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Optimization of Digital Height and Weight Measuring System Using Ultrasonic Sensor Modules

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ABSTRACT:
In the health sector the importance of high degree accuracy in patient's data cannot be over emphasized most especially the body index. This work presents the design and implementation of an optimized digital height and weight measurement system with integrated audio output using HC-SR04 sensor aimed at improving accessibility and speed of anthropometric data collection. The system combined an enhanced load cell for weight sensing and an ultrasonic distance sensor for height measurement, interfaced to a microcontroller that performs signal conditioning, calibration, and data processing. Measured values are displayed on an LCD and simultaneously converted to speech using a text-to-speech module, producing clear audio feedback of the user's height and weight. Results from laboratory testing show weight accuracy within ±0.1–0.5% of known masses and height accuracy within ±3–10 mm depending on the sensor chosen and mounting stability. The results shows that the optimized digital height and weight measuring system take 12.5s for to process an average measurement while the conventional system takes about 24s for the same measurement. This shows 50% improvement in processing speed.
Keywords: load cell, ultrasonic sensor, microcontroller, LCD, height, weight.

I. INTRODUCTION

The ratio of human height to weight is very vital to their health. Height and weight is very essential indicator to human health. For children, it is important to monitor that they are growing at a healthy rate and for adults it is important to monitor whether or not their height decreases [1]. Previously the height and weight measuring system evaluates body dimensions. At different eras,different mechanical and electromechanical technologies were deployed and in the immediate past stadiometers were used for height and calibrated scale for weight. Stadiometer as a device for measuring standing height consists of a vertical ruler with a sliding horizontal board which is adjusted to rest on the top of the head. Scale is a mechanical or electro-mechanical device used to measure the weight or mass of an object and human. Body Mass Index (BMI) is a calculated ratio of a person's height to weight which provides general information about a person's body composition [2, 3, 4]. Pietrobelli et al. [5] defined body mass index (BMI) as a measure of weight adjusted for height, calculated as:

$$B = \frac{x}{y^2} \quad (1)$$

Where: B= Body Mass Index (BMI), x= body weight in Kg and y=body height in m^2

According to World Health Organization, the body mass index was considered an indicator of body fatness and also a surrogate measure of body fat because it measures excess weight rather than excess fat. BMI relies solely on height and weight as well with access to the proper equipment routinely measured and calculated with reasonable accuracy [6]. Body fatness has been an important psychosocial societal challenge [7]. Body weight is influenced by the interaction of multiple factors. Body Mass Index is used to estimate healthy weight of average people. According to WHO model People with a BMI of 25 to 29.9 are considered overweight, and people with a BMI of 30 or above are considered obese [8]. Research had shown that individuals with a higher BMI are more likely to experience obesity-related health problems [9]. BMI categories are used worldwide for all adults 20 years and above in age. Some researchers established that BMI should serve as the initial screening of overweight and obesity for patients [10, 11].

There are various models of classifying BMI the model used in this work is the WHO model, which value indicates the weight within the ideal range as indicated in table 1 below.

Table 1: BMI classification for adult men and women based on the World Health Organization (WHO) [12].

s/n	Body weight status	BMI
1	Underweight:	< 18.5
2	Normal weight:	18.5–22.9
3	Overweight:	23–24.9
4	Obesity I:	25–29.9
5	Obesity II:	≥ 30

