Development of newton dynamometer instrumentation integrated with smart counter applications based on Hooke's law

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ABSTRACT

This research presents the development of an instrumentation system that employs ultrasonic sensors for Newton dynamometer applications. A key parameter measured is the change in spring length before and after loading. The methodology implemented in this study is based on Hooke's Law, applied within the instrumentation devices. The length change data is transmitted to a smartphone via a Bluetooth module integrated into the instrument. This allows for flexible data usage and input through a calculator-based application created with MIT App Inventor, tailored to the relevant supporting parameters. Before implementation, the sensors underwent characterization to assess the linearity of their output compared to a standard measuring tool, specifically a ruler. The linearity test yielded a coefficient of 0.9998, indicating excellent performance for this application. Additionally, the system achieved an average accuracy of 94.12% and an average precision of 99.94%.

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1. INTRODUCTION

The research on advancing the Newton dynamometer marks significant progress in quantifying forces across various scientific and technical fields. The relevant scientific background includes the historical use of dynamometers for force measurement, which has been essential in disciplines ranging from physical sciences to mechanical engineering. Although the fundamental principles of the Newton dynamometer have been established for a long time, recent efforts aim to enhance its precision, sensitivity, and versatility for diverse applications. The evolution of the Newton dynamometer has been propelled by advancements in sensor and electronic technology, leading to increased relevance and new design possibilities. These advancements enable more precise measurements across a wide range, from extremely low to extremely high power levels. Enhanced sensor integration and signal processing techniques facilitate the development of advanced Newton dynamometers capable of generating highly accurate data for applications ranging from fundamental research to complex industrial uses [1]-[3].

The Newton dynamometer is highly versatile and plays a crucial role in various fields. In manufacturing, dynamometers assess product durability and quality while facilitating the development of new products. In medicine and sports, they are used to measure muscular strength, track patient recovery, and analyze biomechanics of movement. Researchers across disciplines such as physics, biology, and mechanics employ this technology to quantify forces. Renowned for its significant contributions to testing, monitoring, and force analysis, the Newton dynamometer remains an essential tool for understanding and applying concepts of force and power [4], [5].

This study involved the creation of a Newton dynamometer that utilizes the HCSR-04 ultrasonic sensor and the NodeMCU ESP32, with the internet of things (IoT) technology as its foundation. This combination provides several advantages, including as exceptional sensitivity, rapid response time, and the ability to conduct non-invasive tests [6], [7]. Prior studies concentrated on developing a spring constant measurement device with an Arduino microcontroller equipped with an ultrasonic sensor. However, it did not incorporate IoT-based data analysis and reading, and solely depended on serial monitors or LCDs [8]. In overcoming the limitations of previous research, the primary objective of this research project is to develop a dynamometer that utilizes IoT principles, allowing for seamless and real-time data transmission and enhanced measurement precision. Automation is a significant factor in the contemporary world [9]. This research utilizes the HCSR-04 ultrasonic sensor to detect the change in spring length caused by applying a load. The measurements obtained are highly accurate, with minimal interference and dependable results. This enables the estimation of the spring constant by analysis based on counting. An essential aspect of this research will involve characterizing and calibrating the HCSR-04 ultrasonic sensor to evaluate its responsiveness to changes in spring length. As technology progresses, this research has potential in the future in the development of IoT-based tool sets where measurements can be made in real time so that errors in reading measurement results such as human error can be overcome.

By integrating the NodeMCU ESP32 module, researchers will be able to wirelessly transmit spring contact data to a central server, facilitating remote access and evaluation. The IoT is a rapidly developing technology that is being integrated into several fields of science and engineering [10]-[13]. The results of this study will enhance IoT-based measurement technologies for dynamometer applications. The Newton dynamometer seeks to improve efficiency, accuracy, and comfort by offering real-time measurements. In addition, the integration of IoT will facilitate data-driven research, streamline process optimization, enhance quality control, and enable the development of novel sensor capabilities [14].

2. METHOD

2.1. Hardware design

System hardware design is related to the integration of all system building components. The system-building electronic components used include ultrasonic sensors, the NodeMCU ESP32 as the system microcontroller, and other system-building devices. The system hardware design can be seen from the block diagram in Figure 1.

