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Autonomous height measurement system for smart health monitoring

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Abstract. Height measurement is considered an essential parameter for health monitoring. The increasing demand for telemedicine services requires a robust and affordable height measurement system. In addition, the system should have the ability to interact with a remote destination. Unfortunately, existing height measurement tools are incompatible with telemedicine services. In this paper, a low-cost autonomous height measurement system has been proposed. Moreover, the system utilizes an ultrasonic sensor to measure the human height and processes the sensor's data through a Micro Controller Unit (MCU). Finally, the MCU communicates with the remote terminal through a Bluetooth module. A particular wearable prototype has been developed to deploy the hardware for real-life applications. The experiment results demonstrate that the results obtained by the proposed system are reliable, with a mean error rate of 0.02%.

Keywords: Height measurement, smart health monitoring, telemedicine, microcontroller, ultrasonic sensor, Bluetooth module

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1. Introduction

Telemedicine services seem to be the futuristic alternative of confronting medical diagnosis and treatment. Having widespread usability, these services gradually getting popular among mass users. Typically, telemedicine services are design to reduce physical afford to meet physicians. In minor or follow-up cases, it can help the patients to get a preliminary diagnosis. In contrast, telemedicine services are also helpful in emergency cases for getting a quick response from a remote physician, mainly when it is tough to arrange a sudden face-to-face meeting.

Consequently, telemedicine services are becoming a trendy and convenient alternative to traditional follow-up and emergency appointment approaches. By taking advantage of recent technologies, many developed countries already introduced several telemedicine services. Following the trend, developing countries also become enthusiastic about their adaptation. However, making a robust and efficient telemedicine system depends on several evaluation factors such as patient outcomes, management decisions, access to care, user satisfaction, and cost-effectiveness [1,2,3]. Moreover, all telemedicine services do not follow a standard operating procedure as well. Depending on their service types, the telemedicine services can be clustered into three basic categories: store and forward data to a remote device, quick service (home-based services), and remote help station-based [4] systems. Regardless of different operation procedures, the primary purpose of telemedicine services always remains unchanged.

Telemedicine services are incorporated with few basic parameters such as height and weight measurement in most common cases. Among these basic parameters, body height measurement is appraised as one of the crucial factors for many disease diagnoses. For quite an extended period, height is widely used in physiology and clinical medicine. Typically, it is used to generalize the biological function concerning body size and conformation [5]. For tracking an infant or child's health and growth, a full or partial height measurement system [6] plays an important role. In addition, height is also considered a mandatory parameter for a human body mass index (BMI) calculation, directly affecting women's reproduction system [7]. Thus, in adulthood or childhood, height measurement is considered an essential parameter for inspecting a woman's body and reproduction system due to the several diagnosis and treatment procedures; height measurement tools drawn the researcher's attention to that particular domain.

Apart from the widespread importance of height measurement, a robust, simple, affordable height measurement system is still missing. In addition, the existing height measurement tools are incorporated with local actuators only. They do not permit a typical user to send their examined height to another remote system or a smartphone app. To sum up, these devices are not compatible with telemedicine services.

In this work, an affordable and low-cost height measurement system has been introduced. The proposed device uses an ultrasonic sensor and Micro Controller Unit (MCU) to calculate human height. The proposed system will automatically redirect calculated heights to a remote system or a smartphone app through Bluetooth connectivity. Additionally, it also allows the user to control the hardware from a remote device. In the end, a wearable prototype has been developed to house the hardware. This paper is organized as follows: Section II emphasizes similar works, Section III describes the proposed system architecture, hardware setup, and experiments. In Section IV, results and findings have been discussed. Finally, section V concludes this work.

