCD screen. The I2C display unit, which is attached to the LCD display, converts serial data into parallel

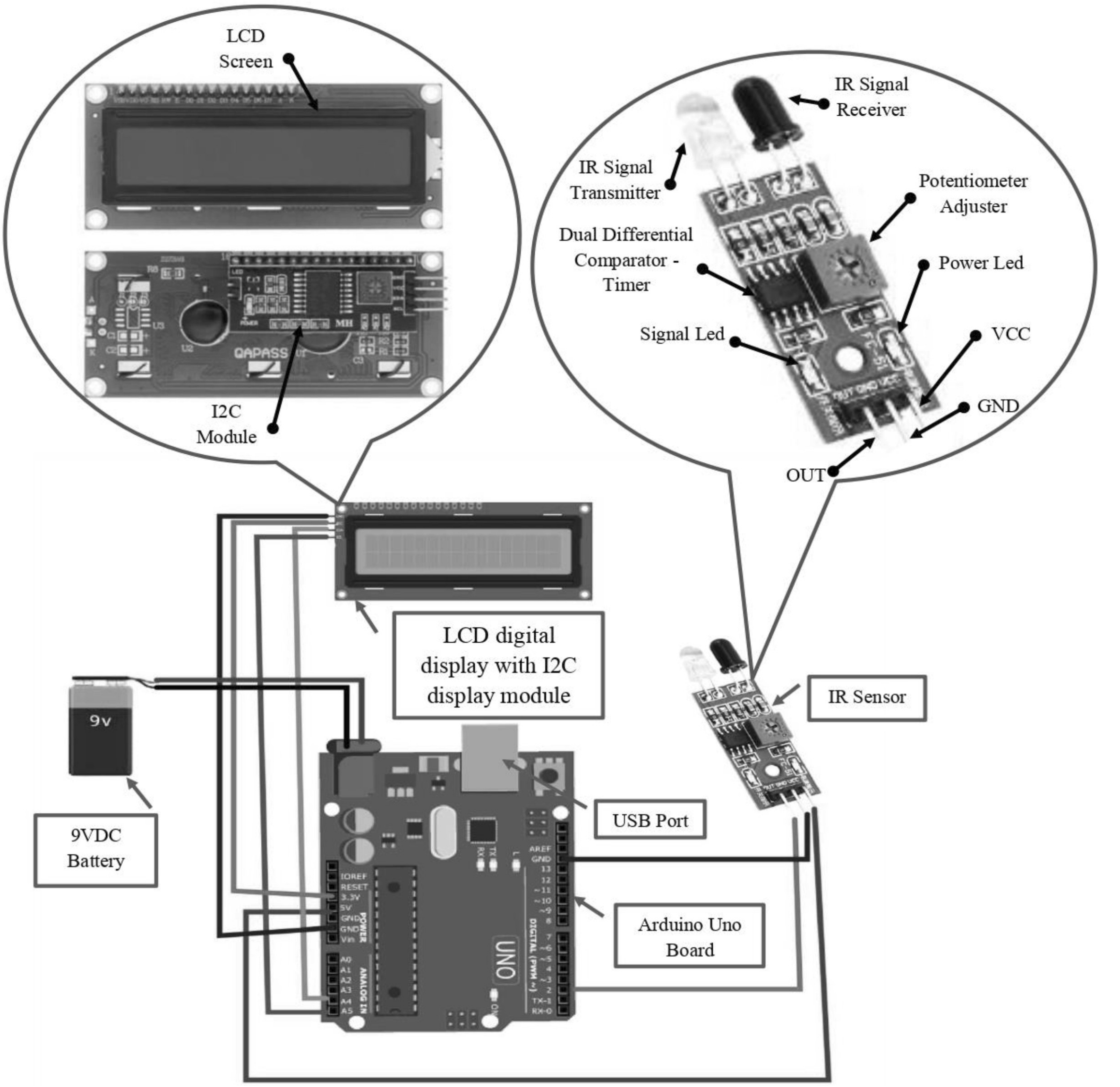

Fig. 1. The sequentially assembled component parts of the Arduino based digital rev-speed module design.

data for display on the LCD screen as digital rotational speed in a unit of revolutions per minute. The entire system is highly energy efficient and easily disassembled and installed (which is ideal for small battery powered devices).

