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# Mobile based augmented reality for flexible human height estimation using touch and motion gesture interaction

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**Abstract.** Human height measurement can be achieved by using contact or non-contact techniques. Contact technique is the traditional measuring method which required human resources to perform the measurement. In contrast, for non-contact technique, several kinds of research for measurement have been conducted, mostly with image-processing methods and only a few with the Augmented Reality (AR) approach. The current measuring approaches mostly required external hardware such as laser pointer or artificial fiducial such as 2D markers. In this paper, the world tracking technique and Visual Inertial Odometry is the method used to estimate the human height. The main aim of this paper is to accurately estimate the human height using augmented reality (non-contacted measurements). The methodology used the Apple ARKit plugin, which is the software development tools to build an augmented reality application for IOS device. An algorithm was designed by using Golden Ratio rules to estimate human height from the lower part of human knee; The estimation result is displayed using AR technology to allow the justification of the accuracy of the result. The application is tested with four different measuring methods. The normal full-height measurement result had a 1.13cm (0.73%) bias and a 1.34cm (0.88%) Root Mean Square Error (RMSE); the self-full height measurement had a result of 0.89cm (0.58%) bias and a 1.27cm (0.83%) RMSE; the normal height estimation from the lower part of knee measurement had a result of 0.12cm (0.06%) bias and a 1.34cm (0.89%) RMSE; the self-height estimation from the lower part of knee measurement had a result of 0.15cm (0.09%) bias and a 1.04cm (0.66%) RMSE. The results show that the mobile phone with VIO can be a potential tool for obtaining accurate measurements of human height.

## 1. Introduction

Commonly, traditional measurements can only be made with the use of measuring tools such as measuring tape or ruler. Although some researches using different measuring approaches such as image-processing methods and marker-based Augmented Reality approach had been done, it was also limited to the help of external sources such as laser pointer or 2D marker [4, 11, 15].

The camera in mobile devices nowadays is equipped with inertial sensors such as 3-axis accelerometer and 3-axis gyroscope. It gave the device 6-axis motion sensing and rotation about the gravity, enabling a new level of spatial awareness in measurement applications.

The term, Visual Inertial Odometry (VIO) arises due to the widely used of the combination of visual and inertial measurement in the robotic field. As mentioned by Rebecq [9], Visual Inertial Odometry is the task of estimating a sensor's ego-motion from a combination of images and measurements from an Inertial Measurement Unit (IMU), which plays a significant role in numerous application fields such as



augmented reality (AR) or virtual reality (VR) applications. Currently, well-known applications that utilize VIO in the mobile device are Apple ARKit and Google Project Tango. With VIO, more accurate tracking can be done. Thus, a new way of measuring distance, length or height can be achieved.

Instead of just taking full human height measurement, human height can also be measured by just measuring a particular part of the body. The divine proportion, Golden Ratio, which was originated by a Greek sculptor and mathematician, Phidias, is a ratio of distances in simple geometric figures [3]. There has been evidence that the human body proportion does follow the Golden Ratio rules and several measurement rules had been derived from that [5, 6].

In this paper, an application utilized the VIO in a mobile device using the built-in camera to obtain the human height using the AR technology for displaying result is proposed. The visual and inertial data are used for obtaining human height. The system tracks visual data of the ground in which people stand on and also track the inertial data of the camera movement. The designed algorithm is then used to compute height measurement using the visual and inertial data.

Furthermore, the Golden Ratio rule in human body proportion was also implemented to estimate the human height by just measuring the lower parts of the knee. This feature is quite useful to get the height estimation for those who have disability problem.

In the following section, the theory and related application are first presented, followed by the methodology, results, and lastly, the conclusion is described.

## 2. Background

### 2.1. Visual Inertial Odometry (VIO)

Visual Inertial Odometry is described as a technique to estimate the change in mobile position and orientation using the built-in camera and Inertial Measurement Unit (IMU) sensor [7]. According to Rebecq, VIO is the fusion of IMU in the Visual Odometry (VO) system which estimates the ego-motion (the 3D camera motion from a combination of images and the IMU's measurements) [9].

### 2.2. Visual Odometry

Visual odometry can be defined as the prediction of camera motions in sequence depending on the perceived pixels' movement in the sequence of images. There are four components in the visual odometry: camera calibration, the feature tracker, the rigid motion estimation algorithm, and the algorithm that matches the point of the features descriptions, the Random Sample Consensus (RANSAC) algorithm.