2. Similar works

Height measurement tools have several real-life applications. Mainly, they are instrumental in disease diagnosis. However, making an automatic height measurement tool introduces many barriers, such as accuracy and affordability. Thus, in the past two decades, many height measurement tools have been introduced in search of a robust system. Caleb et al. [8] invented a height measurement system to measure height in a typical home environment. The system is incorporated with a slide rack configured for mounting to a vertical wall surface. The tools also have a slide mount portion, which again mounted on a slide track. The slide mount portion was configured so that it could travel parallel to the vertical surface. Furthermore, the height measuring gauge has a gauge plank, and it can be movable between two plank positions. That system also includes a backing sheet configured for mounting along a length of the backing sheet on the vertical wall surface and between the height measuring gauge. The backing sheet indicates the measured height in the vertical wall surface.

A more innovative solution for height measurement has been proposed by [9]. They have introduced another mechanical slide carrying height measurement tool in their work, where the tools have a measuring arm. The measuring arm is capable of moving on a vertical scale. Typically, when a human body stands straight underneath the measurement tool, the measuring arms search for the person's head and read out the measured value through an audio output module. Apart from being accurate in height measurement, that system does not offer any feature of sending data to a remote place for further analysis. Scot et al. [10] invented another height measurement system to categorize incoming guests of a theme park for allowing them into some particular rides. On that system, an ultrasonic sensor was fixed on a single point. Thus, it could emit signals to a reflection surface. According to the signal sending and receiving time difference, an approximate height was measured through the device. However, the device was able to categorize the guests into various groups; apart from that, the system requires a fixed reflection surface that may not attach to the head of the incoming guests. A similar height measurement approach has been taken by [11]. On their height measurement tool, they also used an ultrasonic sensor to measure human height. That system additionally offers portability and usage different concepts for calculating human heights. They have mounted their sensor on the sun visor and a switch in the inner part like a cup. When the head of the person wearing the cap touches the switch, it triggers the ultrasonic sensor to emits signals. This portable height measurement system can output data through the different actuators, which are again set on the cap's crown. Despite output data through the actuators, this device cannot send the output to a remote device. Thus, it also could not be integrated into a telemedicine system.

A different height measurement approach has been taken by Jeges et al. [12]. In that study, they have used a calibrated camera to measure the height of the human body. Their height measurement system was prepared for the surveillance system and used an intelligent system to measure the human height through a video height measuring sensor. However, this intelligent system only searches for a height range to reduce the suspect elements for identifying suspicious humans coming from a blind point to a camera sight. This measurement system is not compatible with any telemedicine service.

Most of the existing height measurement systems are incorporated with complex mechanical structures or inconvenient to the mass use. Some existing devices are an exception to these problems and can yields output in digital interfaces. Apart from that, they are also unable to team up with a telemedicine system. A simple and portable device has been introduced to optimize all existing problems through a single device in this work.

3. Present work

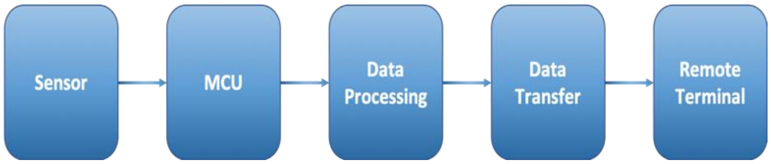


Figure 1: System overview

The present work is incorporated by proposing a more innovative solution for height measurement. In addition, it has been designed especially for teaming up with a telemedicine system. In this work, an HC-SR04 (an ultrasonic sensor) [13], an Arduino-Micro Controller Unit (MCU) [14,15], an HC-05 (Bluetooth module) [16], and laser diode has been used to measure human height precisely. Moreover, the hardware prototype allows users to measure and send calculated height to another Bluetooth-enabled remote device or a system—figure 1 giving a glance at the system architecture. According to the overview, the proposed system will collect height-related raw data from an ultrasonic sensor. After then, the MCU unit will convert the sensor's raw signals into human-readable data. A laser diode has been implanted in the middle of the ultrasonic sensor. Therefore, it can help a typical user to understand the reflection surface. The laser diode will monitor the ultrasonic sensor's performance as well. After conducting a successful height measurement, the MCU will redirect all data to another remote device or a smartphone app. Thus, the remote system or app can store or forward the result to another destination or a telemedicine system [17]. Additionally, the proposed hardware prototype is configured in such a manner that it could receive external commands like re-initiating, showing history, conducting a new height measurement experiment right from a Bluetooth terminal.