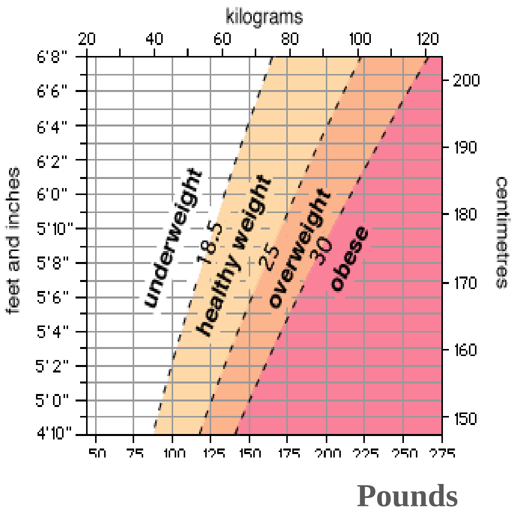

Figure 1: Body Mass Index for Adults

The Height and weight measuring systems with only digital display have been in existence in the recent times with low accuracy and low efficiency as a result most of them could not be relied upon. The earlier versions of height and weight display system did not incorporate audio output, but with recent advancement in technology it has become imperative for the construction of this system knowing that with audio output the process of measuring height and weight can be done effectively and much more efficiently. The resulting effect of the audio output makes it easier to use for those with sight impairment and that find it difficult to read. It also mitigates the challenges in the health care industry or other industries which uses the measuring system for proper data records and accuracy [13]. Measurement of height parameters have been a recurring activity in sciences, engineering, surveying, architecture, building construction technologies etc, the measured parameter include; Human, various material or substance (mainly solid) heights. In many hospitals, schools, fitness centers, and public health programs, the measurement of height and weight is still carried out manually using traditional instruments such as mechanical scales and stadiometers. These manual methods are often time-consuming, prone to human errors and require the presence of trained personnel to read and interpret the measurements correctly. Ultrasonic sensors act as proximity sensors in automated obstacle detection; they are also less susceptible to interference from smoke, gases, and airborne particles. Beyond measuring body heights they could be deployed for various other uses [14].

Furthermore, individuals with visual impairments or literacy challenges find it difficult or impossible to read the measurement values displayed on digital or analog scales. This creates accessibility barriers and reduces independence for such users. Another major issue is the lack of integration between height and weight measurement devices, resulting in separate readings that must be manually recorded and calculated to determine parameters like Body Mass Index (BMI) [15]. This increases the chances of data entry errors and inefficiency in record-keeping. Therefore, there is a need for a digital height and weight measurement system that can automatically capture and process measurements accurately and efficiently, while also providing audio output to announce results to users. Such a system need an enhanced accuracy, accessibility, and ease of use for both health professionals and individuals [15].

The historical development of height and weight measurement systems, though not a singular invention, has evolved through various technological advancements. From simple, physical measurement tools to modern digital systems with audio feedback, the goal has been to efficiently and accurately obtain height and weight data measuring instruments [13]. According to [16], DilaTaufik made the weight and height measurement system display sound output and LCD but with low accuracy. Therefore, in the design of this measuring system the height and weight was developed whose measurement results included ideal, fat and thin information, which is presented in the form of writing on the LCD as well as audio output, thus, height and weight measurement has become more accessible, faster, practical, accurate and complete with ideal weight information[17].

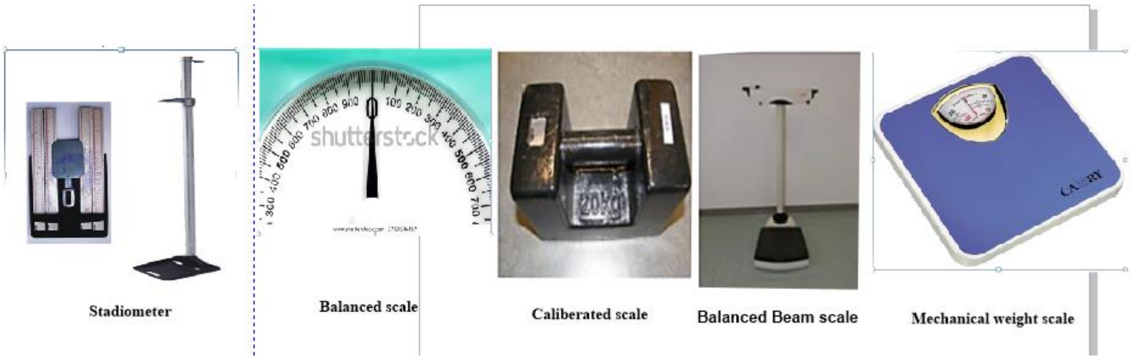

Figure 2: Conventional height and Weight measuring Instruments

Previously various measuring instrument were usedto evaluate body dimensions, for human height the following were used at different times: **Height Board:** Often used for younger children; they typically have a horizontal measuring tray so children can be measured while lying down. **Anthropometer:** A segmented rod used in physical anthropology and clinical field tests to measure various body dimensions.**Laser Sensors / Rangefinders:** Used in science museums or amusement parks to automatically measure height without physical contact.**Tape Measure:** Commonly used at-home with a flat object (like a hardcover book) to mark the head level against a wall. And **Stadiometer:** It was the standard instrument for measuring a person's standing height. It consists of a vertical ruler and a sliding horizontal headpiece that is adjusted to rest on top of the head for precise measurement [17].