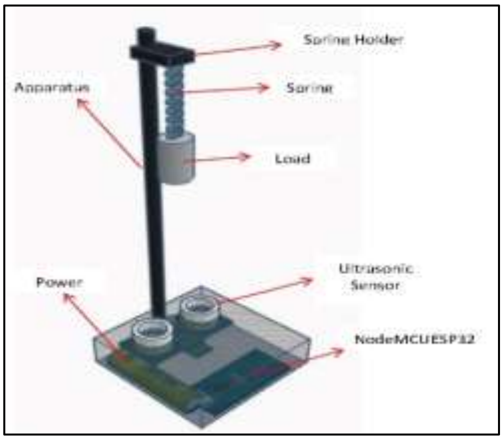


Figure 1. Newton dynamometer hardware design

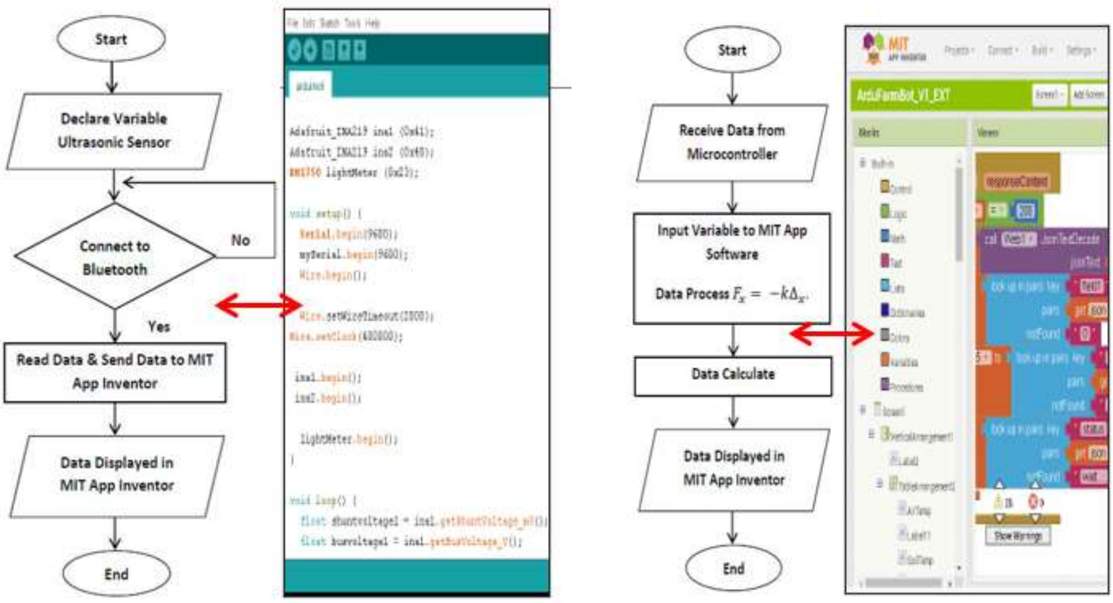
The development of the Newton dynamometer involves the integration of three essential components: sensor-based detection, microcontroller processing, and data display on a smartphone screen. An ultrasonic sensor is used for detection, while the microcontroller handles the processing. The processed data is then displayed on the smartphone screen. Ultrasonic sensors work by utilizing the reflection of ultrasonic waves as a measurement medium [15]. The HCSR-04 sensor consists of two units, namely a transmitter unit and a receiver unit, and an alternating voltage of 40 KHz–400 KHz is provided on a metal plate [16].

The working principle of the HCSR-04 is that the transmitter emits a beam of ultrasonic signal (20 KHz) in the form of a pulse. If there is a solid object in front of the HCSR-04, the receiver will receive the reflection of the ultrasonic signal and will read the pulse width (in PWM form) reflected by the object and the difference in transmission time. The trigger and echo pins are connected to the ESP32 microcontroller, designed and manufactured by Espressif Systems, containing all the essential elements of a modern computer: CPU, RAM, network (wifi), and even a modern operating system and SDK [17].

The IoT is a computing system that interconnects computing devices, mechanical and digital machines, objects, animals, or others that are equipped with a unique identifier (UID) and the ability to transfer data over a network without the need for human-to-human or human-to-computer [18]. Smartphones and IoT devices can access information and Web services and can connect sensors [19], [20]. IoT is a prominent technology in applications in various fields [21]. The ultrasonic sensor can be easily connected to the microcontroller via a single I/O pin [22]. This also includes programming using programming languages. The system will detect the distance the spring changes from the initial position to the final position after hanging the load. The results of data measurements by sensors will be processed by a microcontroller so that the data can be displayed on the smartphone display. Along with the development of practical and online technology, there has been a lot of research into Android-based control and displaying data on smartphone displays [23], [24].

