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Human Movement Monitoring Simulation Using an IoT-based self-powered TENG Intelligent Chair

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Abstract: The internet has had a profound effect on human life. Since each individual has distinct movement characteristics, monitoring human motion can enable identity recognition. This paper describes the development of a self-powered triboelectric nanogenerator (TENG) band's array for recognizing students' identities in the classroom by collecting movement information derived from electric signals during sitting, standing, turning left and right while sitting, and breathing on the chair. The band's array is soft, stretchy, and cheap, constructed of a rubber tube filled with locally created physiological saline. It can be mounted on the intelligent chair in two positions: seat and backrest. Furthermore, utilizing MATLAB software and a specialized algorithm, the band's array can identify and authenticate students' identification in real-time with an ERR of 19.6 %.
Keywords: Intelligent chair; self-powered Triboelectric Nanogenerator; Internet of Things; student motion detection; Identity recognition

I. INTRODUCTION

IoT plays a vital role in improving connectivity in all areas of life in this modern era, as IoT can remotely control the existing network infrastructure. On the other hand, sustainable energy solutions are necessary to reduce energy consumption and avoid exposing humans to environmental pollutants. Since the world suffers from a shortage of electricity, it must create ways that provide energy consumption to overcome this shortage.

There are numerous potential energy sources, such as piezoelectric and triboelectric energy; by incorporating them into IoT-based devices, we can evaluate these issues and find possible solutions. People have unique biometric traits that can be used to prove their identity. In this case, figuring out who they are can be done by noticing how people move. Many sensors have been made for biomechanical motion detection, and they've been getting a lot of attention recently [1-4]. These sensors have given us some information about how our bodies move, which has helped us better understand our daily lives [5-14]. However, many of these sensors need a power source, which stops them from working all the time.

This research paper discusses how to solve the problem of wasting the teacher's time in recording students' attendance in the classroom by moving away from traditional methods such as asking students to sign in at the door or assigning students numbered seats and letting them sign a seating chart when it is passed, as well as cutting a seating chart into segments and circulating them so that each student can print the last of their name, fingerprint system [15], intelligent code scanning with the activation of the GPS, which cannot continuously operate without a power source, which may contribute to wasting energy.

Here, we develop a soft, stretchable, and low-cost self-powered band's array to monitor student motion and recognize its identity. A band's collection is prepared and fixed to the chair horizontally at the XY-axis of the seat and backrest, respectively, as shown in Fig1(c).

The band's array can detect student movement during sitting activity and movement on the intelligent chair, with the working mechanism based on the coupling of triboelectrification and electrostatic effect. The band's array mounts onto the intelligent chair on the backside of the XY-axis to be the top and bottom layers.

When a student starts seated on it, the band's collection can detect seven types of human movement, including sitting, leaving, turning left, turning right, breathing, bending towards the desk, and relaxing on the back seat. Quantitative movement information, such as sitting and standing speed and breathing, especially when taking a rest on the backrest, can also be acquired by the band's array.

Moreover, since people have unique movement patterns and different behavior while sitting and standing on the chairs with the difference in age, gender, weight [14,15], and duration of the lecture, the self-powered band's array can be applied for identification and evaluation.

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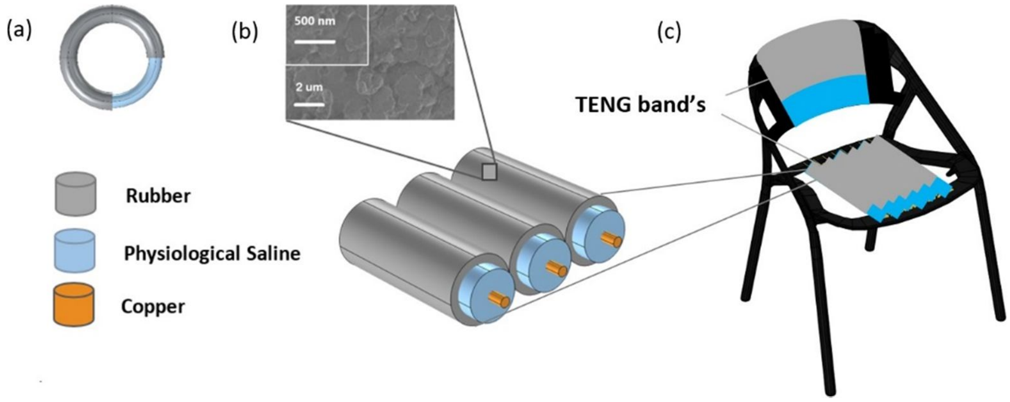

Fig. 1. An overview of the TENG band's structure and applications. (a) A typical TENG band array structure. (b) SEM images of nanostructures on the rubber surface of the band array.[1] (c) Diagram of TENG band's mounted on the intelligent chair for quantitative and qualitative motion information monitoring.

