biometric, centre of gravity, signature, recognition

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BIOMETRIC RECOGNITION SYSTEM BASED ON THE MOTION OF THE HUMAN BODY GRAVITY CENTRE ANALYSIS

In this paper we present a novel approach that enables the determination and measurement of important features associated with the human body movement. This information can be used in the construction of a biometric personal identification system. Biometrics is, essentially, a pattern recognition system based on measurements of unique physiological or behavioural features as acquired from an individual. The domain of biometric techniques is currently placed within recently developed disciplines of science. Biometry or biometrics is simply defined as automatically recognizing a person using distinguishing traits and is widely used in various security systems. Biometry can be defined as a method of personal identification based on individuals' physical and behavioural features. Physiological biometrics covers data coming directly from a measurement of part of a human body, for example a fingerprint, the shape of the face, or from the retina. Behavioural biometrics analyses data obtained on the basis of an activity performed by a given person, for example speech and the handwritten signature. The system of biometrics defined above can now be expanded, and a new biometrics system can be considered. In our approach, human foot pressure on a surface is measured and the pressure data retrieved. The pressure parameters are collected without the necessity of any movements of the feet.

1. INTRODUCTION

Currently biometrics is an elementary security technique that links an identity to an individual, using methods that focus on the diversity between members of a given population. It should be emphasised that biometric devices, including the recent efficient recognition algorithms, are continuously improving, and that biometrics and its techniques are widely used.

The number of biometric applications continues to increase, and a significant subset of these systems can be used as components in electronic identification equipment. Biometrics is already strongly integrated into a range of systems, such as drivers' licensing, surveillance, health identity cards and passports.

Biometric techniques can be applied to two types of authentication: identification and verification. In the verification process, the input object and its characteristic features are compared with one single pattern object from a database, and a judgement is made as to whether these two objects are the same or not. The identification case differs from biometric verification as a database has to be searched in order to match the presented biometric features. Only in this case the user's identity can be confirmed. The objects' required similarity level is established by the designers of the biometric system.

In other words, a biometric system can be designed for two situations: where the authenticated object is known by the system; and when the submitted template is not known and a central database has to be searched, a time–consuming process, especially when the databases are large. This second type of authentication is used by police authorities in their fight against crime.

Nowadays, biometric technologies that utilize signatures, fingerprint, the face, veins, the iris, and DNA analysis are all widely applied in many domains of life, by police departments, border services, financial institutions and by others. However, some techniques of data acquisition, such as DNA and blood analyses, are still expensive, time–consuming, and potential violations of both privacy and of the perceived integration of the individual's body. The paper proposes an approach that overcomes all of these disadvantages.

Today, thanks to modern technologies and refined measurement techniques, new biometric solutions have been introduced in which the human gait, or hand movements, for example, can be treated

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as biometric features which can be electronically observed and measured [4,9]. Medical studies have demonstrated that these features are unique, but their registration and interpretation remains difficult due to frequently appearing measurement noise.

Observation of the some human features can be also successfully exploited in many diseases recognition [1,2,15]. For this reason human behavioural features can be differently interpreted. In the one attempt it will be gait differentiation or postural stability, for example. In the other attempt these features can be interpreted as a biometric differentiation of the people.

Unfortunately, these attempts also require special devices, and some resultant inconvenience. Nevertheless, these devices are cheap and obtainable. It should be clearly noted that the same devices can be used in medicine or as biometric equipment.

In this paper, the gait of a person has been recorded by a special digital device, from which a discrete time–series has been produced and interpreted. In carrying out these investigations, the human body's centre gravity, which is directly correlated to the centre of the pressure applied by the foot, is mapped and used as a reference point.

2. THE SPECIALISED MEASUSURING DEVICE

A wide and varied range of pressure distribution measurement systems are available. These systems can be significantly different from each other. They can be shared, barefoot, or in–shoe measuring devices in which special soles are used.