The system works on the principle of optically transmitting/receiving an infrared (IR) light beam (optical signal). The sensor component contains the transmitter (IR LED), the receiver-photodiode (receiver), the sensitivity adjuster, and three connecting poles. The IR LED emits a continuous beam of light rays. A small piece of reflective tape is applied to the rotating shaft to indicate each rotation. The optical sensor (IR sensor) is placed in front of the rotating object, e.g., spindle shaft. When the rotor object under the influence of the rotating power begins to rotate, the light beam will be reflected and picked up by the photodiode (a semiconductor diode). The diode generates a potential difference (voltage) while it is detecting the reflected infrared light. This absorption of light rays continues as each revolution results in a pulse of reflected light that reaches the photodiode and generates the voltage signal for the Arduino microcontroller (ATmega328). The microcontroller calculates the number of pulses, which represents the number of revolutions, and displays the result on the LCD screen as the number of revolutions in one minute (revolutions per minute, rpm).

3. Results

The assembly of the entire measurement system as suggested is straightforward and configurable. The I2C display module is attached to the LCD digital display by connecting the sockets on the two mod-

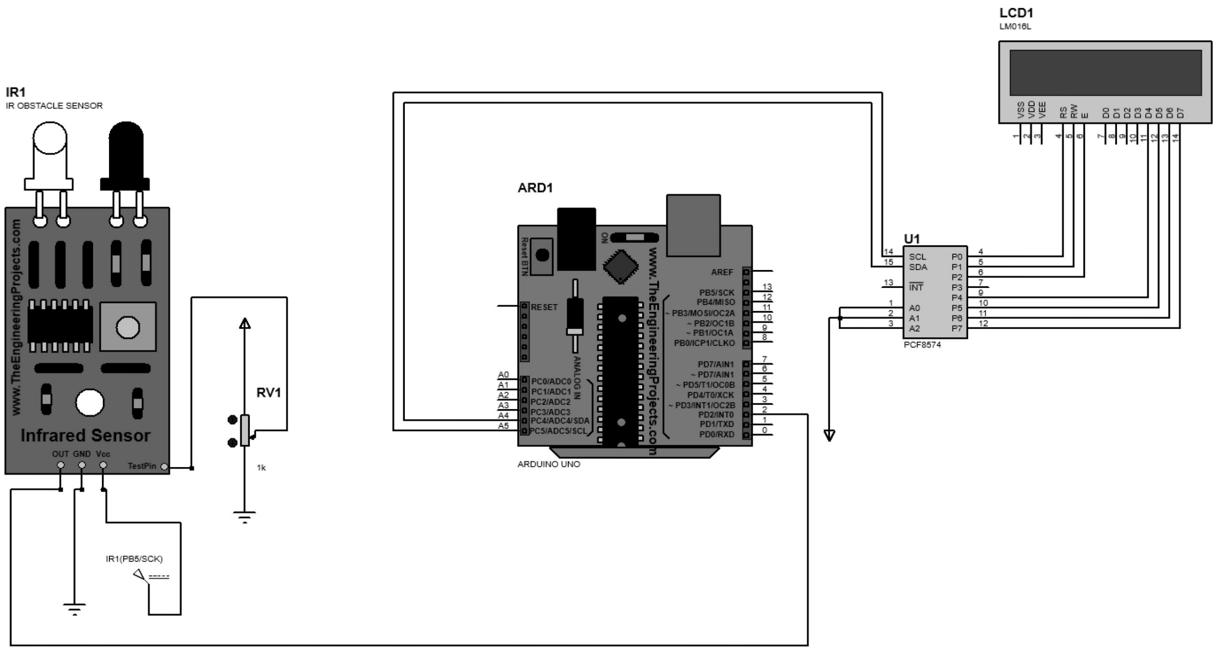

Fig. 2. Diagram showing the connection of the Arduino and the IR sensor (IR sensor) as an identified of the meter device (rpm).

ules, and wires are connected between the I2C display module and the Arduino Uno board. The infrared (IR) sensor is connected to the Arduino Uno board through another set of connecting wires, and then the programming codes are uploaded to the Arduino Uno board by a computer linked to the Arduino website. The computer connection to the Arduino Uno board and data transfer is done via either the 14 digital communication outputs or the Arduino USB port. The Arduino programming code for Arduino operation and connection with the optical sensor is open source and is available for download, use, and modification as needed. The Arduino IDE and code samples can be accessed via the Arduinogetstarted and Arduino websites [15, 16].

