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Research Article

Design of Biomedical Wireless Inclinometer Device and Comparison of Measurements with Image Processing Method

Ahmet Çelik[1*], Eren Gül[2], Deniz Kaptan[3], Ahmet Uslu[4], Okan Üzer[5], Bahadır Çokçetin[6]

[1]Computer Technologies, Tavşanlı Vocational School, Kütahya Dumlupınar University, Kütahya, Türkiye (ORCID: 0000-0002-6288-3182), ahmet.celik@dpu.edu.tr
[2]Electronics and Automation Technologies, Tavşanlı Vocational School, Kütahya Dumlupınar University, Kütahya, Türkiye, (ORCID:0000-0002-7574-8406), eren.gul@dpu.edu.tr
[3]Electronics and Automation Technologies, Tavşanlı Vocational School, Kütahya Dumlupınar University, Kütahya, Türkiye, (ORCID:0000-0002-6055-5038), deniz.kaptan@dpu.edu.tr
[4]Architecture and City Planning Technologies, Tavşanlı Vocational School, Kütahya Dumlupınar University, Kütahya, Türkiye, (ORCID:0000-0001-8745-423X), ahmet.uslu1@dpu.edu.tr
[5]Therapy and Rehabilitation Technologies, Tavşanlı Vocational School of Health Services, Kütahya Health Sciences University, Kütahya, Türkiye, (ORCID 0000-0003-2375-9207), okan.uzer@ksbu.edu.tr
[6]Informatic Technologies, Rectorate, Kütahya Dumlupınar University, Kütahya, Türkiye, (ORCID: 0000-0002-9652-9050), bahadir.cokcetin@dpu.edu.tr

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Abstract

The slope difference between the two surfaces is a physical magnitude that needs to be measured in areas such as physical therapy diagnoses, construction, machinery, geology, geophysics, sports sciences, orthopedics. One of the devices used to measure the inclination difference is the wireless inclinometer. The wireless inclinometer allows you to find the slope of a surface relative to the ground. Inclinometers are widely used as a biomedical device, especially in the field of physical therapy. The wireless inclinometer devices used in this area are imported products and their prices are very high compared to their costs. In this study, an electronic device prototype was produced that can wirelessly measure the inclination difference of an object according to its gravity reference, show the measurement on the screen as an angle value, and record it. To verify the data obtained through the device, the calibration of the inclinometer is carried out with the inclinometer device with an accuracy of 0.001 degrees used in the Geomatics Engineering. In this study; by making measurements on the designed wooden human model, the measurements found by the image processing method were compared with the measurements of the wireless inclinometer device. The smallest angle difference between the angle measured by the device and the angle measured by the image processing method was found to be 0.013 degrees. In this study, it is aimed to develop a cost-effective domestic design and production device with superior features of the designed inclinometers.

Keywords: Range of motion of the joint, Physiotherapy, Biomedical device, Inclinometer, Calibration, Image processing

Biyomedikal Kablosuz Eğim Ölçer Cihaz Tasarımı ve Ölçümlerinin Görüntü İşleme Yöntemi ile Karşılaştırılması

Öz

İki yüzey arasındaki eğim farkı, fizik tedavi tanılarında, inşaat, makine, jeoloji, jeofizik, spor bilimleri, ortopedi gibi alanlarda ölçmeye ihtiyaç duyulan fiziksel bir büyüklüktür. Eğim farkını ölçmede kullanılan cihazlardan birisi ikili dijital eğim ölçerdir. İkili dijital eğim ölçer, iki yüzeyin yere göre yaptığı açılar arasındaki farkı tek seferde bulmayı sağlamaktadır. Eğim ölçer cihazları biyomedikal bir cihaz olarak özellikle fizik tedavi alanında yaygın kullanılmaktadır. Bu alanda kullanılan kablosuz eğim ölçer cihazları ithal ürünler olup fiyatlarının maliyetlerine oranla çok yüksek olduğu görülmektedir. Bu çalışmada, bir nesnenin yer çekimi referansına göre eğim farkını kablosuz olarak ölçen, ölçümü açı değeri olarak ekranda gösteren, kaydedebilen bir elektronik cihaz prototipi üretilmiştir. Cihaz üzerinden elde edilen verileri doğrulamak için eğim ölçer cihazının kalibrasyonu, harita mühendisliğinde kullanılan 0.001 derece hassasiyete sahip eğim ölçer cihaz ile yapılmıştır. Bu çalışma içerisinde; tasarlanan ahşap insan modeli üzerinde ölçümler yapılarak, kablosuz eğim ölçer cihaz ölçümleri ile görüntü işleme yöntemiyle bulunan ölçümler kıyaslanmıştır. Cihazın ölçtüğü açı ve görüntü işleme yöntemiyle ölçülen açı arasındaki en küçük açı farkı 0.013 derece bulunmuştur. Bu çalışmada, tasarlanan eğim ölçer cihazı daha üstün özelliklerde uygun maliyetli yerli tasarım ve üretim cihaz geliştirilmesi amaçlanmıştır.