2.2. Software design

In the field of software design, this research focuses on developing programs that seamlessly integrate the tasks of reading, processing, and outputting data for analysis. Figure 2 illustrates the flow diagram for the system programming. The flowchart includes an ultrasonic sensor that serves as the input reader for changes in spring length, a NodeMCU ESP32 functioning as the processing center and IoT-enabled device, and a smartphone that acts as the data viewer for the output. This flow diagram was implemented as a program using the C++ programming language within the Arduino integrated development environment (IDE), as shown in Figure 2(a). Once the microcontroller analyzes the received data and is programmed via the Arduino IDE, the information is displayed on the smartphone screen. The Android application developed in MIT App Inventor presents this data, as depicted in Figure 2(b). MIT App Inventor is designed for novice programmers who wish to create Android applications. It offers a user-friendly interface, allowing users to develop apps by simply dragging and dropping pre-defined code blocks [25].



(a) (b)

Figure 2. Chart newton dynamometer software design (a) Arduino software and (b) MIT app software

2.3. Hooke's law theory

The movement of an object that is periodic and occurs within a certain time interval through the equilibrium point is called oscillation [26]. Oscillation events are often found in everyday life, for example in the event of a spring hanging vertically under load [27]. The load attached to the end of the spring with mass m is given a deviation x as shown in Figure 3 and then released, the system will move periodically at the equilibrium point caused by the restoring force, this movement is called simple harmonic motion.

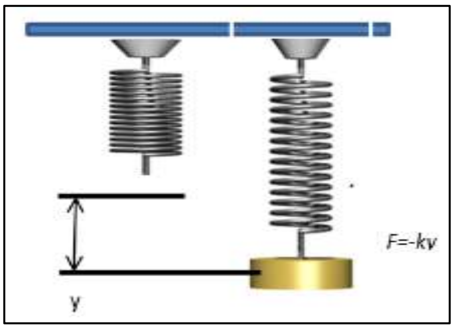


Figure 3. Hooke's law theory

The spring constant provides a description of how much force is needed or applied to cause a change in length of one unit length. For a spring of length (l), the spring force (F_x) that occurs is linear to changes in landing gear position (x). The relationship between the force (F) that stretches the spring and the increase in spring length (Δx), in accordance with Hooke's Law is shown in (1):

$$F_x = -k\Delta_x \quad (1)$$

where F is the tensile force exerted on the spring (N), k is the spring constant (N/m), and Δx is the increase in length due to the force (m). The negative sign indicates that the spring force is in the opposite direction to the deviation. This spring force is a restoring force that causes objects to oscillate as long as there is no air friction. Thus, the value of k using the static method can be calculated from (2):

$$k = \frac{F}{\Delta_x} = \frac{m.g}{\Delta_x} \quad (2)$$

The increase in length of the spring is influenced by several things, including: i) the load applied, ii) the initial length of the spring, and iii) the spring constant. The mathematical equation that describes these factors is Hooke's Law, which explains the relationship between the force exerted on a spring and the increase in its length [28].

3. RESULTS AND DISCUSSION

3.1. Electronic system

An electronic circuit is a combination of various electronic components that are interconnected and integrated to achieve certain functions. The electronic circuit used in this research can be seen in Figure 4. The electronic circuit of the system consists of ultrasonic sensor components (HCSR-04, NodeMCU ESP32, push-button system, and DC 9 V adapter). The ultrasonic sensor will capture sound waves so that changes in spring distance can be detected, based on the working principle of the ultrasonic sensor, which has been explained in the hardware section. Using a microcontroller that has been programmed, it can be analyzed to obtain the difference in distance between the initial presence of the spring and the final presence of the spring, which is called the increase in spring length and is calculated in centimeters (cm). To ensure that the reading data from the sensors in the system will be displayed on the smartphone screen instantly, the NodeMCU ESP32 microcontroller module is used. This module can function as a system microcontroller and can be a device with an Android system. The push button is a reset button that functions to restart the gadget to its initial state with a 9-volt adapter.