Electrical circuit elements are energized via appropriate jumper wires connected to a 9V DC battery. The Proteus design suite was used to sketch the simulation diagram of the electrical circuit of the measuring rev-speed module [17]. The diagram of the circuit simulation for the Arduino digital rev-speed meter (rpm) design using the Arduino Uno is shown in Fig. 2. The diagram illustrates the importance of the operational link of the infrared sensor (IR) interfacing with the Arduino controller, which together will measure the speed of rotation through the associated control program (i.e., Arduino C program code, which is written (or modified) in the C programming language). By rotating the rotor object, the IR beam is reflected once per revolution, the interrupted signal is detected and transmitted to the Arduino, and the Arduino processes these signals and shows the value of rotational speed in revolutions per minute (rpm) on the LCD screen. Intentionally, the data test result of the practical rotational speed module, which is actually a smart sensing technology built-in implementation, is compatible with the Arduino Uno (Arduino software, IDE) software. The functional system process flow is shown in Fig. 3.

Through the application of smart sensing, the analysis of rotational speed was a stream of numbers recorded on the objective spot, written down, and viewed as a function of time (revolution vs. time) through the creation of a simple text display of the speed-numbers on the LCD screen. Connection of the system modules results in an integrated electrical circuit, which starts with the infrared sensor (IR sensor). There are three ports in the precise IR sensor, the first is (OUT) or (DO) and its task is to transmit information from the sensor to the Arduino board. The other two ports are to transfer power from the Arduino to the IR sensor, where the ground port (GND) is used to provide the sensor with the necessary polarity (–), and the third (VCC) is to supply the IR sensor with the required positive voltage from the battery (as shown in Fig. 1). The I2C adapter module installed on the LCD screen must be connected to the Arduino Uno board by connecting wires onto four outputs on the I2C. The first and second outputs are dedicated to transmitting the electric power, namely (GND) and (VCC), and the third and fourth outputs (SDA) and (SCL) are set up for synchronizing data transfers.

Powering the system requires the wires that carry electrical power to be connected to the power outputs on the Arduino board. The infrared sensor (IR

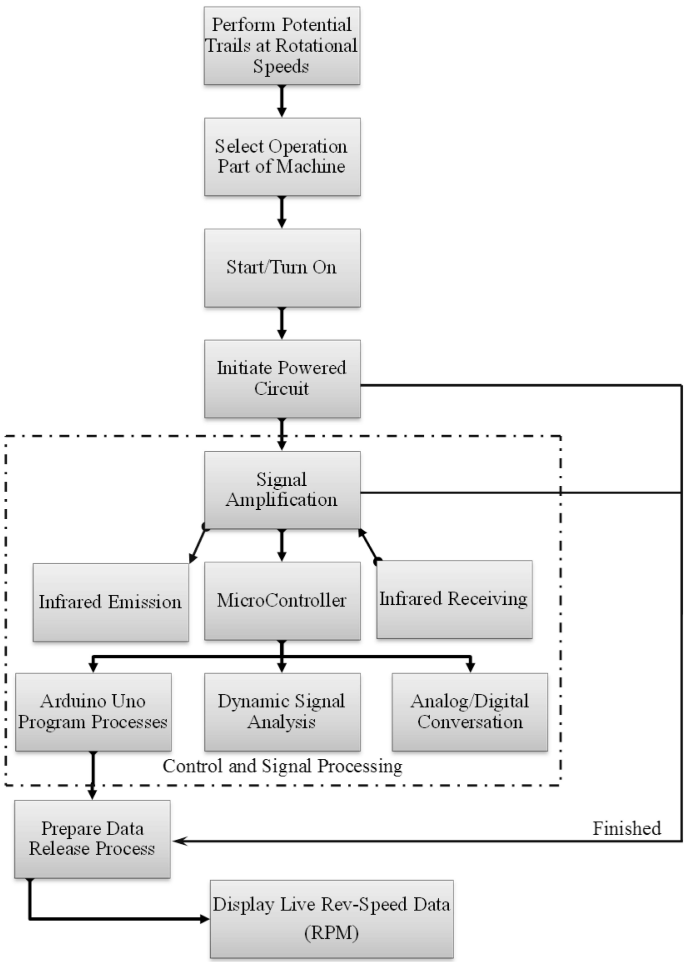

Fig. 3. Functional component process flowchart to perform functional trials at actual rotational speeds.