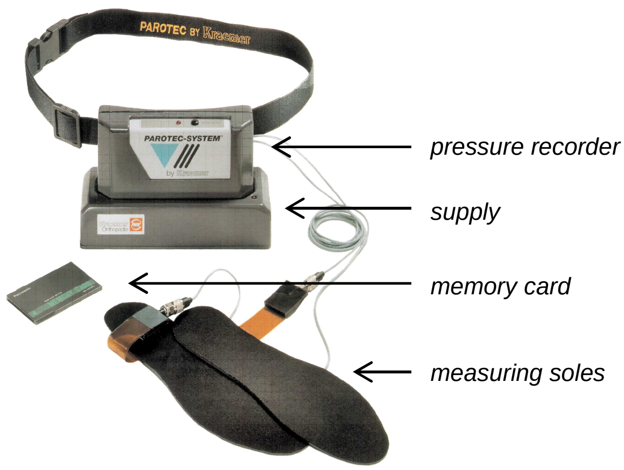

Fig. 1. The main parts of the Parotec System equipment.

This work presented here is based on the Parotec System for Windows (PSW). This project was intensively developed over the years 1991–1996. It is a system in which special pressure–sensitive soles are used.

The Parotec System works well with version 2.0 of the software, but during investigations a new version of the software was also utilized, the so–called GSA 3.0 version [15]. Different versions of the Parotec System are widely used. Presented in Fig. 1 equipment was also utilised, in the same hardware and software configuration, by hundred physicians and researchers. Appropriate examples can find in the works [1,2,10,11,15]. It should be noted that software of the Parotec System were also developed by research workers of Computer Systems Department, University of Silesia, Poland.

This system allows the researcher to record the bio–dynamic data obtained from the pressure of the foot, in either its resting or dynamic modes. Each examined person can move freely during the measurements, while the data are collected and stored, measurement–by–measurement, by the system's microcontroller. The distribution of the pressures of each foot is precisely recorded by the use of this equipment. The main parts of the Parotec System are shown in Fig. 1. The collected data are calibrated by the device itself, after which subsets of it can be graphically displayed (Fig. 2). This figure shows the feet pressure data of the one of our volunteer.

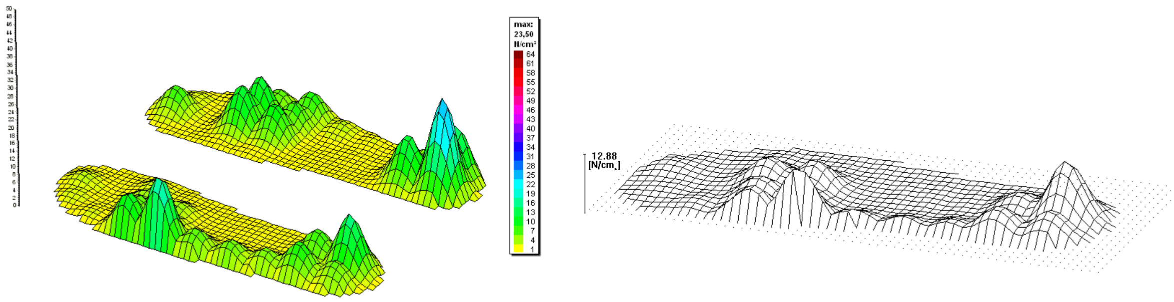

Fig. 2. Graphical representation of the data as displayed by the GSA 3.0 software.

3. DATA RECORDING AND DETERMINATION OF THE FOOT'S PRESSURE CENTRE

Measurement data were gathered from 15 volunteers. The authors had access to only a single size of the soles, so the soles were fastened to the ground. For this reason, the Parotec System was used as a barefoot pressure measuring device.

Each sole contains 24 sensors. Arrangement of the sensors on the left and the right soles is shown in Fig. 6. During the tests each person executed 10 natural motions, requiring body rotation and movement in a restricted area. The measurement activities were time–restricted, having to be completed in 5 seconds. After the programmed time a short acoustic signal was generated, indicating the end of the measurements. As the first operation, calibration of the soles was always performed. This allowed for the establishment of a reference pressure. All subsequent measurements were conducted in relation to the calibrated reference pressure.

During the tests each subject had only to change their body's centre of gravity, without any disconnection of their feet from the ground. Distances between soles and their location were established experimentally. Each of the volunteers' movements were recorded at discrete time intervals, and the pressure values being sampled at a frequency of 10 Hz. This procedure was repeated ten times for each subject examined. Over each measurement the volunteer was to execute the same, or similar, body movements. As each person changed their body's centre of gravity, the change in its location was reflected in the values incident on the soles' pressure sensors.