Camera calibration algorithm cannot be considered as a fragment of the visual odometry, due to it being only a one-time execution which is in the initialization process in which the determination of the transformation between the ground coordinate system (CS) and the camera CS occur [13, 14]. Hence, for the real-time functionality on the mobile device, three main essential parts of visual odometry must be applied, and they are the Kanade- Lucas-Tomasi (KLT) algorithm, the RANSAC algorithm, and the algorithm to determine the rigid transformation.

KLT algorithm [8, 10, 12] is a feature tracker used to find out the movement between two subsequent captured images at time  $t$  and  $t + \Delta t$ .

The RANSAC algorithm is an iterative scheme that used a set of data observed, including the outliers to predict the parameters of a mathematical model [13, 14]. By using this algorithm, it allows robust estimation of the parameter of a model which suits the given data even when the data contain elements highly different from the precise values with the limitation of up to 50% elements.

For the algorithm that determines the rigid motion, only a single point movement that can indicate the whole points' movement is described, instead of describing all the individual points' movement to simplify the computational complexity.

### 2.3. Inertial Measurement Unit (IMU)

The IMU is an independent system which allows the measurement of linear and angular motion by using multiple sensors such as accelerometer, gyroscope and sometimes magnetometer. With an accelerometer, the device's acceleration, tilt and vibration can be detected to identify the movement and orientation. The gyroscope allows the identification of the relative directions: up, down, left, right, forward and backwards. Rotation around the three axes is also part of the gyroscope capability. The axis orientation is not affected by tilting of the mounting. Thus, the gyroscope is used to help provide consistency or to preserve a reference direction. Next is the magnetometer, which allows the detection of magnetic north and is most commonly used in GPS to determine the user's location.

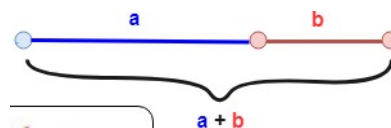
With the capability of determining the direction of gravity (which is in line with the Z-axis of the world CS) by the accelerometer and the direction of magnetic north (Y-axis) provided by a magnetometer, X-axis can be obtained by the computing the cross product of these two directions. However, a gyroscope can measure angular velocity (relative rotation) accurately and its high responsiveness (high sampling rate). It is needed for a more accurate and stable measurement. It can prevented a false rotation returned by the magnetometer in the presence of magnetic interference.

The occurrence of noise, drift and bias is often present in these inertial sensor's measurement, so they are seldom used individually. However, these biases can be highly eliminated through the combination of all three sensors into one sensor, namely the Inertial Measurement Unit (IMU). This combination is typically done by using the Kalman filter algorithm as it is common sensor fusion and data fusion algorithm. The standard method used to measure device movement in between IMU readings is dead reckoning [1]. It is a process of computing current position by using a previously fixed or determined position and advancing that position based upon known or estimated speeds over the time elapsed. The problem is the cumulative error, where the error accumulates over time due to noises and biases in IMU data [1].

### 2.4. Golden Ratio on Human Body

Golden Ratio is simply a proportion of two unequal segments at which the proportion of the long segment to the short segment is equal to the total of the two segments to the long segment (1:1.61803398874989) [6]. As shown in Figure 1, the proportion of the longer segment  $a$  to the short segment  $b$  ( $a:b$ ) is equal to the total of  $a$  and  $b$  to  $a$ . The value of  $\phi$  is given with the number as 1.61803398874989.

