Development of a Digital Body Mass Index (BMI) measuring device for low-resource settings

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Abstract

The global burden of nutrition-related diseases majorly: diabetes, obesity, and cardiovascular diseases have been on a geometrical increase. One way of knowing the risk factor of these is by accurately measuring the Body Mass Index (BMI) of an individual. The design of a digital BMI device, which measures and displays a subject's BMI, was executed. Materials used include an ultrasonic sensor for height measurement, load cells for weight measurement and an Arduino UNO microprocessor which receives the output from measuring devices, calculates the BMI and sends it for display on a liquid crystal display (LCD) screen. This device depicts a low-cost solution for accurate measurement of a subject's BMI. The results of the tests performed on the data obtained from the anthropometric measurements of eight subjects using the digital BMI device, a stadiometer and a weighing scale proved the equipment is reliable in BMI measurement, with 0.32 root mean square error (RMSE) compared to the 1.19 RMSE gotten from the BMI measurement calculated from a wall-mounted height measurement meter rule against the stadiometer measurement.

Keywords: *BMI, Arduino, Anthropometric measurement, Low-resource, Nutritional Status.*

1. INTRODUCTION

Body Mass Index (BMI), formerly called Quetelet Index, is defined as a measure for nutritional status in adults. It is the ratio of a person's weight (measured in kilogram) to the square of the person's height measured in metres (Flegal *et al.*, 2012; Gallagher *et al.*, 1996; WHO, 2000). Mathematically, BMI can be represented as shown in equation 1:

$$\text{Body Mass Index (BMI)} = \frac{\text{Weight (in kg)}}{\text{Height (in meters) squared}} \tag{1}$$

BMI is measured in kg/m^2. It is one of the methods or techniques of measuring body composition or adiposity of body content and therefore, makes it a veritable tool in indicating the obesity status of human beings and in the long run, could contribute to stemming the surge of obesity and other adipose-related diseases (Gallagher *et al*.., 1996). Excess body weight or obesity has been affirmed as an essential risk factor for mortality and morbidity from cardiovascular diseases, cancers, diabetes mellitus, and musculoskeletal disorders, causing approximately 3 million deaths every year worldwide (Flegal *et al.*, 2013; Garrouste-Orgeas *et al.*, 2004; Prentice and Jebb, 2001; WHO 2000; Wolk *et al.*, 2003). It is therefore, pertinent to accurately measure the BMI of an individual to be informed about their nutritional status. This would enable such to take precautions in order to combat the risk of obesity which may be associated with cardiac hypertrophy, and may impose adverse effects on coronary flow reserve and eventually, increase the likelihood of myocardial ischemia in human beings (Alpert, 2001).

Doctors are being saddled with the responsibility of diagnosing individuals with different methods to affirm their weight status. However, some of these diagnostic procedures are expensive, immobile, and hazardous due to radiation emission. The two most common categories of classifying body fat measurement are "field" and "reference" methods (Harvard School of Public Health, 2010) though the latter seems to be a confirmation for the former. Examples of *field methods* measurement techniques are Body Mass Index (BMI), Waist circumference, Waist-to-hip ratio, Skinfold thicknesses, and bioelectrical impedance. These are usually employed in clinics and community settings, as well as in extensive research studies, while *reference methods* measurement techniques are widely used in research studies to confirm or validate the accuracy of acquired data from *field methods*. R*eference methods* include the use of Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI), Dual Energy X-ray absorptiometry (DEXA), Bioelectric Impedance Analysis (BIA), Underwater Weighing (Densitometry), Dilution Method, Air-Displacement Plethysmography, among others (Harvard School of Public Health, 2010); some of these methods cannot be used for children and pregnant women due to hazards like radiation emission.