While for the human weight the followingtechnologieswere used: Beam balance Scales(~2400 BCE): The earliest weighing instrument was the beam balance, consisting of a central pivot (fulcrum) with two pans hanging from either side. An item (or person) was placed in one pan, and standard stones of known mass were placed in the other until the beam was level. The earliest surviving examples—uniform stone cubes and balance beams—date back to the Indus Valley Civilization (modern-day Pakistan).Steelyard Scales(Roman Times, ~200 BCE): Used unequal lever arms, this instrument featured a shorter arm for the load and a longer arm with a single sliding counterweight. By sliding the counterweight along the notched beam until it balanced, a merchant or official could measure heavy objects without carrying an entire collection of stone weights.Spring Scales(1770): Invented by British instrument maker Richard Salter, this was the first scale that did not rely on comparison. Operating on Hooke's Law, it utilized a coiled spring that stretched when a load was applied, pointing directly to a weight reading on a dial.Mechanical Bathroom Scales (Mid-19th to 20th Century): As measuring one's own body weight became common, large lever-and-dial systems were adapted into personal weighing scales.Electronic Load Cells (Late 20th Century to Present): Modern personal scales shifted entirely from mechanics to electronics. They employ strain gauges—sensors that convert physical pressure into electrical signals—to accurately read body weight.[1].

Each of these earlier technologies have their deficiencies which results to some level of inaccuracy hence technological innovations brought aboutdigital height and weight measuring systems utilize sensors and load cells for automated, data collection and immediate BMI calculation. This work tends to incorperate HC-SR04 ultrasonic sensor modules for automated, improved accurate data collection and immediate BMI calculation it will also incorporateIoT for wireless tracking and a storage system. These digital, integrated solutions improve efficiency compared to convention height and weight measurement system and previous techniques.

A height and weight measuring system with audio output can be designed using HC-SR04 ultrasonic sensor module to replace the IR-sensor, for improved efficiency for height and an enhanced load cell for weight, with a microcontroller to process the data and generate voice output. The system can be further enhanced with features like a LCD display and a push button for user input[4],[5].

Most of the measurement systems contain three main functional elements such as primary sensing element, variable conversion element and data presentation element. Variable conversion element consist of variable manipulation element, data transmission element and data storage with playback element. Sensing element is the element in a measurement system that takes information about the condition being measured and transforms it into a more suitable form. Transducer is defined as a device which converts a physical quantity into an electrical quantity. Thesensor act as primary sensingelement of the transducer [17]. Mediatoget [17] stated that the primary sensing element of a measurement system is detecting quantity to be measured (measurand) as a detector through the primary sensor which gives the output in a different analogous form. This output is then converted into an electrical signal by a transducer which converts energy from one form to another suitable form. The schematic diagram of functional elements of the measuring instrument are as shown in Fig. 3

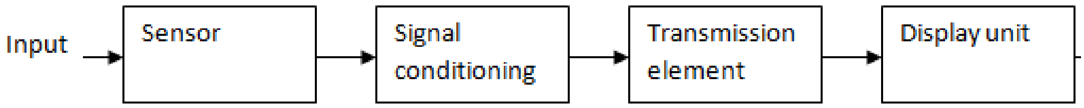

Figure 3: Block diagram of the conventional Measuring equipment

Sanoner [18] studied on distance measuring device for acoustically measuring distance. The researcher used the device to determine the distance of an object through the transmitting and receiving of an acoustic signal. The velocity of acoustic signal and distance travel from transmitting the acoustic signal were compared with output generated. Darmon et al. [5] worked on ultrasonic sensor based portable height measuring device. The microcontroller was used to send a trigger signal to the ultrasonic sensors in order to send bursts of ultrasound that reflect off the floor and return to the receiver. The time interval between the trigger and echo signal is the travel time of the ultrasound wave from sensors to the floor and back. The microprocessor then measured the time interval and used the speed of ultrasound to compute the round-trip distance. Michel and Sylvain, [17] performed experiment on portable human height measuring device. The device was consists of an ultrasonic distance sensor, a controller and several output units. It was used to convert the person's height to the proper measuring unit and communicated to the person through the output unit.