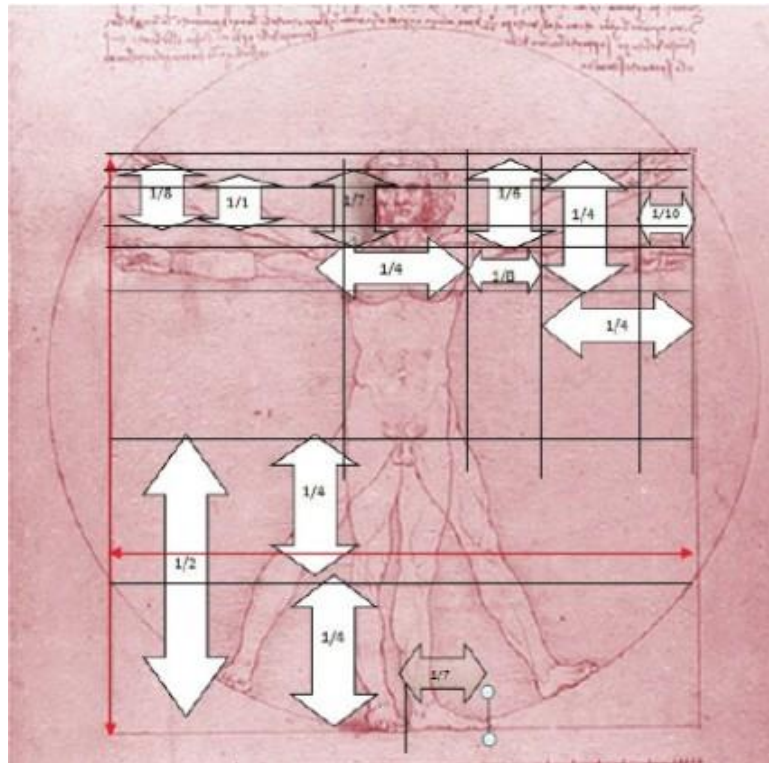
Leonardo da Vinci had established 15 proportion rules [5, 6] used to human modelling based on his work on Vitruvian Man around 1490, as shown in Equation 1.



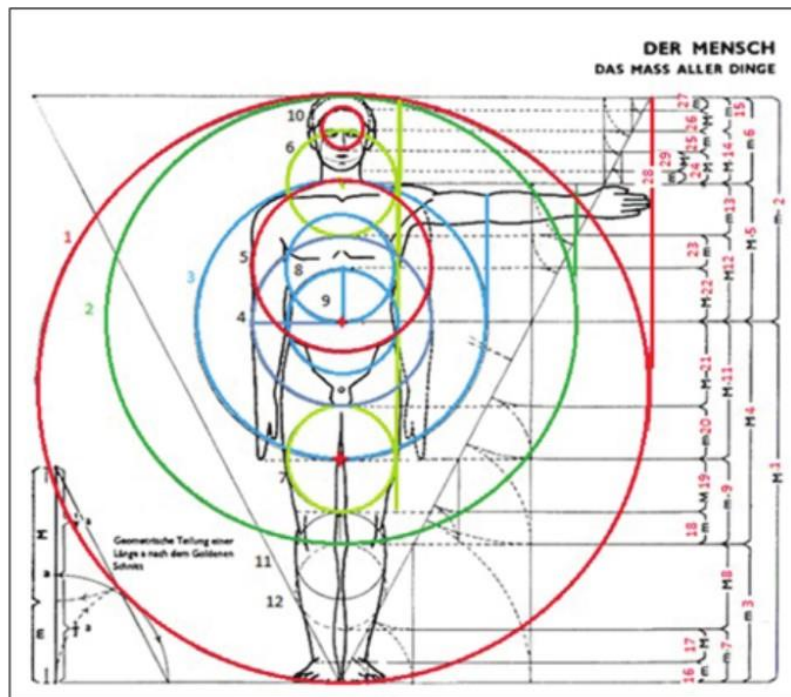
**Figure 1.** Golden Ratio representation in the line segment.

$$\frac{a+b}{a} = \frac{a}{b} = \phi \quad (1)$$

Further work with golden ratio proportions on the human body had been done by a German engineer, Ernst Neufert in 1936 with the book named "Bauentwurfslehre" [5, 6]. Figure 3 shows the 29 proportional measurements derived for the human model, where some of the rules were used in this project for human height estimation.



**Figure 2.** Vitruvian man with proportions by Leonardo da Vinci [5, 6].



**Figure 3.** Bauentwurfslehre by Ernst Neufert. [5, 6].

### 2.5. Related Work

Guan et al [16] have proposed a method using single image containing only a human face to estimate body height in 2009. Eyes, lips and the chin are extracts to identify the height. The height estimation made was based on the facial vertical golden proportion.

Wang and Chen did the project in 2012, which utilized a laser pointer and a camera associated with the image processing technique to get the human height measurement. To perform measurement operation, the user just need to stand on the measurement mechanism, and the detection device on top will automatically calculate the height by using the triangular distance measurement principle [15].

Another image processing research of estimating people height had been done in 2018 by Petr, Kamil, et al. In order to determine the height, a full human image which was captured by a single camera, as well as the presence of at least one object with known size in the image, are required. Several images processing technique had been used such as camera calibration, edge line detection, Hough transform and many more. [17].