The unstandardized measuring procedure of the waist circumference method makes it less accurate in measuring body fat of individuals with a BMI of 35 (Obese II class) or higher (Obese III). The Bioelectric impedance Analysis (BIA) method functions by sending a small, undetectable electric current through the body and then determines body fat by measuring the resistance, based on the inference that current faces a more significant resistance when passing through a fatter body than when passing through a body with little or no fat. This method has the disadvantage of being difficult to calibrate and the influence of dehydration in its accuracy. Also, the interpretation of Waist-to-Hip ratio is complicated, because increased Waist-to-Hip ratio can be caused by increased abdominal fat or decrease in lean muscle mass around the hips. The downside of other options make researchers favour the use of BMI calculation rather than the other available choices as follows: Densitometry requires submerging people into water; Skinfold thickness is tough to measure in people with BMI of 35 or higher; Dilution method is affected by the ratio of body water to fat-free mass during illness, dehydration, or weight loss, thereby reducing the reliability and accuracy of the technique; Air-Displacement Plethysmography's is very expensive; Dual Energy X-ray Absorptiometry (DEXA) produces small doses of radiation and does not measure some specific body fat compartments, such as abdominal fat and subcutaneous fat accurately, while the more reliable and accurate Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI) equipment are expensive to purchase, maintain and are far from being portable (Harvard School of Public Health, 2010).

The weight and height square ratio calculation known as BMI method has therefore, been favoured by clinicians, and different devices have been produced for this measuring technique. AKAS body mass index apparatus uses ultrasonic and load sensors to measure the height (in metres) and weight (in kilograms), respectively *(QUICKLAB, 2010)*. The jamb, located at the top, houses the ultrasonic sensors and sends ultrasound waves through the transmitter, and when it meets an obstacle, it bounces back; the receiver measures the time and the distance it takes to get back to the jamb. Then, the distance measured is subtracted from the height of the stand and this gives the total height of an individual in meters. A load cell uses a precise sensor to measure weight in kilograms, and both the results of height and weight alongside the calculated BMI are displayed on the screen. The AKAS system does more than BMI measurement: it shows seven parameters in two (2) minutes namely: height, weight, BMI, Non-Invasive Blood Pressure (NIBP) in automatic and manual modes, temperature, blood oxygen saturation (SpO2) and pulse rate adding to its costs. At a price equivalent to NGN 982,693.15 *(QUICKLAB, 2010)* during research period, it is quite expensive for personal use at home or in public places in low-resource settings like Nigeria.

The Swastik BMI System and LIXO BMI device also use the same BMI method as the AKAS system, but come at a price of N 224,613.70 and N 505,386.30, respectively *(IndiaMART, 2008a & 2008b)*. These reported devices show that the application of ultrasonic sensors and load cells are appropriate to develop a digital BMI measuring device. Therefore, it was the aim of this study to develop a digital body mass measuring device for low-resource settings that would be cheap, user-friendly and easy to operate so as to alert users of their nutritional status (underweight, normal, overweight or obese), help to inform lifestyle changes, and ensure individuals can promptly contact their physicians if need be.

2. DATA AND METHODS

The overall circuit diagram for the BMI design is shown in Figure 1.

2.1 Hardware Implementation

The main hardware components in the system include load cells, HC-SR04 ultrasonic sensors, arduino UNO (ATMEGA) microcontroller, liquid crystal display (LCD), light emitting diodes (LEDs), resistors, capacitors, an LM7085 voltage regulator, crystal oscillator and a real-time clock.

Figure 2 displays the flow of how the various components are linked up in the transfer of data. The system consists of the ultrasonic sensor, load cells, sensor amplifier, and the arduino UNO (ATMEGA) microcontroller. The load cell reads the weight of the subject and sends the collected data into the sensor amplifier to amplify the voltage to be transmitted into the microcontroller, while the ultrasonic sensor reads and collects the data from the analog and sends the combined data to the microcontroller; thereafter the BMI status is displayed on the screen. The microcontroller controls the proximity sensor; its receiving end sends data to the (6 V output of the) proximity sensor and its transmitting end receives data from the proximity sensor. It then manipulates the data with the help of the program code coming from the proximity sensor that is displayed on the screen as the height measurement.