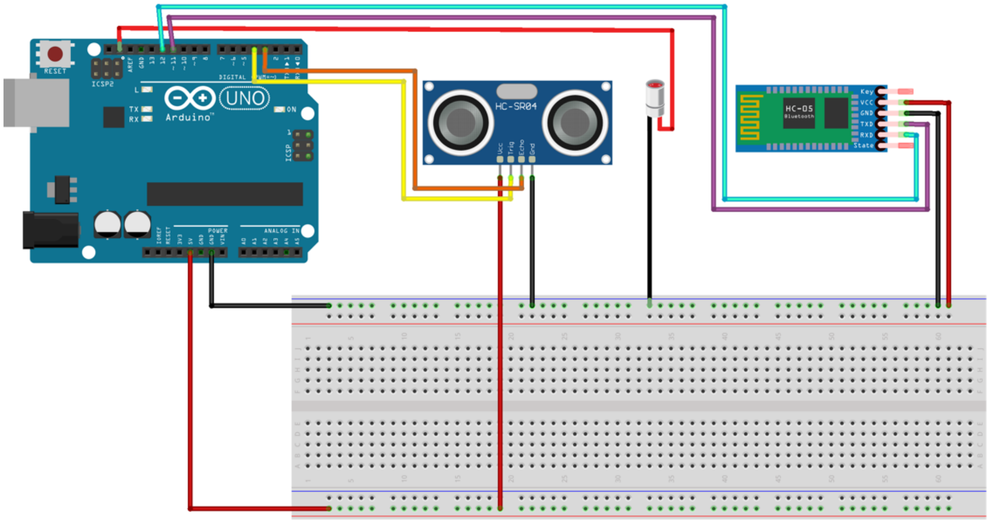
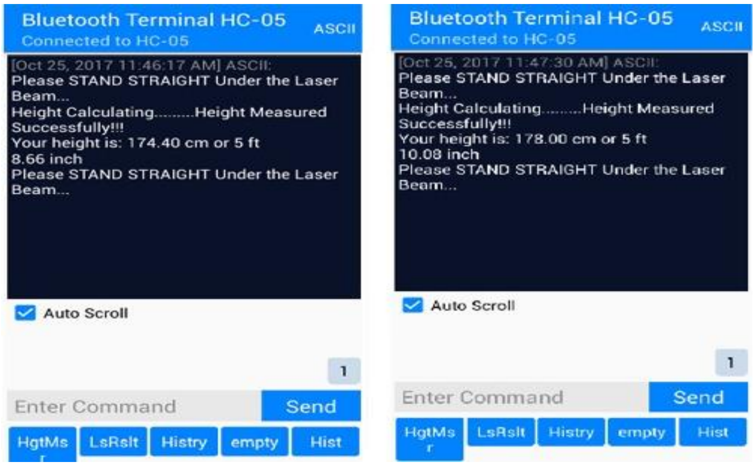


Figure 2: Schematic diagram of hardware

3.1. Hardware setup

Figure 2 illustrates the schematic diagram of the proposed hardware. The MCU has been performing as a power source for the sensor, module as well as diode. Thus, the ground pin of all modules and diode has been shorted with the Arduino's ground pin. Additional pins from both: the ultrasonic sensor (Echo, Trigger) and Bluetooth module (RX, TX) have been configured in the user define digital pins at the Arduino board. Arduino serial output is disabled while configuring the hardware. The default Arduino terminal has been replaced by a third-party Bluetooth terminal in this work, which is set to 9600. Between each sampling and right after a successful data transmission, delays have been introduced. Thus, it could not interrupt the data transmission or sampling procedure while experimenting. However, the hardware is capable of taking at least one sample per second. Note that the MCU itself has to be powered up with an energy source. Here, a 9V lithium-ion battery has been used to power up the hardware. However, any energy source that can provide power around 9 ~ 12V, 1mA can power up the MCU.