There was also research on using the square template to identify the human height performed by a grouped of four researchers in Srinakharinwirot University in 2018. Four steps are used to get the height estimation which are image acquisition, template matching, background subtraction, and lastly estimating the height based on pixel size [18].

Research on estimating human height with object (foot) size had been done at the University of Pennsylvania, in 2018. The human foot was extracted from the captured image using colour mask segmentation to separate the noise of the background and foot. A coin was used as the reference for depth estimation. A linear regression model is trained and used to predict the result [19].

An AppyKids Toy Box application called "How Tall Are You" had been created by Growl Media in 2018 for the purposed to track and measure children height. The application also provided picture saving and sharing functions. The system needs to analyze the room before it started to do the measurement. After that, the user needs to keep the device at the level of the foot and tap the screen. An animated giraffe will be displayed on the screen. The device is then raised to the head level and tap again to complete the measurement [2].

Therefore, this research will fill the gap by applying the golden ratio in estimating human height in the AR environment, which will contribute to assisting disabled people in measuring their height.

## 3. Proposed Method

### 3.1. System architecture

The description of the system for this application is shown in Figure 4. Unity 3D and ARKit plugin were used to develop this application, while XCode was used to build and run this application onto the device. The compatible devices need to be IOS 11.0 and above with camera, gyroscope, and accelerometer.

For the application layer, the camera's visual tracking will first identify the surface by getting the features to point data from the plane detection function provided by ARKit plugin. Once the plane surface data is obtained, the application will proceed to get the hit-testing result from the centre screen in the form of 3D world coordinates once the user clicks on the add point button. Once the starting point is set, the application will utilize the device inertial sensors data to update the ending point.

Once the add button has been pressed again by user, the system will get the current measurement state to identify which ending point to be used. If the state is self-measurement, then the ending point will be based on the camera position; otherwise, if the state is a normal measurement, the point will be based on the pointed position by the centre of the screen. There are two different algorithms to compute the height, which is the normal measure algorithm and golden ratio estimate algorithm. Once the height had been calculated, it was displayed together with the line from the starting point to the ending point using the AR technology.

Figure 5 shows full human height was taken as measurement where it was computed using the normal measure algorithm explained in the next subsection as in Equations (2) and (3). In contrast, Figure 6 shows only the lower part of the knee was taken as the measurement using a normal measure algorithm.

The human height can be obtained through the design golden ratio estimate algorithm as in Equation (5).

3.2. Estimation of Height Increment

The total height is updated with the motion of the mobile device once the starting point had been set. Figure 7 shows the illustrated diagram involved in computing the height increment per frame updated with device motion. The start point, p1 is the point on the ground surface that is obtained from plane detection. Camera position can be obtained through the tracking of the device movement.

Both camera position and the start point, p1 obtained are based on the world origin of the AR session. To get the height of the camera above ground (h1), assumption needs to be made on the position of the point pCam, where pCam is parallel to y-axis of p1. The height h1 can then be obtained by calculating the distance from the camera to pCam.