Anahtar Kelimeler: Eklem hareket açıklığı, Fizik tedavi, Biyomedikal Cihaz, Eğim ölçer, Kalibrasyon, Görüntü işleme

1. Introduction

Today, in the field of physical therapy, the joint range of motion of the patients is measured manually with the device called goniometer. This situation both creates a loss of time and increases the possibility of incorrect measurement.

Keskinoglu and Aydin (2021), in their study; they have designed a low-cost, wireless and wearable electronic goniometer for highly accurate and accurate measurements. The stability of the measurements obtained using the Quaternion-based Kalman filter was determined and the measurements of the developed system were compared with the traditional goniometer. In addition, the Graphical User Interface (GUI) is designed to give visual feedback to the physiotherapist during physical therapy in real time by performing 3D visualization of movements and to analyze the measurement values retrospectively.

Meng et al. (2016) in their study, reported a 60% reduction in root-mean-quadratic error from 2.20 degrees to 0.87 degrees in human-joint angle measurement data obtained using a personal wireless sensor network. The operation of the device designed in the study is based on the monitoring of data received from the worn wireless inclination sensors.

Yang et al. (2013) in their study, they proposed a robust inclination meter system using three single-axis micro-electromechanical system accelerometers and three single-axis flow gate sensors. In the study; three precision axis sensor models are formulated and calibrated using a simple and effective linear model of tilt and azimuth. To improve the accuracy of the proposed model, two different optimal solutions are presented to minimize systematic error. To solve the problems, the internal reflective Newtonian method and the sequential quadratic programming method were used, respectively. In experimental results; in our applied measurement range (0–120), the maximum tilt angle error was 0.09 and in the measurement range (0–360) the maximum azimuth angle error was 0.4 degrees.

Daponte et al. (2018) in their study; they have proposed a new calibration method based on stereo vision for position alignment of Inertial Measurement Unit (IMU) sensors used in human motion tracking systems. In the study, the person to be monitored was fitted with IMU sensors. In addition, visual markings were placed on both IMU sensors and some turning points in the body joints, obtaining data from a static stereo image. The obtained measurement is verified by applying the calibration method on the values, comparing them with an inclinometer and a laser rangefinder.

Won and Golnaraghi (2010) in their study; introduced a new three-axis accelerometer calibration method. The basic principle of the proposed calibration method is that the sum of the three-axis accelerometer outputs is equal to the gravity vector when the accelerometer is stationary. The goal of the proposed method is to place the three-axis accelerometer at six different tilt angles to predict six calibration parameters. The proposed calibration method was also experimentally tested with two different three-axis accelerometers, and the results were verified using a mechanical inclinometer. According to the results they obtained; the proposed method is able to accurately predict the factors of earnings and biases, even when the initial estimates are not close to the real values.

In their study, Jovanovic and Enright (2020), investigated different inclination gauge models to predict the angle of rotation, and now different calibration models to solve the error. The methods developed in the study tested the successes of different models and the developed method is confirmed. In the study, two inclination meters using two different technologies, micro electromechanical system (MEMS) and electrolytic system are used to obtain measurements.

In their study, Wang et al. (2019) calculated the angular slope of human limb muscle sequences by examining ultrasound images. The data obtained from these calculations were used in clinical diagnosis and treatments.