3.2. Software integration



```
[Oct 25, 2017 11:46:17 AM] ASCII:
Please STAND STRAIGHT Under the Laser
Beam...
Height Calculating.........Height Measured
Successfully!!!
Your height is: 174.40 cm or 5 ft
8.66 inch
Please STAND STRAIGHT Under the Laser
Beam...
```

```
[Oct 25, 2017 11:47:30 AM] ASCII:
Please STAND STRAIGHT Under the Laser
Beam...
Height Calculating.........Height Measured
Successfully!!!
Your height is: 178.00 cm or 5 ft
10.08 inch
Please STAND STRAIGHT Under the Laser
Beam...
```

Figure 3: Actual cost to develop the proposed device

The proposed system aims to send calculated data to a remote destination. Moreover, the data transfer has to be autonomous, and it should not require any user interaction. As smartphones are the most available and convenient solution for the mass user, this study utilized the Bluetooth terminal of the smartphone. An open free Bluetooth terminal, which is available in the android play store, has been used to monitor the output of the experiments. Furthermore, the Bluetooth terminal is also used for sending the command (i.e., history, start, timestamp, and so on) to control the hardware prototype. Figure 3 shows the sample screenshot of the used Bluetooth terminal. Note that any kind of Bluetooth terminal can be used to interact with the proposed system. Moreover, this work will allow third-party software developers to integrate the proposed hardware in their respective applications.

3.3. Height Measurement

The developed hardware is designed to measure height accurately. However, the accuracy of the measured height highly depends on sensor placement. Two different methods have been studied to find out the appropriate position of sensor placement. The methods are as follows:

Method-I: The height measurement sensor has been placed in a fixed position. It targets the correspondence skull as a reflection surface.

Method-II: A particular wearable prototype has been developed. The hardware has been attached to the wearable prototype, such as it can be placed like a cap.

3.3.1. Method-I

Figure 4 demonstrates the basic setup for Method-I. As the figure shows, the height measurement procedure with Method-I begins with the initiating hardware in a static location. For the first time when the hardware is powered up, the ultrasonic sensor begins to emit signals and tries to initiate it on a floor or reflective surface. In addition, the device's initial position is not a fixed value. It can be re-initiated from the connected smartphone or remote terminal as per user requirements. After initiating, the system will wait for the command from the remote control for measuring height. When it receives any user command of height measurement, it will begin searching for another reflective surface, which is less than the initial position. Typically, the device takes a person's skull as the reflection surface and calculate the actual height of correspondence as follows:

$$AH = IP - RS$$

Where, **AH** = Actual Height, **IP** = Initial Position, and **RS** = Reflection Surface

Algorithm 1 Finding Initial Point

```
$sensorData$
$FilteredData[i]$
while $i \neq 20$ do
  if $sensorData > 0$ and $sensorData < 3000$ then
    $FilteredData[i] \leftarrow sensorData$
  end if
  $i \leftarrow i + 1$
end while
```

Note that in Method-I, an initial point has to be selected. The following algorithm has been developed to find the appropriate initial point: While initializing the hardware prototype, it is widespread to receive garbage data. However, the initial point must have to be precise in order to measure accurate height. The algorithm (1) has been introduced to initiate the device:

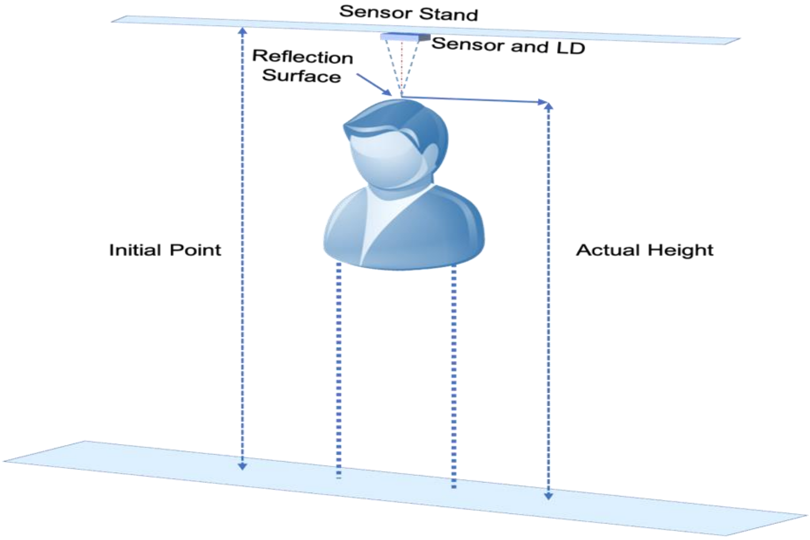


Figure 4: Overview of Method-I

3.3.2. Method-II

For method-II, a wearable prototype has been developed. The wearable has been designed as a baseball cup. Thus, it can be placed into the user's head. Figure 6 demonstrates the top and bottom view of the wearable prototype. Moreover, the MCU, power source, Bluetooth module, circuit connection has been placed into the crown. It has been tried to make the circuit connection invisible from the user. A stand has been attached to the top of the wearable so that it can hold the ultrasonic sensor and the laser diode. The overall hardware configuration remains unchanged. However, the height measurement strategy has been changed for method II. As Figure 5 shows, in Method-II, the ground has been considered a reflection surface. Subsequently, it does not require any initial point as the method I. Here, the initial point has been set to 0.

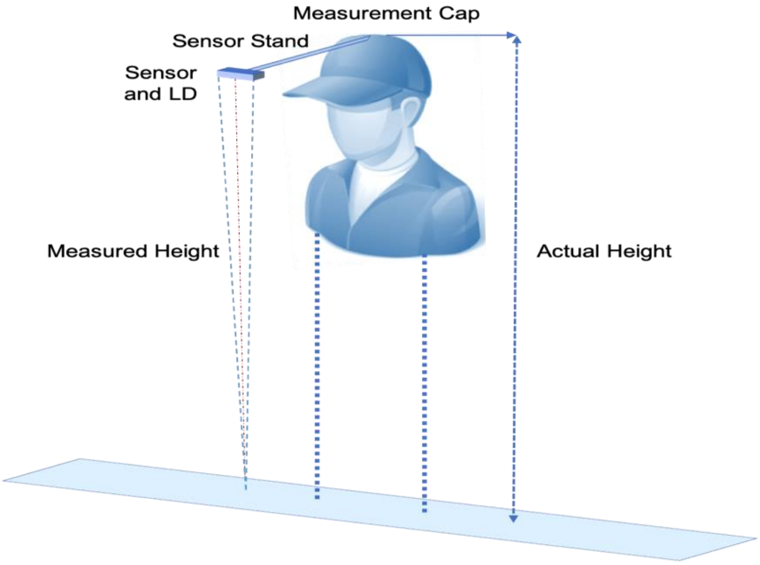
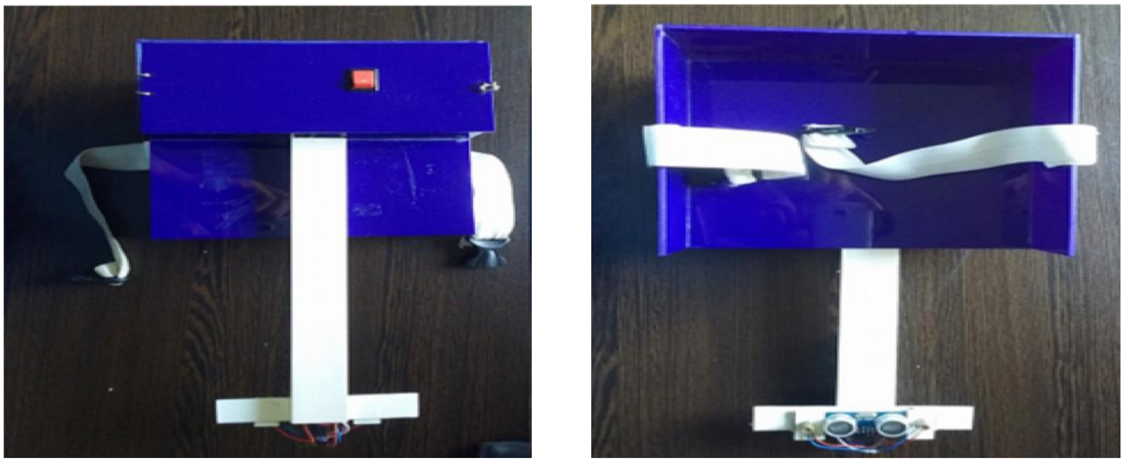