Each attempt can be displayed graphically (Fig. 3), where each curve represents the body's centre of gravity as it changes during each test.

From the trajectories as seen in Fig. 3 the body's centre of gravity C_S can be determined with similar centres being recorded for the left (C^L) and the right (C^R) foot, respectively. This process will be more precisely described in Section 4 of this paper.

a) b)

Fig. 3. a) Graphic representation of the four single motions of the same person (volunteer) during a 5 sec. biometric test, b) The same four motion trajectory superimposed.

During the measurement process a set of 150 separate time–series were recorded; in each time–series the movements in the body's centre of gravity, changes in the foot's pressure, and the elapsed time were generated and stored. In the future, on the basis of this dataset, a series of subsequent investigations will be carried out.

4. DETERMINATION OF THE BODY'S CENTRE OF GRAVITY

The measuring sole, as placed in an $X-Y$ Cartesian system, is displayed in (Fig. 4). On the surface of the sole the 24 sensors are located as shown. These sensors are positioned at the points C_{P_i}, where any point C_{P_i} has the (x_i, y_i) coordinates, and where $i = 1,...,24$. Each sensor C_{P_i} has a measuring area of S_i. The pressure distribution inside of the cell of each sensor is taken to be uniform across the cell's area. At each point C_{P_i}, the force vector $\vec{F_i}$ is located (Fig. 5).

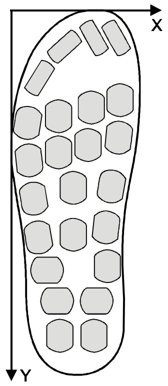

Fig. 4. Sensors location in the Cartesian reference system

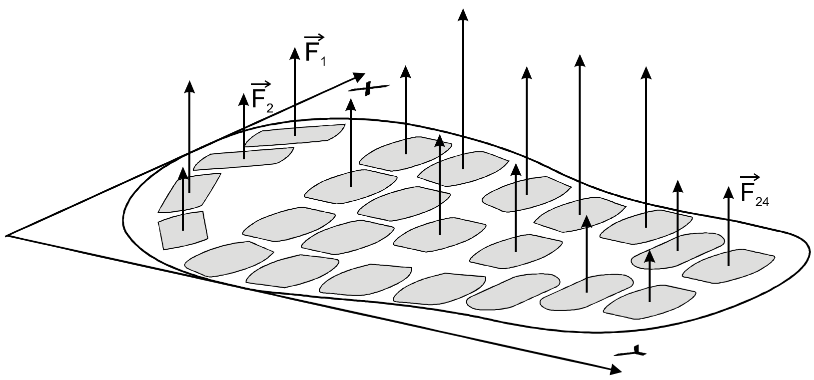

Fig. 5. The forces $\vec{F_i}$ hooked in the C_{P_i} points [1]

The *Centre of the pressure force* $C^L(C^R)$ is independently determined for the left (C^L) and the right (C^R) sole [1]. This point has the coordinates (x_0, y_0), and given that $\alpha = L$ or $\alpha = R$, respectively:

$$x_0^\alpha = \frac{\sum_{i=1}^{24} F_i^\alpha x_i^\alpha}{\sum_{i=1}^{24} F_i^\alpha}, \quad y_0^\alpha = \frac{\sum_{i=1}^{24} F_i^\alpha y_i^\alpha}{\sum_{i=1}^{24} F_i^\alpha} \tag{1}$$

where:

x_i^α, y_i^α – the coordinates of the point C_{P_i} of the single *i*-th sensor on the left or right sole,

F_i^α – the force vector $\vec{F}_i$ on the left or right sole. These values are calculated from the formula:

$$F_i^\alpha = P_i^\alpha \cdot S_i^\alpha \tag{2}$$

P_i^α – the pressure value of the *i*-th sensor on the left or right sole,

S_i^α – the area of the *i*-th sensor on the left or right sole.

These points for either foot will be indicated by the symbols C^L, C^R, respectively such that $C^R \to (x_0^R, y_0^R)$ and $C^L \to (x_0^L, y_0^L)$.

The *Distribution pressure point* C_S is a projection of the body's centre of gravity on the Cartesian coordinate system [1]. The location of this point depends on:

– the values C^L and C^R,

– the value $W^{\alpha} = \sum_{i=1}^{24} F_i^{\alpha}$.