In their study, Liu et al. (2019) calculated the angle between limb and rod using image processing methods using a stabilization bar. The results obtained can be applied in orthopedic treatment methods with low cost and high success rate.

When the world height averages are considered, it is seen that men and women have different measurements. Average height lengths can vary between continents and even between countries. According to 2019 data, the average length of men and women in Turkey is 170.65 cm (NCD Risc, 2017).

In this study, after the design, production and calibration of wireless inclination meter; measurements are carried out on the wooden model, which is designed in average human dimensions to compare the results. The results obtained are compared with the slope measurements calculated using image processing techniques and the results are evaluated.

2. Material and Method

The method applied in this study is shown on Figure 1. On the human model, the joint range of motion was calculated both with the data obtained from the designed wireless measuring device and with the image processing algorithm. In the last step, these values were compared.

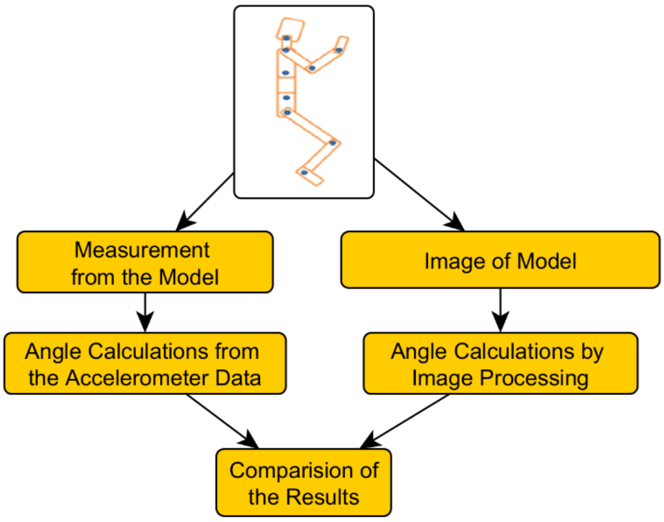


Figure 1. Flow chart of the study

Angle values are found with a similar calculation in both methods. The accelerations of 3-axis accelerometer are evaluated as follows; the acceleration measured by the axis parallel to the gravity is taken as y, the acceleration measured by the axis perpendicular to the gravity and the movement axis of the device is taken as x. In the image processing algorithm, the vertical distance between the reference points on the wooden human model is taken as y and the horizontal distance as x. Equation (1) is used to find the angle value. This equation is detailed in the image processing method section.

$$Angle = \tan^{-1}\left(\frac{y}{x}\right) \qquad (1)$$

2.1. Structure of the Wireless Inclinometer Device

The wireless inclinometer device designed in this study consists of two structures, hardware and software. The electronic circuit of the inclinometer device is shown in Figure 2. The inclinometer circuit includes accelerometer, microcontroller, wireless communication module and battery. The display circuit includes microcontroller, wireless communication module and computer interface.

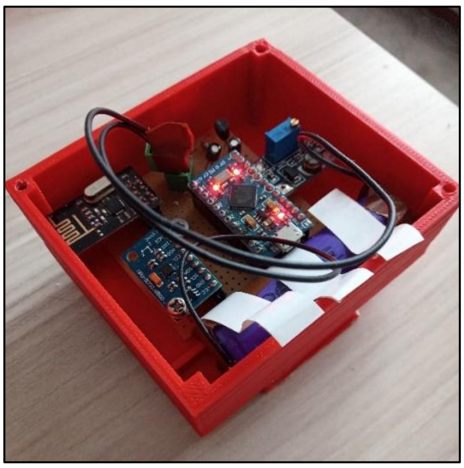


Figure 2. Inclinometer circuit (project archive 121E424)

The slope values measured -with the help of sensors- by the inclinometer device are sent to the receiver circuit wirelessly. The measured values are recorded with the help of the signal receiver circuit integrated into the computer system. The wireless receiver circuit integrated into the computer system with the help of the USB bus is shown in Figure 3.

Figure 3. Signal receiver circuit integrated into the computer system (project archive no. 121E424)

The measurements taken are shown in an interface program written in C# programming language. This interface program is shown in Figure 4.