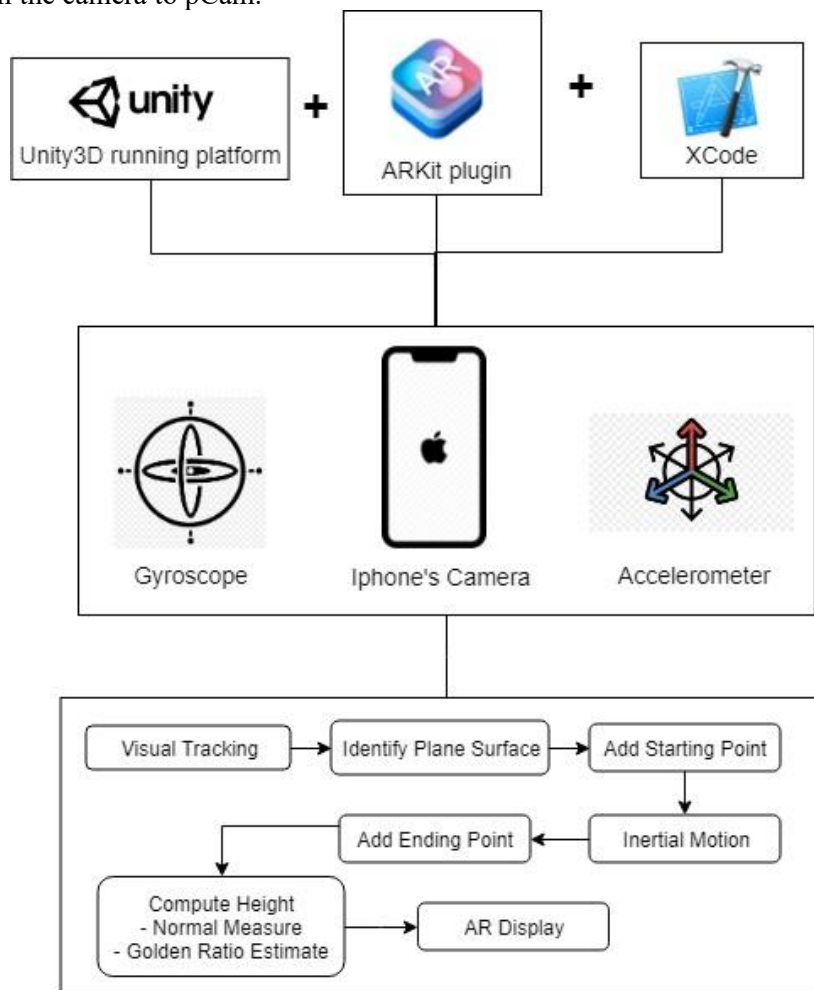
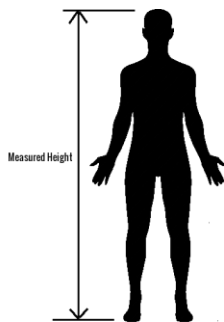


Figure 4. System Architecture.

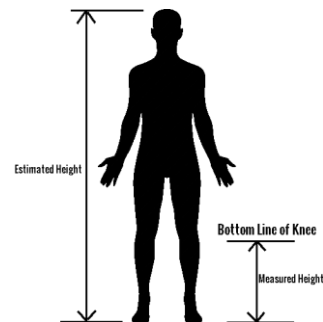
The angle of elevation,  $\theta$ , is obtained from the orientation of the device. The overall equation used to obtain the height increment is in Equations (2) and (3) below.

$$h2 = \tan(\theta) \times \text{dis tan ceto } p1 \tag{2}$$

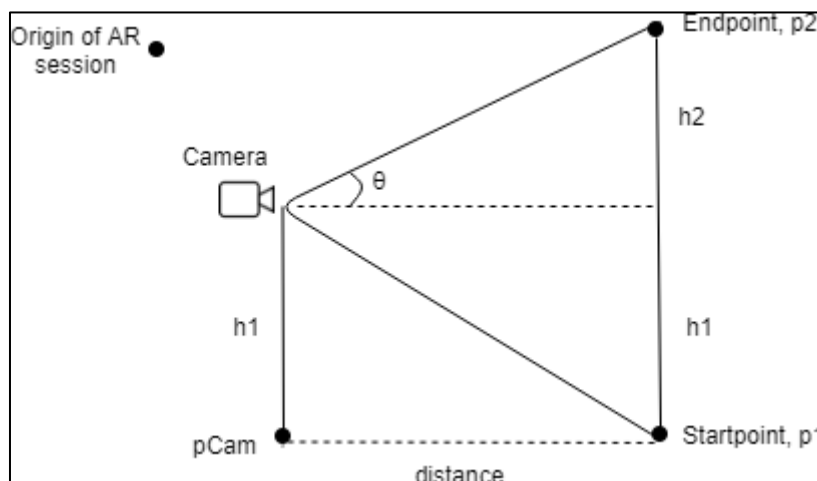
$$\text{Height} = h1 + h2 \tag{3}$$



**Figure 5.** Full height measurement.



**Figure 6.** Lower part of knee measurement to estimate human height.



**Figure 7.** Height Computation Schema.

### 3.3. Golden Ratio Height Estimate

Since the human body followed the golden ratio rules as described in Figure 2, human height can be obtained by measuring just a small part of our body. The human height was estimated with a known height from foot to the bottom line of the knee. The algorithm involved the use of M3, M4, M1 and M2 as illustrated in Figure 3.