Figure 5: Overview of Method-II



(a) Top View (b) Bottom View

Figure 6: Figures side by side

3.4. Data sampling and processing

Depending on the method, steps for the height measurement can be different. In contrast, every method follows a common procedure for data sampling and finding the final result. The data samples have been taken from the sensor for each data pointing (calibration and human height calculation). Furthermore, data samples have been stored in an array. The garbage values have been filtered out from the sample data. In addition, most appeared value has been considered the final sample value for determining the initial point (Method-I) or the human height. Finally, the calculated height has been sending through the Bluetooth module to a remote device. Figure 7 illustrating the data flowchart that has been used in this work.

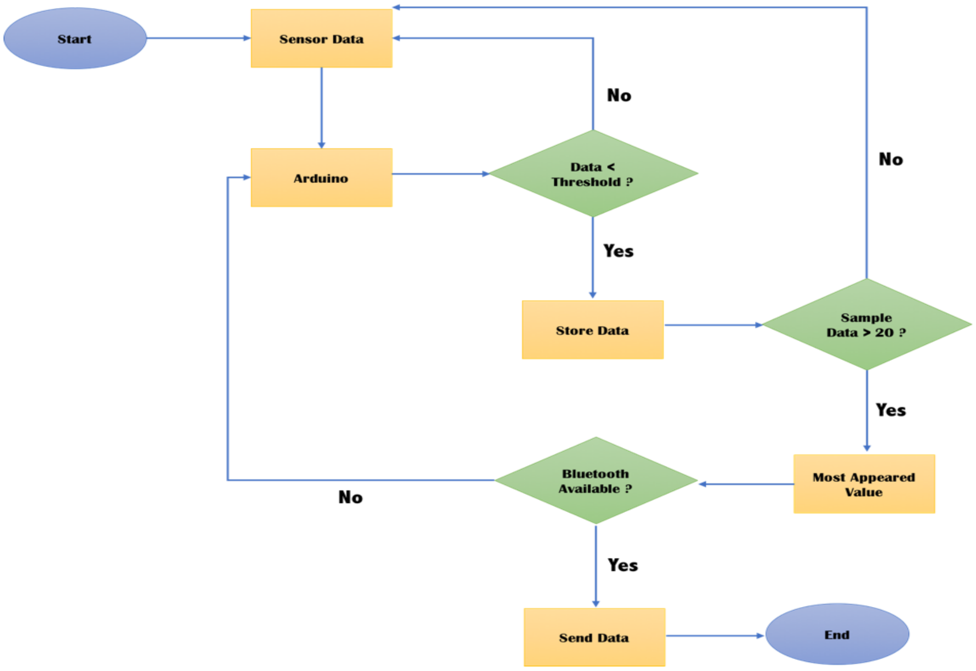


Figure 7: Data flow

3.4.1. Data sampling

The body movement and uneven surface can affect data sampling. A set of data samples (D) has been considered for computing the accurate height. Algorithm (2) has been developed to measure the height of a correspondence. For data sampling, the measurement unit is fixed in millimeters.