II. MATERIAL AND METHODS

a) Materials

The materials used for the design of height and weight measuring system under study are listed below.

i) **Load Cell:** The load cell uses the principle of strain gauge to convert a force such as tension, compression, pressure, or torque into a signal that can be measured. As the force applied to the load cell increases, the signal changes proportionally.

ii) **Amplifier (HX711):** this is an amplifier circuit that allows you to read load cells to measure weights. The wiring is done between the microcontroller and the load cell. The Hx711 communicates with the microcontroller using two-wire interface.

iii) **Arduino Mega (Microcontroller):** This is an 8-bit microcontroller board based on Atmega2560. It is a programmable chip that processes data from the ultrasonic sensor and load cells and displays them on the screen.

iv) **TFT Touch Screen: this is a 3.5-inch touch screen based on ili9486 driver**. It is interfaced to a microcontroller to enable the user to see the processes and user data on the display.

v) **DF Player:** It is a mini MP3 player for Arduino microcontrollers. It is a low cost MP3 module with a simplified output directly to the speaker. Mp3 files are stored in an SD card inserted on the DFplayer and then played using instructions from the microcontroller. The speaker can be connected directly to the DFplayer module or via an amplifier circuit.

vi) **HC-SR04 Ultrasonic Sensor**: This sensor measures the distance of an object using the speed of sound. It does this by transmitting the sound pulse via its trigger pin. As the sound is reflected by the object, it is received by its receiver unit. The echo pin is used to detect when the reflected sound has been received. The microcontroller can be used to calculate the time taken by the reflected sound to get to the receiver.

(vii)**Liquid Crystal Display(LCD)**

Liquid crystal display is an electronic display device that operates by applying a varying electric voltage to a layer of liquid crystal, thereby inducing changes in its optical properties.

(viii)Accessories: Accessories are peripheral or add-on to the system that provides functions not available on the major components of the equipment such as Light emitting diode (LED), Zener diode, Resistors, Capacitor, Switch, Variable resistor, Printed Circuit Board (PCB), Adapter, Regulator, Pin socket, Jack plug, Wires and Software.

b) **Methodology**

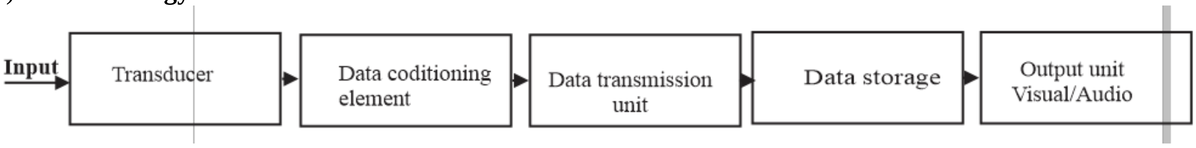

Figure 4: Block diagram of the proposed optimized Digital height and weight system

Load cell is a transducer that receives an input (weight) as a change in forces and converts it to an output of a change in length. This transduction process is as a result of another sensor known as strain gauge, the resistors that changes its resistance when bent. The change in length is a measure of the change in weight.
Change in Forces (Input) → Change in Length (Output) → Change in Strain gauge's Strain
Electrical Strain is directly to proportional to the Mechanical Strain as given in equation 2 to 8.