As the measurements have to be dynamically calculated, they are each recorded against a discrete time point *t*. The dynamic Cartesian coordinates of the point $C_S(t)$ can be determined as follows:

$$x(t) = \frac{W^L(t)x_0^L(t) + W^R(t)x_0^R(t)}{W^L(t) + W^R(t)}, \quad y(t) = \frac{W^L(t)y_0^L(t) + W^R(t)y_0^R(t)}{W^L(t) + W^R(t)}, \quad t = 1, 2, ..., n \tag{3}$$

where *n* is a number of the recorded samples (the signal being studied).

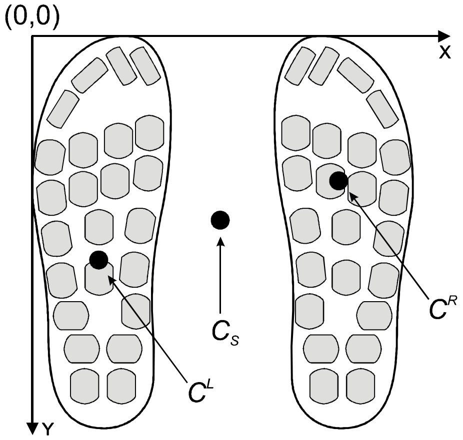

Fig. 6. Displacement of the points C_S , C^L and C^R in the static measurement.

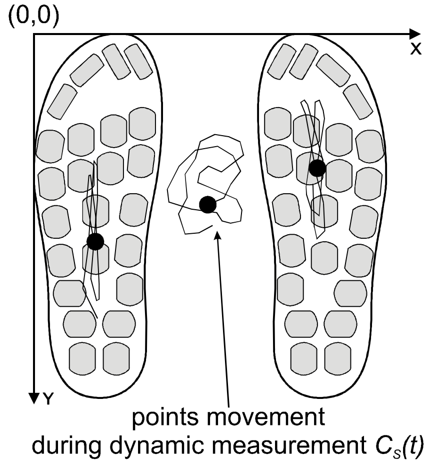

Fig. 7. Movement of the points $C_S(t)$, $C^L(t)$ and $C^R(t)$ during dynamic measurements.

After studying Fig. 7 it can be seen that multiple trajectories can be analysed: the coordinates (x, y) of the point C_S , and pressure $p(t) = W^L(t) + W^R(t)$ of each point C_{P_i} . It is dynamically recorded during volunteer body motion.

5. NORMALISATION OF THE PAROTEC SYSTEM TIME – SERIES

As was previously discussed, body movements trajectories (see Fig. 3) can be treated as discrete time–series. Unfortunately, these trajectories are not uniform as they come from different persons – and it is obvious that every individual has unique biometric features. The simplest method of comparison is a features matching. To undertake these initial computations, the data must be normalised. However, this means that each time–series has to have the same number of samples. This problem can be overcome through the use of the common Dynamic Time Warping (DTW) technique [3,5,7]. Additionally, the DTW algorithm optimises alignment of any two time–series. The DTW is a simple technique, well–known amongst the research community, and is not again described and detailed here.

The measure of the fit between two sequences X and Y is the well– known correlation coefficient R^2 [8]. The value of the correlation coefficient can be taken as a measure of the similarity between two time–series of the length of k .

Let x_i be a sample of the initial sequence X , so $x_i \in X$, and $i = 1, ..., a$.

Let y_i be a sample of the initial sequence Y , so $y_i \in Y$, and $i = 1, ..., b$.

The DTW algorithm transforms the sequences into the form X' and Y'. After DTW procedure, both the sequences $X'(Y')$ have the same length *k*.

The similarity measure can be calculated as follows [8]:

$$R_f^2 = \frac{\sum_k (X' - \bar{X}')(Y' - \bar{Y}')}{\sum_k (X' - \bar{X}')^2 \sum_k (Y' - \bar{Y}')^2}, \tag{4}$$

where:
X', Y' – two sequences after processing by the DTW algorithm,
$\bar{X}', \bar{Y}'$ – the average value of all elements of the sequence X' and Y', respectively.

In the domain being studied, the sequence *f* can be the coordinates (x, y) or the pressure *p*.