Algorithm 2 Data Sampling

```
$sensorData$
$sampleData[i]$
while $i \neq 20$ do
    $sampleData[i] \leftarrow sensorData$
    $i \leftarrow i + 1$
end while
```

3.4.2. Garbage filtering

HC-SR04 can produce garbage values due to several issues: sending and receiving signals, transmission delay, and fluctuation of reflection surface [18]. Moreover, these garbage values can directly affect the outcomes. Thus, algorithm (3) has been developed to filter out the garbage values from the raw data. Note that a threshold value has been set to omit the garbage from the sample data. For Method-I threshold is equivalent to the initial point. For Method-II threshold value is set to 3000 (mm).

Algorithm 3 Garbage Filtering

```
$sampleData$
$FilteredData[i]$
$threshold$
while $i \neq 20$ do
  if $sampleData[i] > 100$ and $sampleData[i] < threshold$ then
    $FilteredData[i] \leftarrow sampleData[i]$
  end if
  $i \leftarrow i + 1$
end while
```

3.4.3. Finding the final height

This step has been designed to determine the final heights from the filtered data. However, it heavily relies on the garbage filtering strategy. The filtered data has been considered to measure the final height of correspondence. In addition, the final height has been calculated with algorithm (4). In a nutshell, the most appeared value has been considered as the final height.

Algorithm 4 Finding Measured Height

```
$filteredData$
$sampleData[i]$
$count = 1$
$temp = 0$
$tempCount$
$mHeight = filteredData[0]$
while $i = 0 \neq length(filteredData)$ do
  $temp = filteredData[i]$
  $tempCount = 0$
  while $j = 1 \neq length(filteredData)$ do
    if $temp == filteredData[j]$ then
      $tempCount \leftarrow tempCount + 1$
    end if
    if $tempCount > count$ then
      $mHeight = temp$
      $count = tempCount$
    end if
    $j \leftarrow j + 1$
  end while
end while
```

4. Experiments and results

The proposed hardware setup has experimented with different measurement methods. To test each method, two target samples **F** and **M**, have been considered. Here, **F** and **M** is the sample set of female and male correspondence, respectively. Each sample set is comprised of 15 persons with different heights.

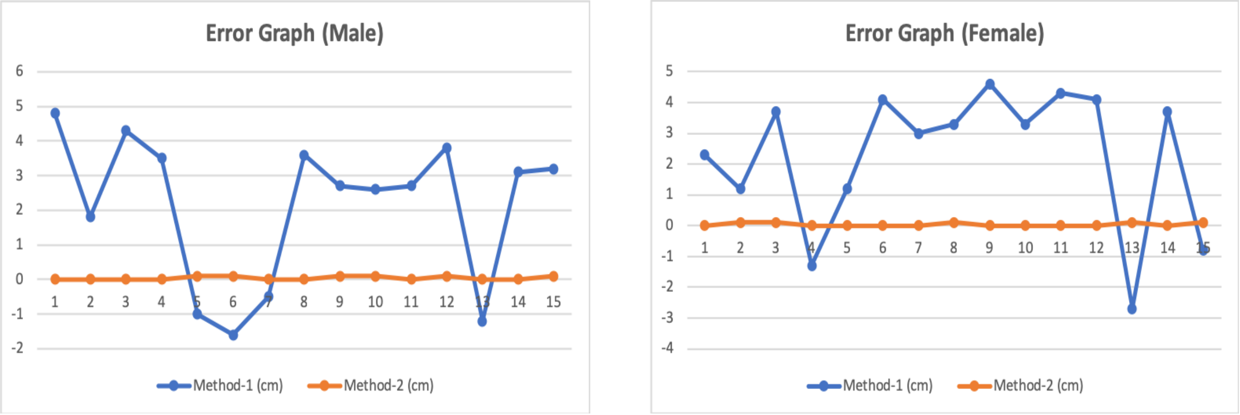
4.1. Results

Table 1 shows the hardware performance for each method. Results indicate that method-II is more consistent than Method-I for both sample sets (F and M).