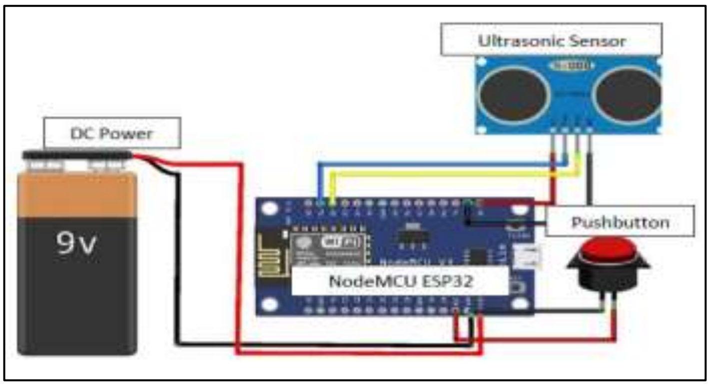


Figure 4. Electronic system

3.2. Hardware system

This dynamometer consists of an HCSR-04 ultraonic sensor to detect the presence of springs on the surface of the system. An ultrasonic sensor is placed on the surface of the system to see changes in the distance between the springs so that changes in the length of the spring, known as Δx, can be seen. The NodeMCU ESP32 module used in this research is connected to an ultrasonic sensor and functions as a system-programming microcontroller and device that supports the IoT system. In the construction of the system mechanism, an iron pole is used to hang the spring so that the distance of the spring from the system support can be varied. The sensor system and microcontroller system are placed on the support of the iron post to detect changes in spring length. This Newton dynamometer can be seen in Figure 5.

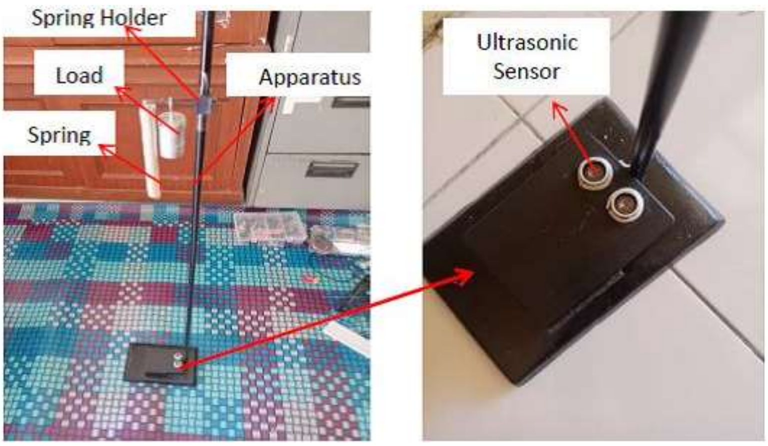


Figure 5. Hardware system

3.3. Software system

This data visualization results from a design implemented using MIT App Inventor, featuring a Bluetooth-based communication infrastructure. The system software design includes adjustable input parameters that can be modified according to the system's specifications. The HC-SR04 ultrasonic sensor serves as the input sensor, detecting the presence of a load suspended on the spring. Additionally, all collected data will be calculated using the empirical method employed in the accepted spring constant technique. This program is exclusively compatible with Android operating systems. The application includes various input variables, such as the acceleration due to gravity. The interface features two key buttons: a Bluetooth connection button and a calculate button, each with distinct purposes. The Bluetooth button establishes a connection between the Android device and the NodeMCU ESP32 module within the system. In contrast, the calculate button computes the values of all parameters inputted into the software. Beyond displaying data, this application also functions as a calculator for the system. Figure 6 illustrates the system display.

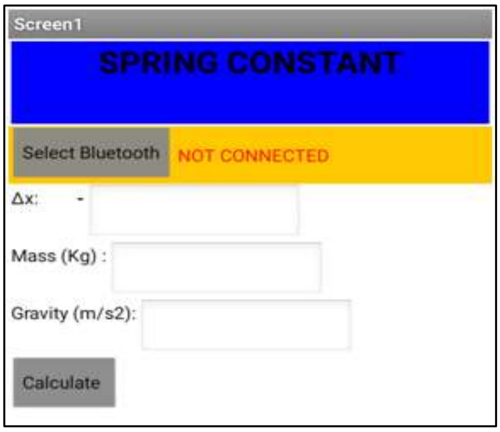


Figure 6. Software system

3.4. Validity test for the sensor

To ensure that the use of sensors in this system aligns with the application objectives, a characterization test is conducted to assess the linearity of the sensors against standard equipment, specifically a ruler. The initial distance of the spring before the load is applied, as well as the distance after the load is suspended, are critical parameters for calculating the change in spring length using the spring constant method.