sensor) and the I2C adapter module connect to the power, where the voltage leads (+) are connected to the Arduino 5V outputs and polarity leads (–) are connected to the Arduino GND outputs. After the assembly of elements of the designed measuring module is complete, the ready-made programming codes, which can be found on the internet (or it can be written based on the design instructions), are downloaded to the PC and then uploaded via the Arduino program (Arduino software, IDE) to the Arduino Uno board via the USB port. One of the problems that may occur during installation is that the LCD screen does not display properly, and through investigation it became clear that a brightness calibration (contrast) must be adjusted on the I2C display adapter module via that port behind the module, which is calibrated using a screwdriver to rotate the built-in potentiometer on the backside of this adapter module (LCD contrast adjustable) to adjust the contrast between the background and the written characters on the LCD screen for the successful demonstration of an accurate and apparent reading (Fig. 1). After uploading the programming codes, the Arduino to computer USB connection is detached and the 9V-DC battery is connected on the Arduino Uno board, and the designed measuring module is complete (Fig. 4).

4. Discussion

After device completion, an experiment was conducted at the educational farm at King Saud University to measure its accuracy and suitability for the rotational speed experiments. Using an agricultural tractor, the installed digital measurement module was compared to another commercial device (Tachometer). The experiment compared both digital measuring modules to measure the rotational speed of the power take-off shaft of the agricultural tractor (PTO), which is a rotation shaft located at the rear of the tractor to which agricultural equipment is attached and driven (Fig. 5). Tractor's PTO is furnished as an actuator for many farm equipment operations. In other words, the PTO is typically used for transferring the tractor engine's rotational power to another application.

The measurement results of the designed module (Table 2) showed readings of optimal accuracy

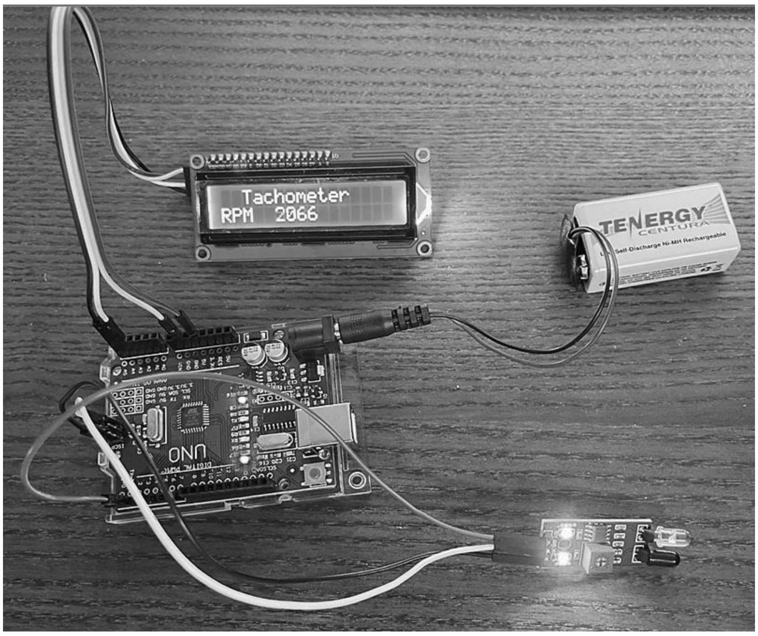

Fig. 4. Digital measurement module after connecting the battery (9V-DC) and completing its design.

Fig. 5. Measuring the rotational speed by the designed module and a commercial Tachometer rpm counter on the tractor rear power take-off shaft (PTO).