6. EXPERIMENTAL RESULTS

During the experiments utilizing the pressure–sensitive sensors as described, the human body's centre of gravity was dynamically analysed. The movements of this centre were observed to be a unique biometric feature. On the basis of these collected observations, a verification–mode biometric system was designed.

From the data collated by the Parotec System, coordinates and the pressure p observed in each cell of the measurement soles were sampled in the discrete time *t*. These parameters operated as individual, dynamic biometric features. On the basis of these features, the biometric recognition system was designed.

To increase computational efficiency, the DTW algorithm was modified to use the "slope weighting" [5]. This allows for a reduction in the total area over which the DTW searches optimal paths. These modifications accelerate the computational process. The obtained results have been collected in Table 1. A mean similarity measure between the trajectories has been included in this table. These trajectories can be considered to be specific “signatures” of each of the examined individuals. The mean similarities within each subject (each measured volunteer) are in the range [0.238 to 0.96] (mean: 0.709).

The average similarities between different subjects fall into the range [0.121 to 0.569] (mean: 0.345). It should be noted that if a similarity was 1.0, then the two compared objects would have been identical, possessing a similarity of 100%.

In other popular recognition systems, for example in hand–writing signature recognition systems, the similarity measures are of a very high level, around 0.90. It follows, then, that the repetitiveness of such measurement objects is also very high. These are common behavioural features of the individuals being evaluated. Additionally, one's personal signature is practised over many of the domains of everyday life.

Some volunteers (u2, u5, u13) exhibited such a high repetitiveness of their trajectories: their body movement characteristic motions were always similar to each other.

Nevertheless the average value of the similarity measure of the three parameters (x, y, p) studied here is only $R^2 = 0.709$. This suggests that the required repetitiveness of the motion sequences used here may be difficult to achieve.

Table 1. The average similarity measures of the bodily motion trajectories

user \ feature	R^2					
	p		***x***		***y***	
	A	***B***	***A***	***B***	***A***	***B***
u1	0.238	0.154	0.404	0.335	0.723	0.349
u2	0.722	0.212	0.960	0.394	0.927	0.465
u3	0.523	0.274	0.383	0.309	0.703	0.448
u4	0.745	0.140	0.934	0.515	0.466	0.262
u5	0.824	0.274	0.930	0.569	0.935	0.381
u6	0.496	0.235	0.672	0.442	0.591	0.375
u7	0.523	0.121	0.763	0.475	0.663	0.275
u8	0.739	0.282	0.739	0.504	0.722	0.433
u9	0.476	0.255	0.673	0.499	0.590	0.397
u10	0.823	0.197	0.889	0.412	0.874	0.350
u11	0.681	0.251	0.693	0.510	0.661	0.346
u12	0.531	0.138	0.644	0.482	0.603	0.388
u13	0.926	0.320	0.913	0.454	0.921	0.434
u14	0.613	0.232	0.861	0.533	0.817	0.360
u15	0.787	0.134	0.665	0.423	0.944	0.224
Average:	0.643	0.214	0.741	0.457	0.742	0.365

A – the average similarity measure of the trajectories of the same person,
B – the average similarity measure between the trajectories of the different persons.

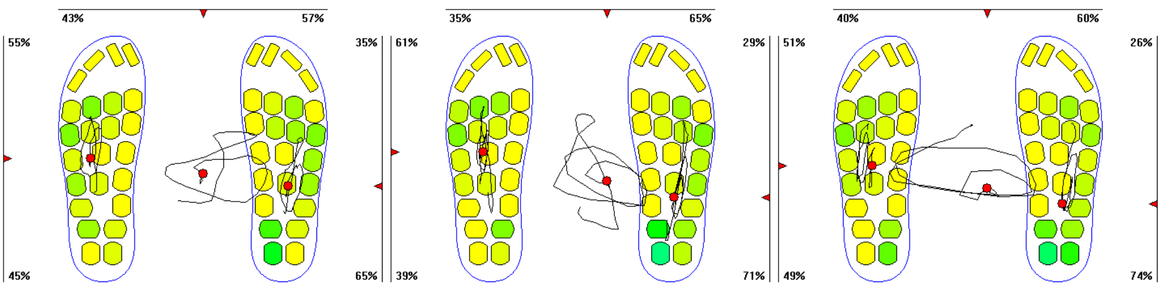

Fig. 8. Examples of trajectories (body motions) taken from one subject. In this picture the body's centre of gravity the left and the right foot's pressure distributions have been shown.