Figure 7 presents the linearity test data for the HC-SR04 ultrasonic sensor, which is employed to detect the presence of springs in this system. The linearity result obtained from this testing procedure is 0.9998. These data indicate that the HC-SR04 ultrasonic sensor is highly effective for detecting the presence of springs in the system.

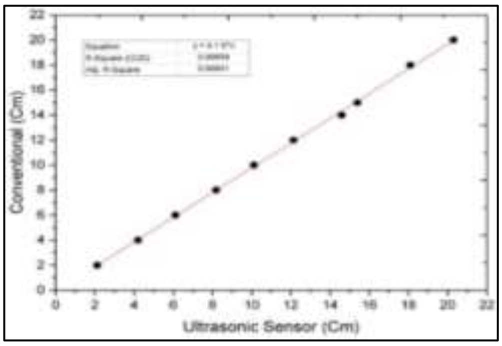
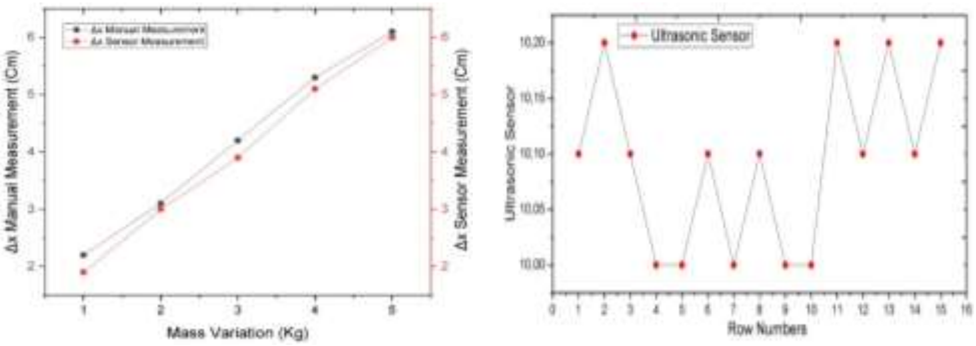


Figure 7. Graph sensor linearity test data with conventional standard tools

3.5. Sensor accuracy and precision testing

Sensor accuracy testing is carried out by comparing the measurement results detected by the sensor with standard measuring instruments. This measurement was conducted to assess the accuracy of this sensor-based system. This system uses an ultrasonic sensor with the HC-SR04 specification. The HC-SR04 ultrasonic sensor is used to see the presence of objects, where the object in this system is a spring so this sensor is used to see the presence of springs when system measurements are taken. The accuracy data of the HC-SR04 ultrasonic sensor in this system can be seen in Figure 8.

The accuracy test findings of the HC-SR04 ultrasonic sensor were utilised to determine the change in the length of the spring after applying a load as shown in Figure 8(a). The test involved comparing the measurements obtained from a conventional ruler measuring device with the sensor results from 5 different sets of data. The purpose was to determine the accuracy of the HC-SR04 ultrasonic sensor, which was found to be 94.12%. Subsequently, the HC-SR04 ultrasonic sensor underwent precision testing. Precision refers to the act of measuring a parameter multiple times in identical conditions in order to assess the degree of agreement among the obtained values. The system precision testing involves the utilisation of the HCSR-04 ultrasonic sensor. The testing is conducted repeatedly, ensuring that the same conditions are maintained. The purpose of this testing is to evaluate the accuracy of the data generated by the system. The test was conducted 10 times on the HC-SR04 Ultrasonic sensor to achieve a precision of 99.94% as shown in Figure 8(b).



(a) (b)

Figure 8. Graph test level of sensor (a) accuracy and (b) precision

4. CONCLUSION

In this research, the Newton dynamometer uses an ultrasonic sensor with a smartphone display designed using the Hooke's law method which detects the presence of a spring before and after hanging the load. The system hardware used is a system frame in the form of an iron pole with a square support, HC-SR04 ultrasonic sensor, push button, NodeMCU ESP32 and an integrated 9 V power supply. The system's software is compiled using MIT App Inventor, which includes input settings and sensors that read the input. The results of the ultrasonic sensor characterization test to detect the presence of springs showed a very good response, namely 0.9998. The accuracy of the HC-SR04 ultrasonic sensor is 94.12% and the precision is 99.94%. This value is an important indicator to see the system response when carrying out related measurements. So readers can use a dynamometer that utilises the principles of the IoT, which enables seamless and real-time data transmission and improves measurement precision as well as to avoid errors in the measurement process such as human error.

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