M3 – The height from foot to the bottom line of knee

M4 – The height from the bottom line of the knee to the navel

M1 – The height from foot to the navel

M2 – The height from the navel to the top of the head

Generally, the value of M3 is estimated using the rules and method in Figures 1 and 3. With known value M3, M4 can be obtained by using the Equation (4) obtained from the golden ratio rule where the value  $\phi$  is 1.61803398874989.

$$M4 = M3 \times \phi \quad (4)$$

The height from foot to the navel, M1 is calculated where  $M1 = M3 + M4$ . Next, the height from the navel to the top of the head, M2 is also calculated with the equation derived from the golden ratio proportion as in Equation (5).



$$M2 = M1 \div \varphi \quad (5)$$

Lastly, the total height is obtained by calculating the sum of M2 and M1. The overall equation used for estimating the human height by measuring the lower part of human knee is shown in Equation (6).

$$Height_{Est} = M3 \times (1 + \varphi) \times \varphi \quad (6)$$

### 3.4. Evaluation of the Accuracy of Human Height Estimation

The accuracy of the human height estimations was evaluated using bias, relative bias (relBIAS), root mean square error (RMSE), and relative RMSE (relRMSE), as shown in the Equations (7), (8), (9) and (10) below.

$$BIAS = \frac{\sum_{i=1}^n (x_i - x_{iref})}{n} \quad (7)$$

$$relBIAS = \frac{\sum_{i=1}^n (x_i - x_{iref})}{n} \times 100\% \quad (8)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (x_i - x_{iref})^2}{n}} \quad (9)$$

$$relRMSE = \sqrt{\frac{\sum_{i=1}^n (x_i / x_{iref} - 1)^2}{n}} \times 100\% \quad (10)$$

Based on the equations above,  $x_i$  is the  $i^{\text{th}}$  measurement,  $x_{iref}$  is the  $i^{\text{th}}$  actual value, while  $n$  is the number of trials or estimations. Since RMSE is a measure of how well the model performed by measuring the difference between estimated values and the actual values, it is chosen to be the method for evaluating the accuracy.

## 4. Results

The results of the project are analyzed to evaluate the accuracy of the proposed technique, two measuring methods can be made with this application, which is a normal measuring method and self-measuring method. The purpose of normal measuring method is to help people measuring the height while the self-measuring method is to measure self-height. For each measuring method, it is split into two categories which are full height measurement and height estimation by measuring the only lower part of the knee. This section first showed some screenshot output for height measurement using both algorithms (golden ratio estimation and normal measurement), followed by presenting the evaluation results on human height estimation based on all measuring methods implemented in this application.

### 4.1. Output Result

Figure 8 showed the screenshot of example height measurement result for full height measurement using only the normal measure algorithm as in Equations (1) and (2). The measurement was taken from the ground until the head level—the two white dots indicating the start and the endpoint of the measurement. The height text was displayed in the middle of the line rendered as in Figure 8.

Figures 9 and 10 showed the example height estimation screenshot taken after measuring the lower part of the knee using the Equations (1) and (2). The final height was computed by using the golden ratio estimate algorithm as in Equation (5).

### 4.2. Evaluation on Human Height Estimation

The estimated results of the human heights using all four methods were similar to the actual human height measured, as shown in Figure 11.

The statistical results are summarized in Table 1. It is shown that all the estimation methods had relatively small BIAS and RMSE. Normal full height measurement had BIAS (-1.13 cm, -0.73%) with RMSE (1.34 cm, 0.88%), while self-full height measurement had BIAS (-0.89 cm, -0.58%) with RMSE (1.27 cm, 0.83%). Normal height estimation from the lower part of knee measurement had BIAS (0.12 cm, 0.06%) and RMSE (1.34 cm, 0.89%) whereas the self-height estimation from the lower part of knee measurement had BIAS (-0.15 cm, -0.09%) and RMSE (1.04 cm, 0.66%). The normal height estimation from knee measurement had the greatest dispersion of estimated values, as shown in Figure 12.