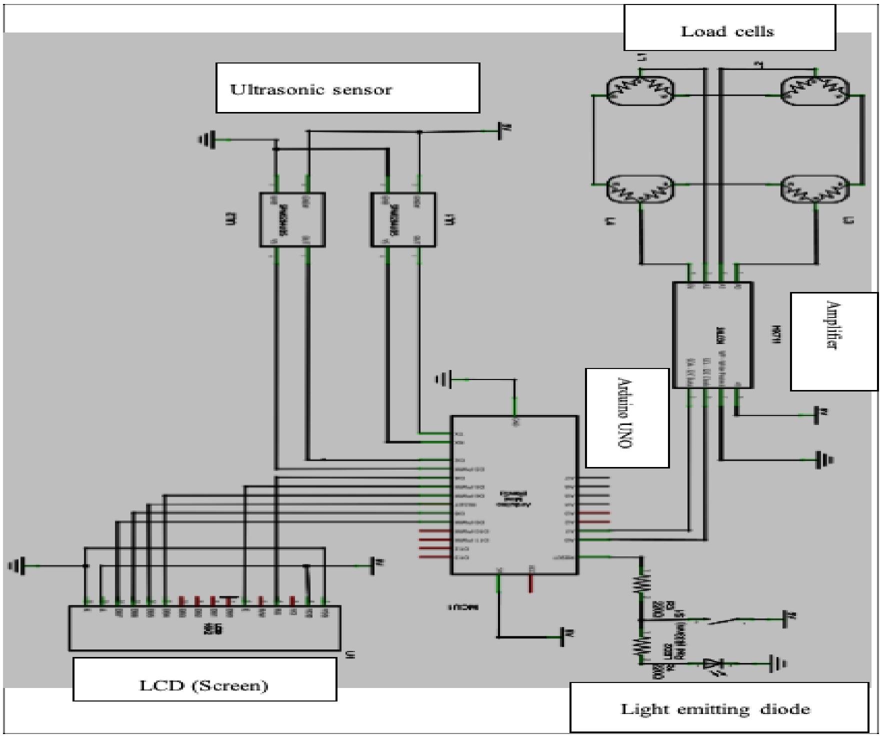

Figure 1: *BMI Measuring Device Circuit diagram.*

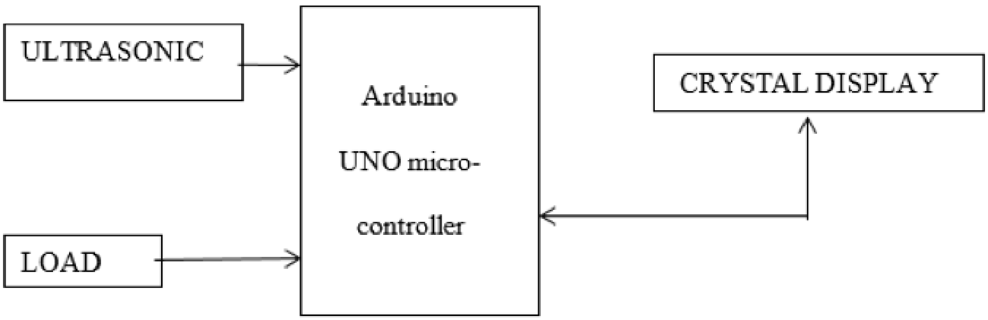

Figure 6: *BMI Measuring Device Block diagram.*

Figure 3 shows the proposed pictorial representation of the BMI device. The stand entails a flat scale for the support of the subject to be weighed. The height of the column from the top surface is eight feet (8ft), i.e., the maximum height the machine can measure is 200 centimetres or 2 meters. The proximity sensor is located at the centre of the column to determine the height of the subject alongside the microcontroller, which is situated in the middle of the column. The height from the base of the load cell to the surface of the load cell is 6 inches or 15 centimetres and supported by some springs. The springs are located on the bottom of the column. A footprint is indicated on the flat scale for the subject to place their feet in the right and appropriate manner for accurate and proper reading of the weight.