$$M_s = \frac{l_c}{lo} \quad (2)$$

Were Ms= Mechanical strain, Lc= Change in length, Lo= Original length

$$E_s = \frac{R_c}{R_o} \quad (3)$$

Es =Electrical Strain; Rc=Change in resistance; Ro=Original Resistance

Compression in Load Cells

Electronic compression in load cell was adopted, an electro-mechanical weight sensor which is used to measure force or weight. It has a simple yet effective design which relies upon the well-known transference between an applied force, material deformation and the flow of electricity. They are incredibly versatile devices that offer accurate and robust performance across a diverse range of applications. The gravitational force on the body being measured when is transferred to an elastic element produces a measurable deflection.
The change in resistance of a strain gauge of resistance R when subject to a strain ε is given by equation 4.
Change in resistance,

$$e = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) E$$

(4)

$$e = \frac{1}{4} * K(\varepsilon 1 - \varepsilon 2 + \varepsilon 3 - \varepsilon 4)E$$

(5)

Where K= guage factor and

$$\frac{\Delta R}{R} = K\varepsilon (6)$$

$$e = \frac{1}{4} * K * \varepsilon * E$$

(7)

For sensitivity and accuracy of the load cells
Sensitivity (S) of load cells is the reciprocal of the calibration factor (c)

$$S = \frac{1}{c}$$

(8)

$$= \frac{\lambda(1+v)E}{2A\gamma}$$

(9)

Where λ= guage factor; E= Modulus of elasticity; V= poisson ratio
The output voltage= e A= cross section area of the beam
The range of sensitivity of a beam type load cell also depends on the shape of the cross section of the beam as well as the calibration factor at the point of application of the load

Vibrating Wire Sensor

This enhanced load cell consists of a wire that is kept vibrating at its resonant frequency by a variable-frequency oscillator. The resonant frequency of a wire under tension is given by equation 10. The measurement of the output frequency of the oscillator allows the force applied to the wire to be calculated, this assist the load cell.

$$F = \frac{1}{L}\sqrt{\left(\frac{M}{T}\right)} \quad (10)$$

(iii) **Interaction model of HC-SR04 Ultrasonic Sensor**

$$\phi(M,t) = f_{field}(M,t) * v_o(t)$$

(11)

Where $\phi(M,t)$ are the simulated field and M and t are computed for the propagation time

$$\phi(M,t) = \int \frac{v_o\left(t - {}^{r}/_{c_o}\right)}{2\pi r} ds$$

(12)

Where $\phi(M,t)$ are the potential of the velocity of the velocity at the point M at time t; r= distance between source and the point (M); c_o= wave speed in the medium.

$$v(M,t) = \nabla\phi(M,t)$$

(13)

Emitter field impulse response
$\mathbf{h_e}(M,t)$= the potential of the velocity produced at the point M by the transducer subjected to a particle speed d(t)
The radiated field can be modeled by an impulse reponse filter

$$\mathbf{h_e}(M,t)$$

(14)

Hence the emitted potential becomes

$$\phi(M,t) = \int \frac{v_o\left(t - {}^{r}/_{c_o}\right)}{2\pi r} ds = v_o(t) * \mathbf{h_e}(M,t) \quad (15)$$

$$\mathbf{h_e}(M,t) = \int \frac{v_o\left(t - {}^{r}/_{c_o}\right)}{2\pi r} ds \quad (16)$$