Table 2. The results of the reading of the designed module and a commercial device (Tachometer) on the rear shaft of an agricultural tractor (rpm)

Iterations of Reading	Commercial Digital Tachometer (rpm)	Designed Digital Speed Module Reading		
		Rotational Speed (rpm)	**Absolute Error (rpm)**	**Relative Error (%)**
1	360	382	±22	6.11
2	418	422	±4	0.95
3	426	440	±14	3.28
4	660	710	±50	7.57
Average	466	488.50	±22.50	4.47

compared to a commercial Tachometer. For those interested in the digital measuring modules, this designed module can be very useful due to its simplicity and low installation cost. Finally, the results of the designed module readings were compared with those obtained using a digital commercial Tachometer. The designed module provided a reliable reading with an average relative error about 4.47% (Fig. 6). The overall test results (Table 2), illustrate that the designed module measurements were made with less relative error, i.e., the digital measuring module is accurate for the rotational speed to an average of ±22.50 rpm (±45π rad/min), which indicates that the measurements by

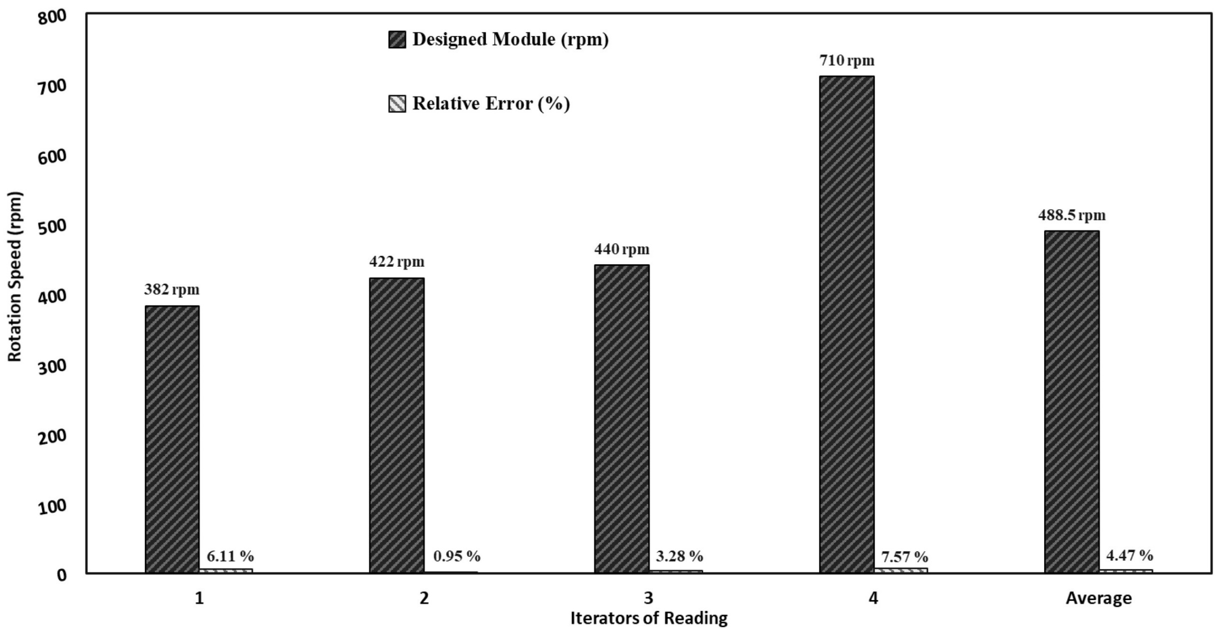

Fig. 6. Relative error and measured rotational speed of the digital rev-speed module designed based on Arduino application.

the designed module are more reliable and accurate. The designed digital measuring module and the limited cost of its execution represent an acceptable step towards more widely used application of the technology for accurate acquisition of the running data of the mechanical parts of tractors and agricultural equipment. An associated benefit would be improved monitoring, and ultimately the operation and performance of agricultural machinery or any other agricultural systems that depend on the rotational power.

Practically, it should be noted that the optimal measurement performance of the designed module, for which the design and literature details were discussed as a main objective in this study, was with a relative error of 4.47% and with a total cost of designing this appliance at about $12.36 (not counting the inflation rate in the total cost), which is rather low-cost. As well as, its additional benefit of installation on old agricultural tractor models that do not have an inner dashboard or any other older designed farming systems still in use, that is, the number of revolutions per minute (rpm) can be easily displayed on the tractor's instrument panel display, obtaining a low-energy electrical circuit, and generally maintaining the energy consumption and its applications in agricultural machinery operations.