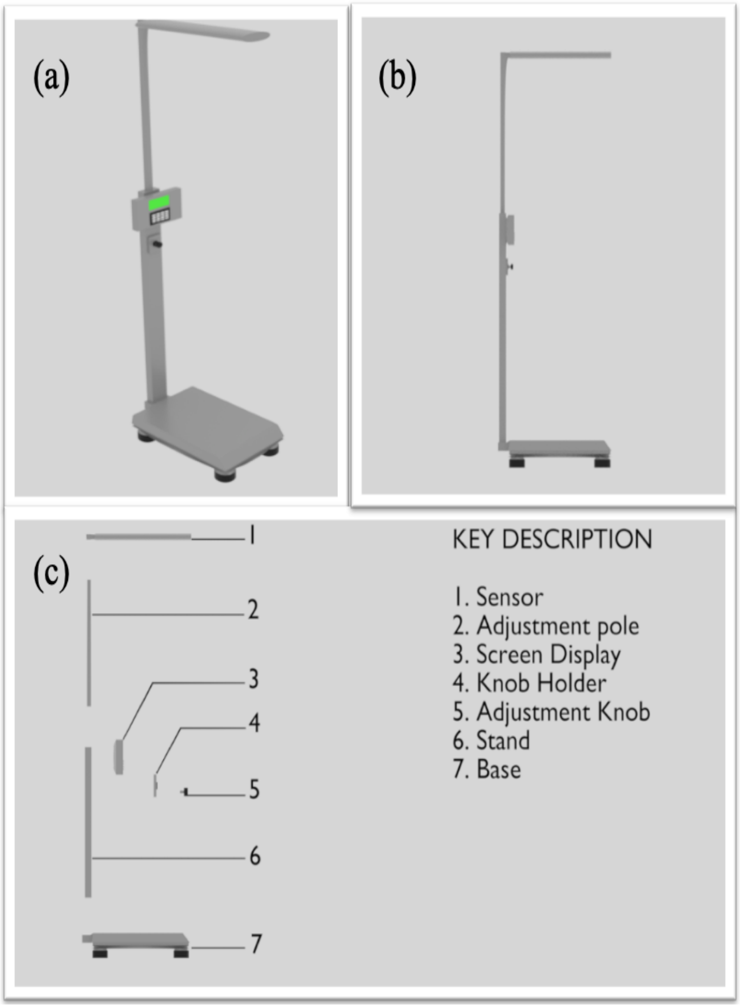

Figure 3: *(a) Pictorial representation of the proposed BMI device using BLENDER software. (b) Side view of the BMI device using BLENDER software. (c) Exploded view of the BMI device using BLENDER software.*

2.2 Software Implementation

The program code used was C language and was tested with the Arduino UNO after which it was implemented to the hardware to test its functionality. When the whole installation was implemented, a test to check for accuracy, speed and reliability was carried out. The algorithm design was the main focus of the software development for the microcontroller, which uses the Arduino Uno microcontroller board based on Atmega328 with fourteen (14) digital input and output pins and powered by a 5 V battery. The algorithm for the microcontroller was designed to calculate the BMI from the measurement of the weight using the load cell and the height using the ultrasonic sensor, and in turn displays the weight status of the individual as normal, underweight, overweight or obese corresponding to the body mass index (BMI) of the user.

Figure 4 illustrates the algorithm of BMI calculations for four (4) different bodyweight groups: underweight (BMI < 18.5), normal (18.5 ≤ BMI < 25), overweight (25 ≤ BMI < 30) and obese (BMI ≥ 30) based on the guideline for nutritional status classification for adolescents and adults (WHO, 2000):