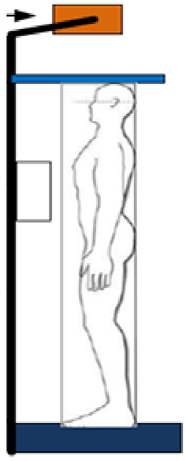

Figure 5: Automatic height and weight measuring system

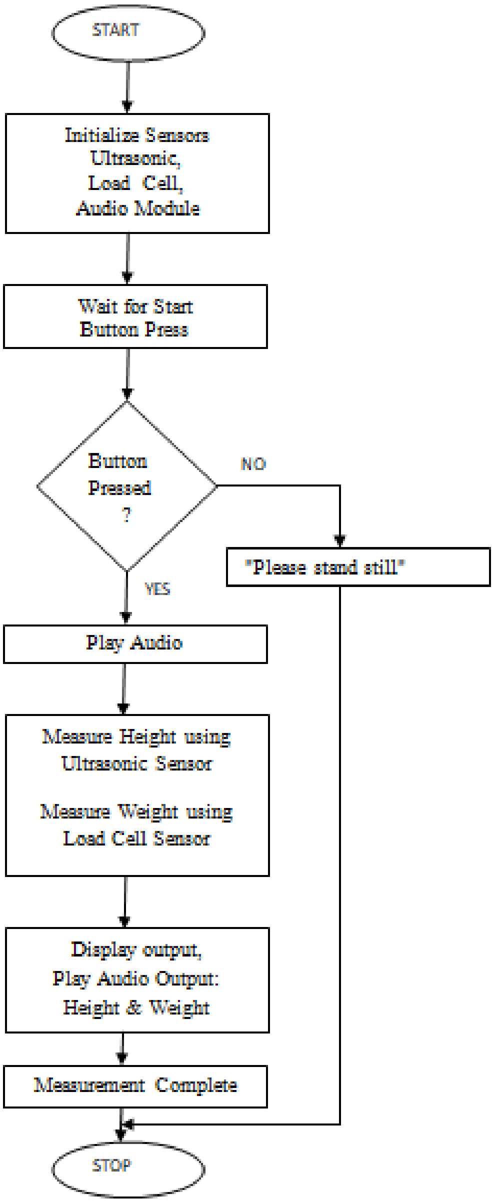

Figure 6: Flow chart of a height and weight measuring system

III. RESULTS AND DISCUSSIONS

To validate the accuracy as well as the improvement on processing time on the optimized digital height and weight measuring system using HC-SR04 ultrasonic sensor over the conventional system, measurements were carried out using two systems to compare the output of the optimized. For the height the Height infrared sensor meter (HS) and the stadiometers (STM) standard height meter were used to compare the optimized digital height and weight measuring system using HC-SR04 ultrasonic sensor (DHWS). Similarly for the weight, the bathroom weighing scale (**BWS**) which is the conventional weight scale, the high precision digital scale (**HPDS**) which is the standard scaleand Digital height and weight measuring system (**DHWS**) with enhanced load cells which is the improved system. A simulation was carried out to ascertain the performance of the IR-sensor and ultrasonic sensor. The data (weight and height) of five different persons were measured and the following results were obtained. The results are as shown below.

Table 1: Comparing the output weights of the BWS, HPDS and DHWS

BWS (KG) (Conventional)	DHWS (KG) (Improved load cell)	HPDS(KG) (Standard)
70.06	70.18	70.18
68.25	68.39	68.39
77.04	78.10	78.11
81.53	81.62	81.62
75.35	75.71	75.71