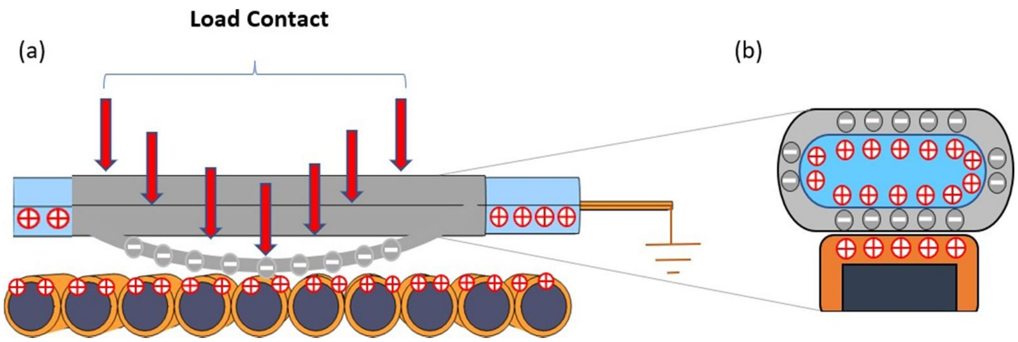

Fig. 2. Operating principle of the Intelligent chair. (a) When a body objectis in contact with the intelligent chair. (b) a two-dimensional model view ofthe TENG-Sensor mounted on the chair.

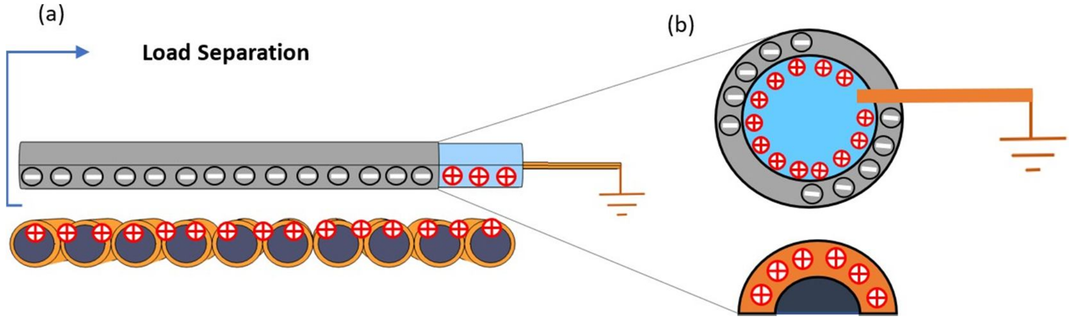

Fig. 3. Operating principle of the Intelligent chair. (a) When a body object is in separation mode (b), a two-dimensional model view of the TENG-Sensor mounted on the chair.

II. RESULTS AND DISCUSSION

In this section, we present the intelligent chair model and conduct studies on the application of multiple loads that simulate the weights of students while sitting on the intelligent chair and purify the difference in output voltage and time-domain variance studies. By using the COMSOL Multiphysics program, A diagram of the self-power TENG band' was created, shown in Fig. 1(a). It consists of a rubber tube filled with physiological saline (conductivity: 1.45 S/m at room temperature); the rubber layer is about 200-um thick. Its diameters can be reduced to fit with seat dimensions. Fig. 1(b) shows an optical picture of the TENG band [1]. The inductively coupled plasma (ICP) method creates nanostructures on the rubber surface to increase surface contact area and thus performance, as shown in Fig.1(b). As illustrated in Fig. 1(b), The band' array has been installed on both the chair (seat) and the backrest to detect standing contraction and expansion while sitting. Monitoring body activity while standing and sitting collects quantitative motion data such as standing, sitting, turning left-right, and speed.