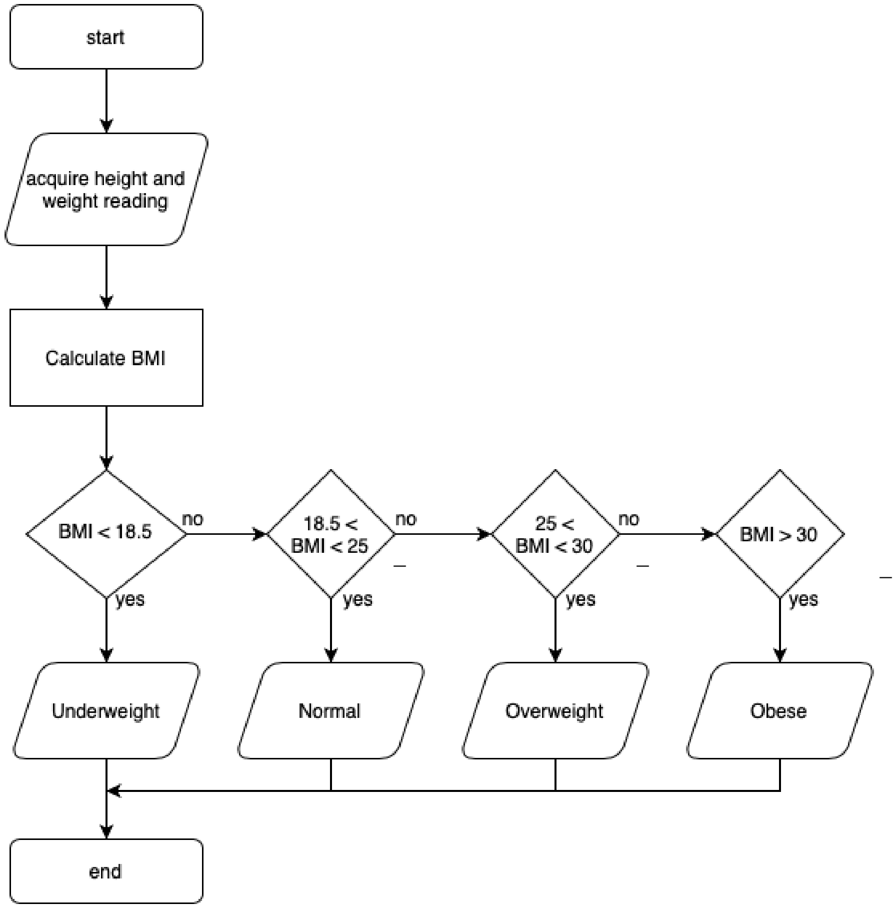

Figure 7: *Algorithm of the BMI Calculation for four (4) bodyweight group.*

Three (3) sets of experiments were conducted to determine the accuracy of the developed device using a stadiometer and a weighing scale as the control. The performance of the device was tested against the calculated BMI gotten from the values of a wall-mounted height meter and a weighing scale. This reliability test was carried out by comparing the BMI from eight subjects (four males and four females) using a stadiometer, wall-mounted meter, and the designed digital device.

3. RESULTS AND DISCUSSIONS

3.1 Device operation

The load cells coupled with the ultrasonic sensor sends the analog data (weight and height) into the microcontroller, and the program code in the microcontroller sends the received data from the analog to digital to the display unit with the help of a digital signal converter. The data obtained is then processed, and the Arduino Uno microcontroller then uses these values to calculate the BMI. Finally, the nutritional status of the user would be displayed on the LCD screen based on the value of the calculated BMI as shown in figure 5.

Figure 8: *Picture of the LCD displaying the nutritional status of an individual during testing.*

3.3 Anthropometric measurement reliability test

Height and weight measurements of four male and four female subjects were obtained using a stadiometer and weighing scale, respectively. By using equation 1, Body Mass Index (BMI) values were generated by merely dividing the weight of an individual by the square of its height for each subject. This served as the control for the comparison of the digital device, and the commonplace wall-mounted meter for height measurement in many low-income settings. Then the developed BMI measuring device was used to acquire the BMI data of the same subjects, and the wall-mounted meter was used to acquire the height data of the same subjects for subsequent BMI calculation. The obtained data and the Root Mean Square Error (RMSE) of the wall-mounted meter readings', calculated BMI and the BMI of the digital ultrasonic device were compared, as shown in Table 1 and 2, respectively.

Table 2: *The BMI reading of the constructed digital device versus calculated BMI from manual wall reading of height and BMI calculated from height using a stadiometer as control*

Subjects	**Stadiometer and ordinary weighing scale**			**Wall reading and ordinary weighing scale**			**Digital measurement**		
	Height (X1)	**Weight (Y1)**	**BMI (B1)**	**Height (X2)**	**Weight (Y2)**	**BMI (B2)**	**Height (X3)**	**Weight (Y3)**	**BMI (B3)**
1	1.77	70	22.34	1.83	70	20.90	1.76	70.2	22.66
2	1.75	60	19.59	1.77	60	19.15	1.75	59.95	19.58
3	1.805	81	24.86	1.85	81	23.67	1.8	80.2	24.75
4	1.65	80	29.38	1.7	80	27.68	1.62	78	29.72
5	1.59	56	22.15	1.6	56	21.87	1.56	54	22.19
6	1.48	70	31.96	1.5	70	31.11	1.47	69.7	32.26
7	1.71	71	24.28	1.75	71	23.18	1.7	70	24.22
8	1.65	78	28.65	1.7	78	26.99	1.62	77	29.34