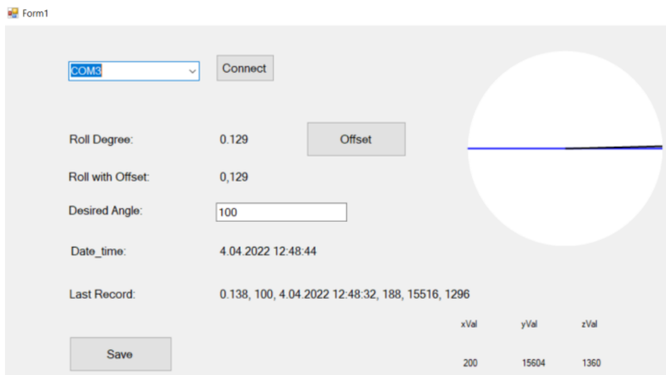


Figure 4. Computer interface program (project archive 121E424)

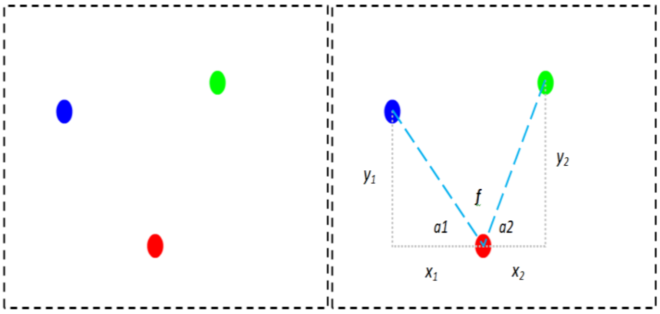
In the interface program, the "Roll Degree" value is the measurement in degrees from the slope measuring circuit. An “offset” value is obtained by pressing the Offset button. This value is subtracted from the Roll Degree value and displayed on the screen, and the value in grad measured from the inclination measuring device is written in the "desired angle value (Grad)" section. In the last stage, the date and time information of the measurement and the last recorded data.

The “xVal”, “yVal”, “zVal” values are the acceleration values of the axes coming from the inclinometer circuit. In the user interface, the circular display shows the horizontal direction of the slope measuring circuit. When the Save button is pressed, all values are saved in a file with a “.txt” extension.

The inclinometer circuit is mounted on the inclinometer used in Geomatics Engineering for calibration. In this way, the measurements measured by the two devices were compared and calibrated using the curve fitting method.

2.2. Calculation of Tilt Angle with Image Processing Method

In the method used in the study, first the reference points (red, green and blue) were determined for image processing and then the lines passing through the center of these reference points were found. The horizontal and vertical line lengths to the center point to be used in the angle calculation are calculated using the horizontal and vertical distances passing over the reference points. The colors for the reference points in the study were chosen randomly and the same colors were used on the real model.



a) b)

Figure 5. Displaying the angle between the reference points a) Reference points b) Distances of the reference points used for the angle calculation to the center point

Figure 5.a shows the reference points on the image. Red, green and blue colored objects were used to represent these points. In Figure 5.b, the horizontal vertical distances to the red center point and the angles between the lines passing through the red intersection point are shown. The angle calculations in Figure 5.b are shown on Equations 2, 3 and 4.

$$a1 = \tan^{-1}\left(\frac{y_1}{x_1}\right) \quad (2)$$

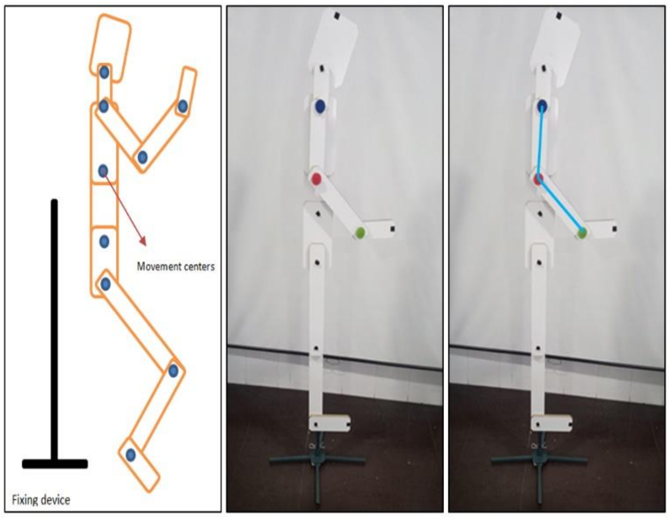
$$a2 = \tan^{-1}\left(\frac{y_2}{x_2}\right) \quad (3)$$