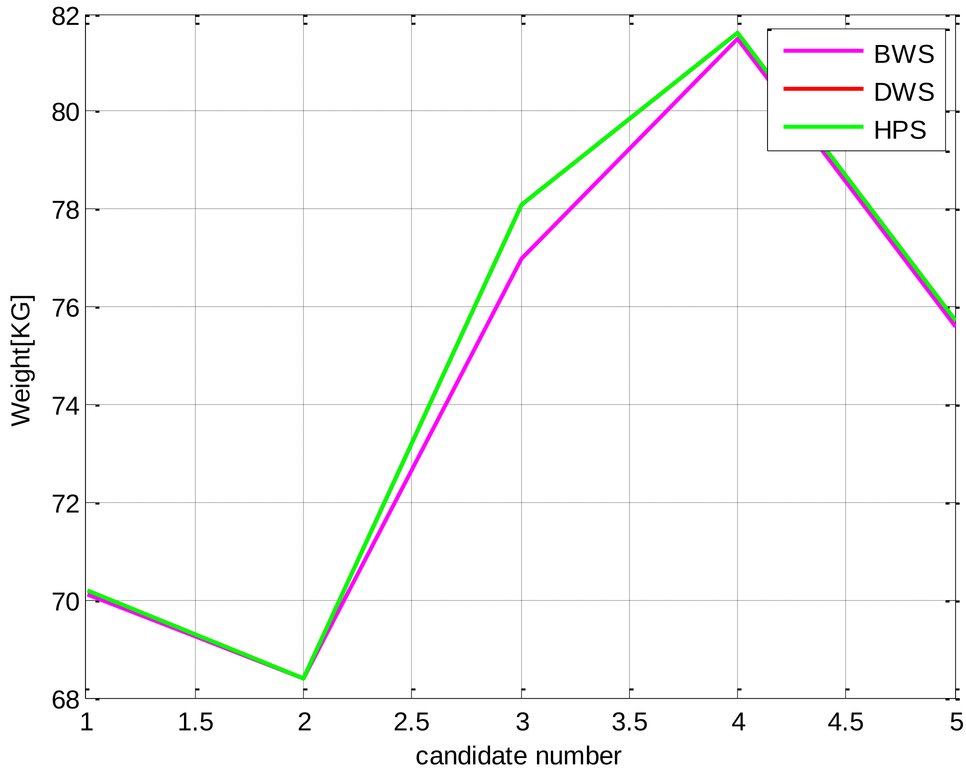

Figure 7: Weight measurements using BWS, DHWS and HPDS

Table 1 and figure 7 show weight measurement using three different measuring systems the BWS (conventional), DHWS(improved)and HPDS (standard). It was observed that the outputs of DHWS were equal to HPDS which is the standard system.

Both the DHWS(with enhanced load cells system) and HPDS (the standard system) and BWS (conventional) measures and produces output in two decimal places. The output of DHWS and HPDS are in consonant showing that the optimized DHWShashigh degree of accuracy when compared to BWS (conventional). The results show that the output of digital height and weight measuring system (DHWS) is equal to that of the high precision digital scale (HPDS).

For the height measurement the stadiometers (STM) standard height meter, Height IR sensor height measuring system (HS) and digital height and weight measuring system (DHWS) were deployed

Table 2: Comparing the output of the STM (standard), HS (conventional) and DHWS (Improved).

STM (M) (Standard)	HS (M) (conventional)	DHWS (Improved HC-SR04)
1.81	1.78	1.81
1.72	1.64	1.71
1.84	1.82	1.84
1.41	1.38	1.41
1.62	1.58	1.62

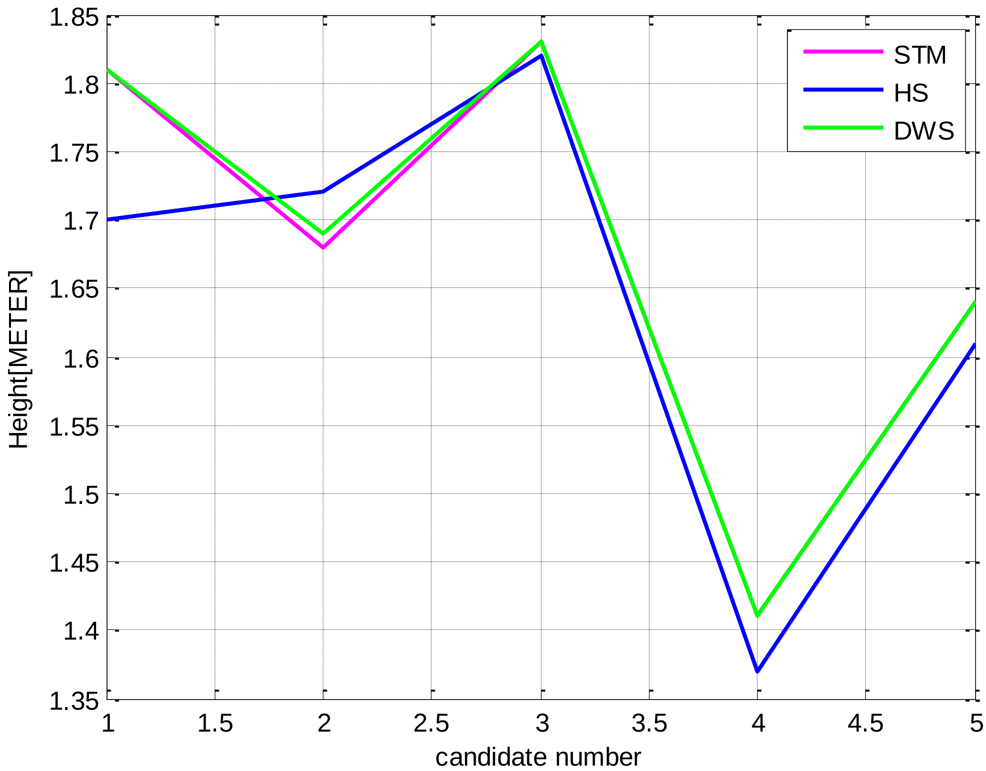

Figure 8: Height measurements using STM, HS and DHWS

Table 2 and figure 8 shows measurement outputs using STM, HS and DHWS for five different individuals. The output shows that the DHWS and STM are equal signifying the accuracy of the

DHWS over the HM which is the conventional system.
It could be observed that DHWS has a higher precision as it produces its outputs in two decimal places. The height accuracy is within ±3–10 mm depending on the sensor chosen. The results showed that the digital height and weight measuring system (DHWS) improved is equal to that of the stadiometer (STM).