Table 3: *The RMSE of BMI reading by various methods*

Subjects	Absolute difference (B1 -B2)	Absolute difference (B1 -B3)	$(B1-B2)^2$	$(B1-B3)^2$
1	1.44	(0.32)	2.08	0.10
2	0.44	0.02	0.19	0.00
3	1.19	0.11	1.43	0.01
4	1.70	(0.34)	2.90	0.11
5	0.28	(0.04)	0.08	0.00
6	0.85	(0.30)	0.72	0.09
7	1.10	0.06	1.20	0.00
8	1.66	(0.69)	2.76	0.48
		Total	11.35	0.80
		Mean	1.42	0.10
		RMSE	**1.19**	**0.32**

Results from the reliability test showed that there is an agreement between the calculated BMI result from the stadiometer height reading (the control) and the designed digital BMI measuring device, which is ascertained from the low root mean square error (RMSE) of 0.32 when both measurements of the same subjects were compared. This result is more reliable than the BMI result obtained from the wall-mounted height-measuring meter with an RMSE value of 1.19. This difference could be associated to error due to parallax in measurement, the limitation of the ruler calibration, and/or the human error when taking the readings. Five subjects' nutritional status were classified "normal" by the digital BMI device, two subjects were classified as "overweight", and one subject was classified as "obese". These classifications agree with the calculated BMI using a stadiometer and weighing device.

As shown in Table 2, different anthropometric techniques had been used to verify the weight of eight individuals (four males and four females) in the University of Ilorin, Nigeria. It was observed that females (subjects 5-8) had higher BMI values than males (subjects 1-4), possibly because of sedentary life choice, leptin concentration, ethnicity and body perception as opined by Chukwuonye *et al.* (2015) and Okafor *et al.* (2014).

The findings of this study support the view of widespread obesity amonsgst African woman as the subjects with higher BMIs in this study are women. This is also observed in women from Eastern Mediterranea and South East Asia, where prevalence of obesity amongst women ratio has exponentially doubled that of men in these regions (Amira *et al.*, 2011; WHO, 2014b).

The results of Kuan *et al.*(2011) diasgree with those btained in this study, mainly due to the cultural differences between Nigerians and Malaysians. Whereas Malaysian women maintain certain diets and take in vitamins towards achieving a certain 'ideal' body figure, many Nigeria females prefer excessive body fat due to the perception that chubbier people are well-nourished in comparison to slimmer ones (Okafor *et al.*, 2014).

Another factor that might contribute to higher BMI values in females is Leptin concentration. According to Hellstroèm *et al.*. (2000), Leptin is a hormone that helps in regulating the body fat mass. It is highly secreted in women and thereby increases the accumulation of adipose tissues in ladies. Okafor *et al.*, (2014) also identified yet another factor that makes women more likely to have higher BMI values: a higher intake of food, without expending much of the energy obtained from the food, especially in cases of 'full house wives". Such were observed to have a more sedentary lifestyle, sending their children on errands rather on embarking on it themselves, thereby undergoing little or no exercise. There is not much avenue as a result, to expend energy and burn down body fat, increasing the risk and indeed occurrence of obesity.

4. CONCLUSIONS

The developed digital device was able to automatically measure the weight, height, calculate the BMI, and display a user's nutritional status based on BMI value on the LCD sccreen. Anthropometric measurements were conducted to determine the reliability of the digital device. Results showed that the root mean square error obtained from the reliability test was less than 1, which proved that the automated data acquisition employed in the device is reliable to be used to measure the BMI of an individual. The portable digital BMI measuring device is not only beneficial for clinical but also cheaper to purchase for home use (cost approximately NGN 90,000 to make) to monitor nutritional status of users' especially at risk groups, and towards maintaining a healthy lifestyle.

Towards improving this system, the following recommendations are made:

- The system can be programmed to give a nutritional and/or lifestyle modification suggestions to users based on their nutritional status and established medical literature, when coupled with an application.
- Load cells of higher values can increase the maximum weight measured. Likewise, height measurement range can be increased with addition of ultrasonic sensors.
- Aesthetics may be improved by painting with brighter colours; usability can also be improved by adding a text-to-speech synthesis module to cater for blind users.
- A payment feature can be incorporated into the machine that operates like a vending machine for use in public places, where for a token, an individual can find out his or her BMI. Funds raised from such could support various government health efforts or be used to increase nutritional status awareness.
- Vital signs such as blood pressure, oxygen concentration (SpO2), etc. can be incorporated into the design to enable the device measure them as well.

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