$$f = 180 - (a1 + a2) \quad (4)$$

y1 and y2 values show the vertical distances to the red reference point, x1 and x2 values show the horizontal distances to the red reference point. Angle a1 shows the angle between the line drawn between the blue and the red points and the horizontal line passing through the red point, the angle a2 shows the angle between the line drawn between the green and the red points and the horizontal line passing through the red point. Angle f represents the angle between the two lines.

2.3. Two-dimensional Human Model Designed for Measurement

The aim of this study is to follow the treatment processes in the field of physiotherapy. In the first stage, the 2-dimensional drawing of the model created by using the average dimensions of the real human model for the application of the designed device and the wooden model design are shown on Figure 6.



a) b) c)

Figure 6. Designed 2D model and reference points a) Drawing of the designed model b) Wooden form of the designed model c) Determination of reference points on the designed wooden model by image processing method and display of lines for slope (project archive no 121E424)

3. Results

The measurement values obtained after the calibration of the wireless inclinometer device were quite close to the real values. The difference between the actual value and the value measured by the wireless inclinometer device was found to be between -0.5 and +0.5 degrees. The highest difference measured was 0.356 degrees, and the lowest difference value was -0.02 degrees.

The success of the inclinometer device, which is calibrated and has a relatively small sensitivity value, on the designed wooden human model has been tested with the software designed using image processing techniques. The table of 4 different angle measurement values obtained using the image processing interface is given in Table 1.

The measured values are the smallest precision measurement values obtained from the head-neck and elbow regions of the designed wooden model. Calculations were made by converting image resolutions to 600x600 pixels. Measurements were made with the software developed by marking the red, green and blue points on the neck and elbow regions of the wooden model, which was viewed with the help of the camera.

Table 1. Slope measurement results obtained by image processing method

Apart of Body	Size of Image	Image	Angle Measured by Image Processing	Real Angle Measured by Device	Difference
Neck	600x600	1.jpg	50.689	50	0.689
Neck	600x600	2.jpg	49.262	50	-0.737
Neck	600x600	3.jpg	49.861	50	-0.138
Neck	600x600	4.jpg	50.140	50	0.140
Neck	600x600	5.jpg	50.129	50	0.129

Neck	600x600	6.jpg	80.483	80	0.483
Neck	600x600	7.jpg	80.695	80	0.695
Neck	600x600	8.jpg	79.215	80	-0.784
Neck	600x600	9.jpg	80.013	80	0.013
Neck	600x600	10.jpg	79.261	80	-0.738
Elbow	600x600	11.jpg	40.411	40	0.411
Elbow	600x600	12.jpg	39.768	40	-0.231
Elbow	600x600	13.jpg	39.948	40	-0.051
Elbow	600x600	14.jpg	39.296	40	-0.703
Elbow	600x600	15.jpg	39.800	40	-0.199
Elbow	600x600	16.jpg	59.743	60	-0.256
Elbow	600x600	17.jpg	60.115	60	0.115
Elbow	600x600	18.jpg	60.091	60	0.091
Elbow	600x600	19.jpg	59.893	60	-0.106
Elbow	600x600	20.jpg	60.221	60	0.221

The measurement graph of 4 different angles obtained using the image processing interface, the angles calculated by image processing (Measured Angle: M_A) and the angles measured by the developed wireless inclinometer device (Real Angle: R_A) values are shown in Figure 7. According to the measurement results made with this technique, negative or positive deviations were observed. In the tests performed, many measurements were made and the data of the images -in which the 4 angles were calculated closest to the real angle value- were evaluated. In the study, the real angle and the tilt angle differences obtained by the image processing method were compared. As a result, the smallest angle difference was determined as 0.013 degrees in the neck region, where the true angle value is 80 degrees. The largest angle difference was obtained as 0.784 degrees in the neck region, with the true angle value of 80 degrees.