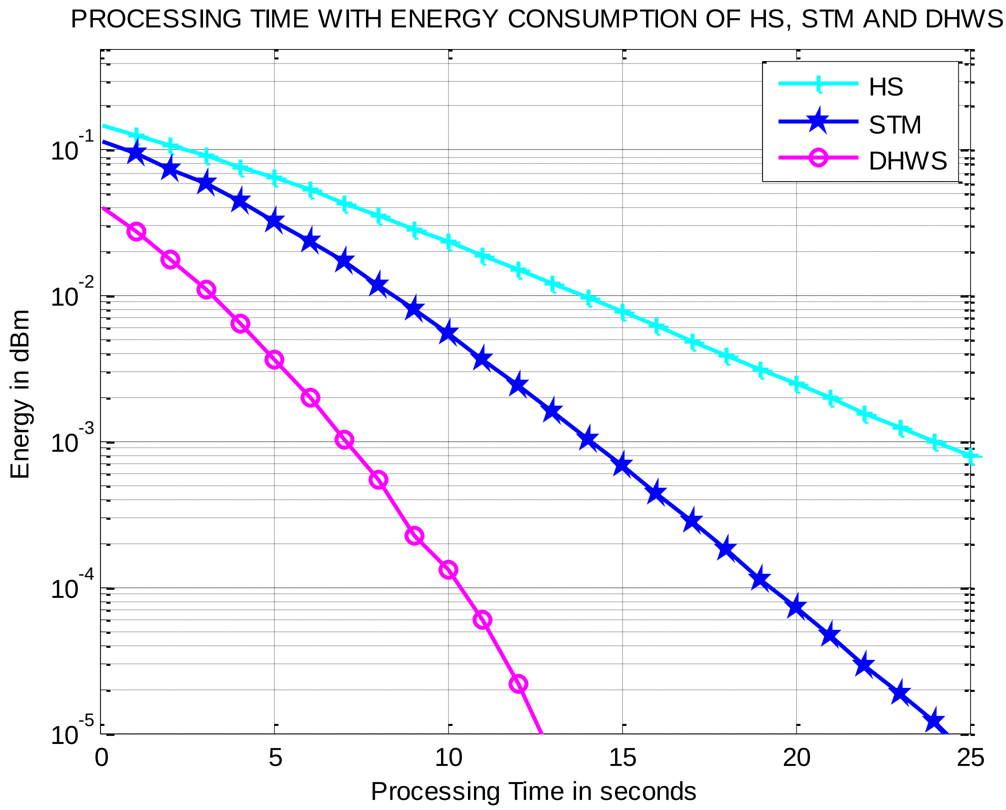

Figure 9: Processing time of HS, STM and DHWS

Figure 9 shows the processing time and the energy expended in an average measurement. It could be observed that it take 12.5s for DHWS to process an average measurement while it takes about 24s for STM to perform the same task and take much higher time for the HS to carry out the same task.
On the energy consumption, it could be observed that the DHWS consumes the least energy followed by the STM when compared with the three systems This shows that the digital height and weight measuring system (DHWS) has a higher degree of accuracy, higher processing speed with lower energy consumption. Hence it is very reliable for both height and weight measurements.

IV. CONCLUSION

The height and weight measuring system with audio feedback has proved to be a better system when compared with the existing height and weight measuring system. This is because it posses higher degree of accuracy, higher processing speed with lower energy consumption. Also, the feature of audio output gives it advantage or edge over otherexisting heights and weights measuring systems. This system has applications in hospitals, schools, fitness centers, and for personal health monitoring at homes.

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