Since people have unique movement patterns and Different behavior while sitting and standing on the chairs with the difference in age, gender, weight, and duration of the lecture, the self-powered band's array can be applied for identification and evaluation of identity, as shown in the contacting mode in Fig. 2(a). After collecting the signals representing sitting and standing movement of different students by applying different samples were generated by MATLAB that simulate the weights of the students while they are sitting at the preparation time conducted by the teacher, the system identifies them via a template database of monitoring. The program can match identities through sitting and standing without delay. The diagram and COMSOL simulation results of the band's array working principle are shown in Figs. 2(a) and 2(b). By mounting the band's array on both the chair (seat) and the backrest, an example, due to the triboelectric effect, the rubber will be negatively charged when the rubber contacts the lower electrode covered by the nylon that has a positive charge with a lower electron affinity. At the same time, the electrode will be positively charged. The contraction and relaxation of the body caused by sitting posture cause an increase and decrease of contact area between the rubber and a conductor surface that the nylon loses electrons and becomes charged positively, which leads to electric six potential differences between the band's electrode (physiological saline) and the lower layer conductor (the nylon) with the ground conductive object in the open-circuit condition because of the electrostatic effect. This potential difference will drive electrons to flow between the band's array electrode and the ground in the short-circuit condition. The simulation results agree with the working principle described above. Simulation details can be found in Figures. 2(a-b), and 3(a-b) shows the open-circuit voltage, short-circuit transferred charge density, and short-circuit current density of the band's array, with peak values of 89.4 V, 7.1 uC/m 2, and 0.62 mA/m^2, respectively. Such power density enables the band's array to power on various LEDs fixed on the intelligent chairs for visible attendance. The transmitter TX circuit can also transmit the data to the Rx receiver circuit that collects data due to their movement. The band can maintain its performance even under a tensile strain of as high as 300 percent [1]. Making it compatible with the intelligent chair and bears pressure repeating while sitting and standing. The VOC and delta (Qsc) increase initially and decrease as the strain increases from (0 - 200) percent. The band's array has maximum electrical outputs values when the strain is 200 percent. The band's collection can detect student's movement, which includes changing the sitting positions, thus changing the pressure ratio on a band's array particular site, which affects expansion and contraction compared to another volume change when the band surface is pressed perpendicular for both XY- axis by the human body.

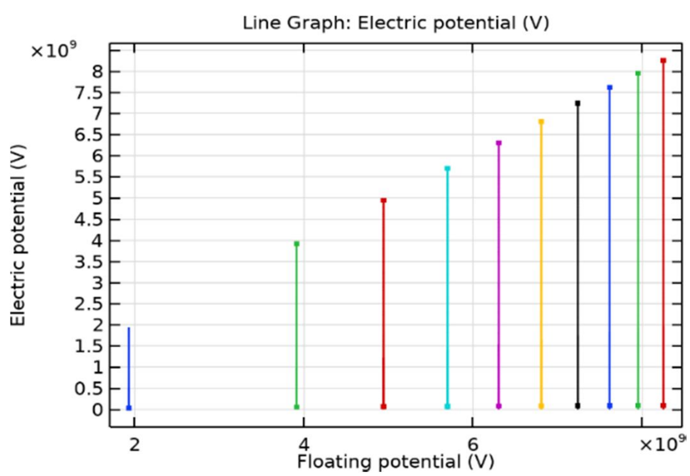

Fig. 4. Showing a floating potential output result of ten students' weight simulated using the MATLAB program.

The intelligent chair can monitor gentle and violent movements during sitting and standing. When the band's array is mounted on the backrest, it can detect breathing, as shown in Fig. 1(c). Signals during student standing, sitting, and relaxation with band's array mounted on the back and down seat are shown in Fig. 1(c). During bending, the body (the back) towards the desk and relaxing it results in expansion and contraction in the band's array and recovers periodically. When the bending angle increases, the amplitude of the potential difference increases, as shown in Fig. 4. The movements mentioned above displayed the voltage and transferred charge signals during separation in Fig. (5-6); it can also be used in movement count detection. Besides extracting movement information, the band's array can also identify and authenticate the student while he sits to detect their movement behavior characteristics. Each individual has their movement behavior, which the band's collection can monitor mounted on the intelligent chair. The framework for the recognition system includes data acquisition, data processing, and analyzing identity.

The system can recognize the student by matching the measured movement with templates in the database by collecting voltage waveforms of the student's movement pattern. After data processing, Information about the student's movement is compared with all templates in the database. Before that, we made a sample movement template using MATLAB to simulate the actual student's activity. A good match between the body movement and one of the templates in the database can authenticate identity, and a checklist for attendance to confirm or deny the student's presence in the database. At the same time, a mismatch would fail authentication of identity.