Therefore, for tractor control technology and systems, this simple innovative unit is a computerized unit that will instruct and assist the tractor's operator on how to accelerate and actuate the general agricultural implements attached with the farm tractors during field operations. Thus, this study anticipates to provide researchers with more information for appropriate evaluation techniques of machines such as rotational power measurement, in addition to encouraging technical and automated machines' investigators and academics of engineering education interested in studying the science of new technologies and evaluating the functional behavior of machines to consider all the tasks behind the results of this study in order to better understanding of the metrics of the rotary machines, which can be applied in agriculture to study the use of precision instruments such as micro-sensing technologies in agricultural machinery and more especially to maintain and improve new technologies of precision agriculture systems.

The theoretical method based on lectures is often used when teaching courses in electrical circuits, the use of modern technology, and the management and operation of agricultural machinery and equipment. The learning objectives are normally limited to learning theoretical content with scientific reference. Engineering professors have struggled with the transition from theory to practice. In 2002, Thompson [18] proposed the studio approach to an inclusive pedagogy of design, engineering, and production via an overall 'object' approach which would shift focus from simply classroom to an end to end view. Thus, the expected benefits of this an instructive project design, which primarily aims to facilitate and disseminate its usages, lie in increasing the student's knowledge and practical participation, achieving the desired academic goals, in addition to obtaining the required degrees in the formal academic courses. In general, after the project was implemented substantially, students who participated in the final academic project achievement were verbally polled regarding the project's usefulness to further understand the engineering concepts taught in the classroom environment, and the knowledge gained by the actual mechatronic concepts to reality exercise. The results provided an indication that the students were more interested and enthusiastic in applying their engineering knowledge in their graduation projects and actual real time data gathering.

Finally, digital measuring instruments designers have been interested in the opportunity provided by electronic open systems to explore the implementation of these open systems and their applications instructions, such as the Arduino Uno application, which can also be clearly specified as a system-on-electronic-module (SOEM). Arduino open tools provide a transparent learning environment in which the professional student will focus on network design and digital measurement training. The main advantage of the electronic devices, such as this an Arduino digital speed meter that is designed and by using open source platforms is that their design can be easily better optimized. Those interested in digital electronic measurement can contribute to its redesign, development, and adaptation for future applications. So, the use of such open source platforms typically gives everyone more experience in understanding the various applications of precision instrumentations for digital measurement and this greatly encourages the sustainable use and operation of the mechanization and precise agricultural management.

5. Conclusions

Rotational power measurement significantly affects field capacity and field operation efficiency of agricultural machinery. In this study, a symmetric digital rev-speed meter was designed based on the open source Arduino Uno application. The meter is an electronic digital potentiometer and transducer that is used to measure the speed of rotation of the rotating shafts by taking advantage of the infrared (IR) reflection feature. It provides accurate information about the number of revolutions per minute (rpm) and through field operations with agricultural machinery and equipment, the actual rotational speed was observed and optimized using this precise measuring instrument to the most accurate digit. The optimal measurement performance of this rather low cost designed module was within an acceptable relative error.

The smart sensing approach described in this rotary velocity measurement system, which falls under the practical concept of sensing and circuit applications based on open Arduino application programming, is excellent for engineering student training. Designing an easy and inexpensive portable toolkit (a speedometer), which is an example of a mechatronic application, was intended to enable the university student to design electrical circuits in a classroom based on applying the engineering knowledge gained in coursework classes and then establish and deploy solutions to obtain the grades required for academic courses.

The design results provided an indication that the concept and construction of this simple design could eventually be the basis for further development of digital measurement devices. In addition, open-source development platforms, such as the Arduino platform, provide a pathway for simple implementation of electronic projects, which can be quickly conceived, learned, and understood. The open-source platforms' software programming can be modified in a simple way to suit the needs of any application. Therefore, undergraduate engineering students' acquisition of adaptive knowledge in building innovative electrical circuits, through an open source of computer programming, supported by academic faculty knowledge and undergraduate course activities, has achieved considerable success and more student experience in understanding the various applications of precision digital measurement devices.

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