**Figure 8.** Full Height Measurement.



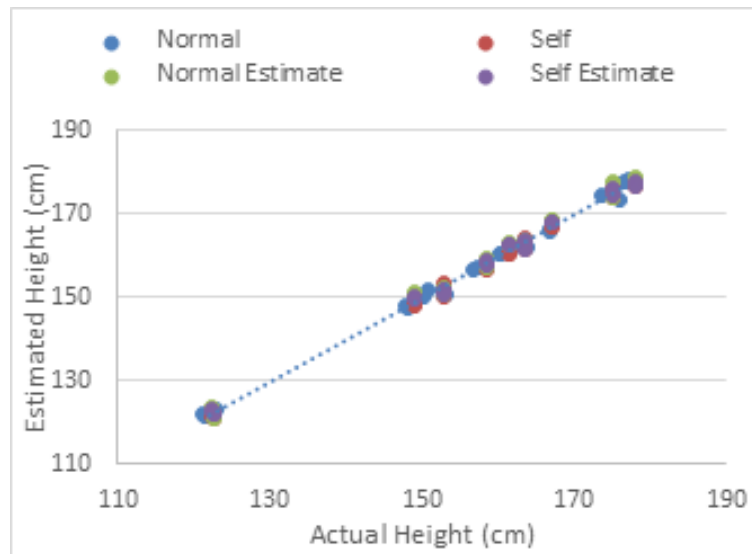
**Figure 9.** Height estimation result from only lower part of knee measurement.



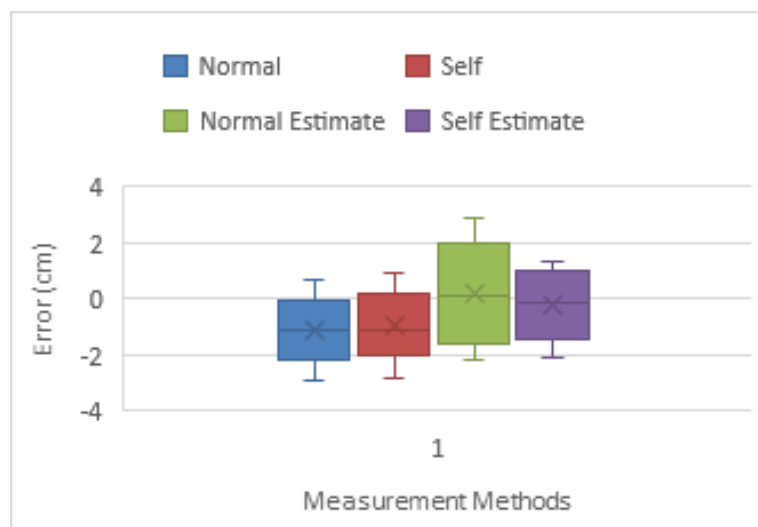
**Figure 10.** Height estimation result from only lower part of knee measurement.

**Table 1.** Accuracy of human height estimation using all available methods.

Methods	BIAS (cm)	relBIA S (%)	RMSE (cm)	relRMSE (cm)
Normal full height measurement (Normal)	1.34	0.88%	-1.13	-0.73%
Self-full height measurement (Self)	1.27	0.83%	-0.89	-0.58%
Normal height estimation from lower part of knee measurement (Normal Estimate)	1.34	0.89%	0.12	0.06%
Self-height estimation from lower part of knee measurement (self Estimate)	1.04	0.66%	-0.15	-0.09%



**Figure 11.** Scatter plot of human heights for all four available methods.



**Figure 12.** The errors in the human height estimations using different methods.

Based on the results of all the measuring methods, the normal measuring method has the highest RMSE (1.34 cm), while self-height estimation from knee measurement has the lowest RMSE (1.04 cm). It is believed that the reason leads to this difference in error might be the parallax error, where the viewing angle makes the line looks like a parallel to the targeted ending point, but in fact, it does not.

#### 4.3. Comparison with other methods

A comparison with other methods was made as there were many papers studied on human height measurement. Table 2 shows the features comparison among other's methods and proposed method. The object size measurement method is a method that measures foot size to estimate human height and required a reference object which is a coin. For the proposed method and Wang and Chen method, both do not require any reference object. Full body image is captured for Wang and Chen method. The proposed method supports the measurement of the lower part of the knee to estimate the human height as well as a full body.

**Table 2.** Features comparison among other's methods and proposed method.

	Object size measurement method [19]	Wang and Chen Method [15]	Proposed Method
Reference Object	Yes (coin)	No	No
Full Body Captured	No. Only foot	Yes	No. Can be full body or lower part of knee
Type	Image Processing	Image Processing	Augmented Reality
Involve Golden Ratio	Yes	No	Yes

## 5. Conclusion

This paper presented a description of the application developed to estimate human height using mobile phone with VIO. The human height was estimated by full measurement or lower part of knee measurement. The results showed that this method had the potential to be used for accurate human height estimation.

It is recommended that further improvement can be made by applying automatic identification of the ending point for measurements such as the top of the head level, and the lower part of knee measurement.

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