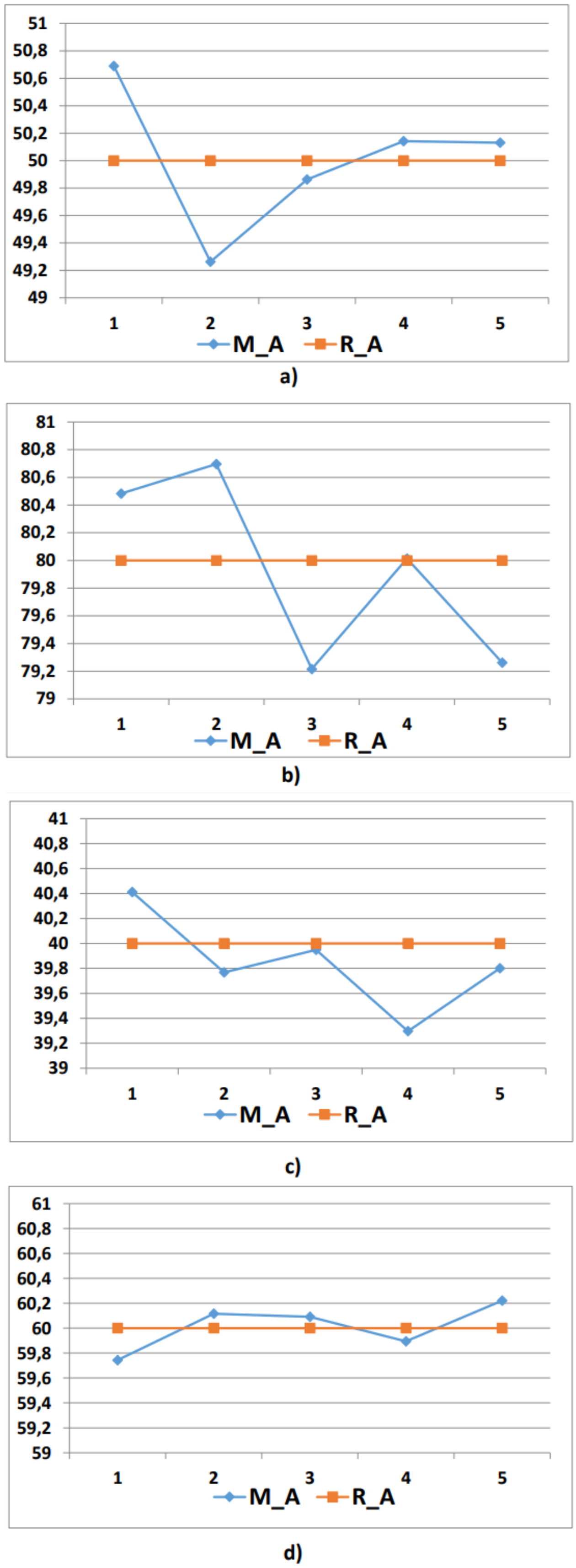


Figure 7. Measurement results obtained according to image processing techniques a) Neck region 50 degrees b) Neck region 80 degrees c) Elbow region 40 degrees d) Elbow region 60 degrees

4. Discussion

In this study, a wireless inclinometer circuit that can be used in physical therapy and diagnostic procedures is designed and an angle value can be measured relative to the horizontal axis using this circuit.

Wireless inclinometer circuit is calibrated using an inclinometer used in Geomatics Engineering. As a result of the calibration, measurements were made with less than 0.5 degree of error.

The results obtained were tested on the wooden model and the results were recorded. The measurements taken on the wooden model were confirmed by the measurements made using image processing techniques. It is seen that the error rates are small relative to conventional inclinometers used for this purpose.

In this study, the designed device consists of hardware and software interface. The software interface differs from its counterparts thanks to its user-friendly measurement recording feature and web interface. The use of image processing technique in slope calculations and the comparison of the measurement results with the designed device made this study unique. The light intensity of the working environment is of great importance in measurements made with image processing techniques.

5. Conclusion

As a result, the designed device has become usable on real cases and the measurement results have been verified. In future studies, the device will be introduced in cooperation with health institutions and feedback from employees is expected about its use.

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