Figure 8 shows the error comparison for both methods. The error graph for both males and females demonstrates that the error rate of method-II is much stable. Moreover, the error for method-II is less than 1% cm. In contrast, the error rate of Method-I is varying between- 3 cm to 5 cm. Table 2 shows the mean error rate of both methods. It is to be noted that, Method-I much higher than method-II. Moreover, it has been affected by the reflection surface, which is again considered the top of the skull. Due to the interference of hair, the measured height with Method-I seems to be inaccurate.

Male				Female			
Person	**Actual (cm)**	**Method-1 (cm)**	**Method 2 (cm)**	**Person**	**Actual (cm)**	**Method-1 (cm)**	**Method 2 (cm)**
1	175.5	170.7	170.7	1	152.4	150.1	152.4
2	169.5	167.7	167.7	2	147.3	146.1	147.2
3	174.4	170.1	170.1	3	165.9	162.2	165.8
4	175.5	172	172	4	154.9	156.2	154.9
5	177.2	178.2	178.2	5	157.5	156.3	157.5
6	180.3	181.9	181.9	6	162.3	158.2	162.3
7	174.1	174.6	174.6	7	160.1	157.1	160.1
8	167.6	164	164	8	163.4	160.1	163.3
9	176.4	173.7	173.7	9	164.7	160.1	164.7
10	170.2	167.6	167.6	10	171.4	168.1	171.4
11	160.5	157.8	157.8	11	161.4	157.1	161.4
12	168.9	165.1	165.1	12	159.2	155.1	159.2
13	182.3	183.5	183.5	13	155.4	158.1	155.3
14	173.2	170.1	170.1	14	153.8	150.1	153.8
15	179.6	176.4	176.4	15	164.3	165.1	164.2

Table 1: Experiment results of Method-I and Method-II



(a) Error for male attendance

(b) Error for female attendance

Figure 8: Error comparison of Method I and Method II

Method	Gender	Mean Error Rate (%)
Method-I	Male	1.24
Method-I	Female	1.40
Method-II	Male	0.02
Method-II	Female	0.02

Table 2: Mean error rate of Method-I and Method-II

4.2. Cost analysis

The proposed work aims to develop an autonomous height measurement system at a low cost. Thus, it could be affordable for the mass user. Figure 9 shows the approximate cost of developing a single prototype. The overall cost for the hardware development and deployment was kept under USD 15 (approximately). However, this cost should significantly drop during the mass production phase.

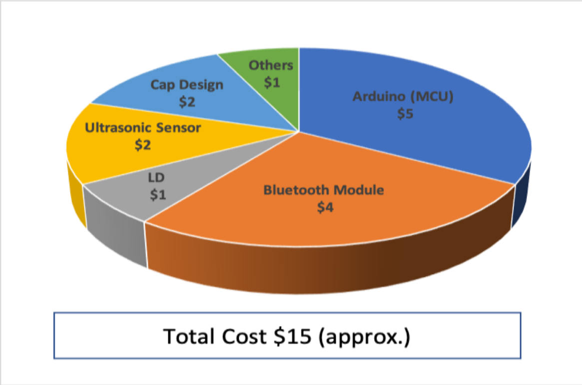


Figure 9: Actual cost to develop the proposed device

5. Conclusion

In this study, an autonomous height measurement system has been proposed. Moreover, the proposed system utilizes an ultrasonic sensor to measure human height. A laser diode has been used to help the user to locate the reflection. An MCU has been used to process raw data. To the end, the measured data has been transferred to a remote terminal for further processing. Thus, it can team up with any kind of telemedicine service. Two methods have been studied to confirm the feasibility of the proposed autonomous height measurement system. Moreover, a unique wearable prototype has been developed to reduce measurement errors. In addition, the cost for developing the hardware prototype was kept under USD15 (approx.). Moreover, the experiment results demonstrate that the newly developed wearable prototype helps the hardware measure accurate heights—the mean error rate of the proposed system observed under 0.02%. The proposed system will be extended with several body sensors (i.e., heart rate and body temperature) for further improvement in the foreseeable future. It has been planned to develop a smartphone application for user convenience.

Conflicts of interest. There is no conflict of interest.

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