In the main investigation, the importance of the similarities R_x^2, R_y^2, R_p^2 was tested. On the basis of this research we can check which biometric features have the biggest influence on the biometric recognition level. To achieve this goal, the additional feature R_a was constructed [13]:

$$R_a = R_x^2 \cdot w_x + R_y^2 \cdot w_y + R_p^2 \cdot w_p \qquad (5)$$

where:
w_x, w_y, w_p – the influence weights for the features x, y and p, respectively.

Additionally, the condition:

$$w_x + w_y + w_p = 1 \qquad (6)$$

should be always fulfilled.

During the tests, the weightings w_x, w_y, w_p were varied over the range [0,1], under the constraints of equation (6). Upon each change of the weights, the average ERR coefficient in the round–robin cycle was computed. The results are presented in Table 3. For technical reasons this table displays only the values of the most important weights. The best classification results were obtained when the parameters were set to be $w_x = 0.4$; $w_y = 0.3$; $w_p = 0.3$ for which the classification error was equal to 16.741%.

Table 2. The best values of the most important weights and their influence on the average ERR coefficient.

for all attempts of the R_x^2, R_y^2, R_p^2				
w_x	w_y	w_p	**ERR [%]**	R_a
0.5	0	0.5	18.074	0.480
0	0.5	0.5	18.352	0.468
0.3	0.3	0.4	16.886	0.482
0.3	0.4	0.3	17.185	0.499
0.4	0.3	0.3	16.741	0.502
0.2	0.2	0.6	17.926	0.455
0.2	0.6	0.2	19.057	0.525
0.6	0.2	0.2	18.790	0.539
0.1	0.1	0.8	18.994	0.436
0	0.1	0.9	19.407	0.428
Average:			18.141	0.518

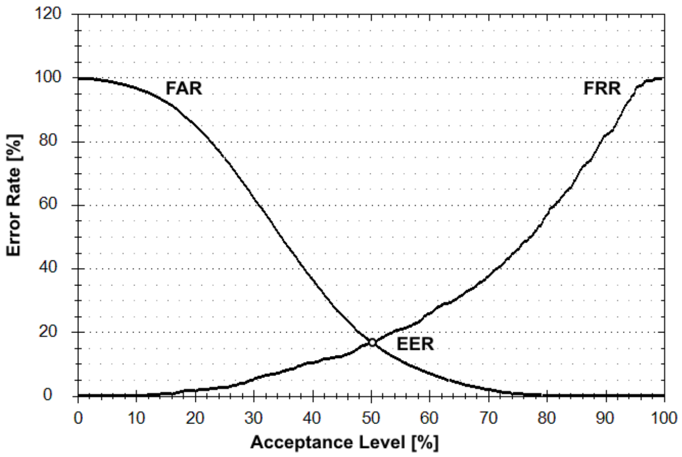

Fig. 9. The ROC (FAR–FRR–ERR) curves for the best weights $w_x = 0.4$; $w_y = 0.3$; $w_p = 0.3$.

As a result of this investigation we can see that the best classifications are obtained when the values of the weightings are similar to each other.

7. CONCLUSIONS

In this study we selected human body features that can be used in biometric systems. The motion of the human body was analysed, without any movement of the feet and without any disconnection of the feet from the ground. Our employment of these features is novel and unique. In our first attempts the error classification levels we obtained were already small. We have, in this paper, listed our experimental results, accompanied by the FAR, FRR and ERR factors; see Fig 9. After time–consuming tests, these factors can be shown as curves. This is a commonly used approach to the presentation of investigation results, enabling easy comparison with the work of other authors.

The location of the centre of the pressure of the foot in humans can change slightly, even during simple standing. Further, the postural stability of a person decreases with an age and as a consequence of some diseases [2,11,15]. This phenomenon was intensively discussed, especially in the works [1,2,10,15]. Nevertheless these problems have not been analysed and measured in this paper. Because the ability to retain posture is different for each person, changes of body's centre of gravity can be considered and analysed as an idiosyncratic biometric feature.

From the investigation results obtained, we conclude that results can be improved further, and that a biometric system can be developed in future works. This work will necessitate further investigations over a larger group of volunteers.

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