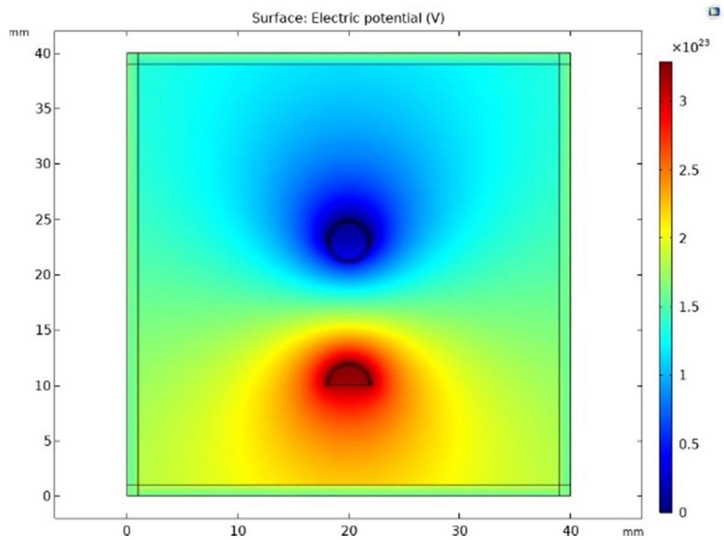

Fig. 5. Shows The TENG self-powered intelligent chair's electrical potential output depends on the number of contacts and separation between the top and bottom layers made by the ten students' 'bodies weight

Ten variables participated in the simulation by generating a random student's weight using an algorithm in the MATLAB program. As for the actual experiment, it will be done later to match the simulation results. The open-circuit voltages were generated while the student was standing in the separating mode, as shown in Figs. (3-4-5). The data were collected of the ten students sitting, turning right and left while sitting, relaxing and leaning towards the desk, and standing. Each set contains at least 0.1 s of data, and each student's sample was measured no fewer than ten times. Each variable sample generated a unique set of waveforms that are different from others. All waveforms display a high peak value and a low peak value in one unit, representing standing and seating separately. The high and low peak values ratio varies from students' sample to others due to each student's unique seating and standing behavior morphology. Fig.5 showsa linear increase in the electrical potential output voltage with time.

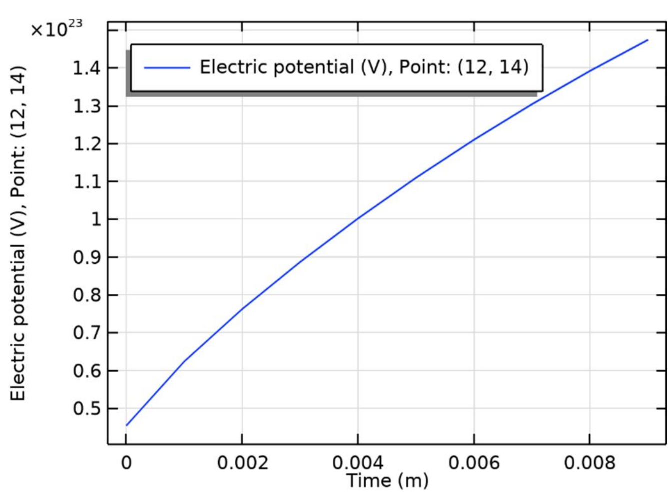

Fig. 6. Two-dimensional simulation results for the TENG self-powered intelligent chair's working mechanism are shown in the separation mode

Moreover, the difference between the peak-to-peak value corresponds to the degree of inclination of the student's back on the chair while relaxing behavior or standing and the time interval between two adjacent peaks that correspond to the actual movement that varies from one person to another. Theseare specific characteristics that distinguish the students. Using two sets of data at a

$$C = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (1)$$

time, the Pearson Correlation Coefficient is calculated for each possible pair as mentioned in equation (1). The following equation calculated the Pearson Correlation Coefficient: where x and y are the voltage sequences that are compared and n is the length of the voltage sequence. Performance of the authentication method is characterized by False Rejection Rate (FRR) and False Acceptance Rate (FAR). FRR and FAR reach an equal error rate of 19.6 %.

III.CONCLUSION

In summary, a self-powered triboelectric band's array is developed to recognize students' identity attending class by collecting movement information derived from electric signals during sitting, standing, turning left-right through sitting, and breathing on the intelligent chair. The band's array is soft, stretchable, and low-cost, composed of a locally made rubber tube containing physiological saline. It can be mounted to the intelligent chair in two positions, a seat and backrest, to monitor various students' movements. Quantitative and qualitative soon of movement information such as sitting and standing velocity also can be derived from the dynamic signal it generates. Furthermore, due to each individual's detected distinct gait pattern, when paired with a specific algorithm using MATLAB software, the band can identify and authenticate human identity in real-time with an ERR of 19.6 percent. This work opens new windows for self-powered motion sensors andhuman-machine interfacing.

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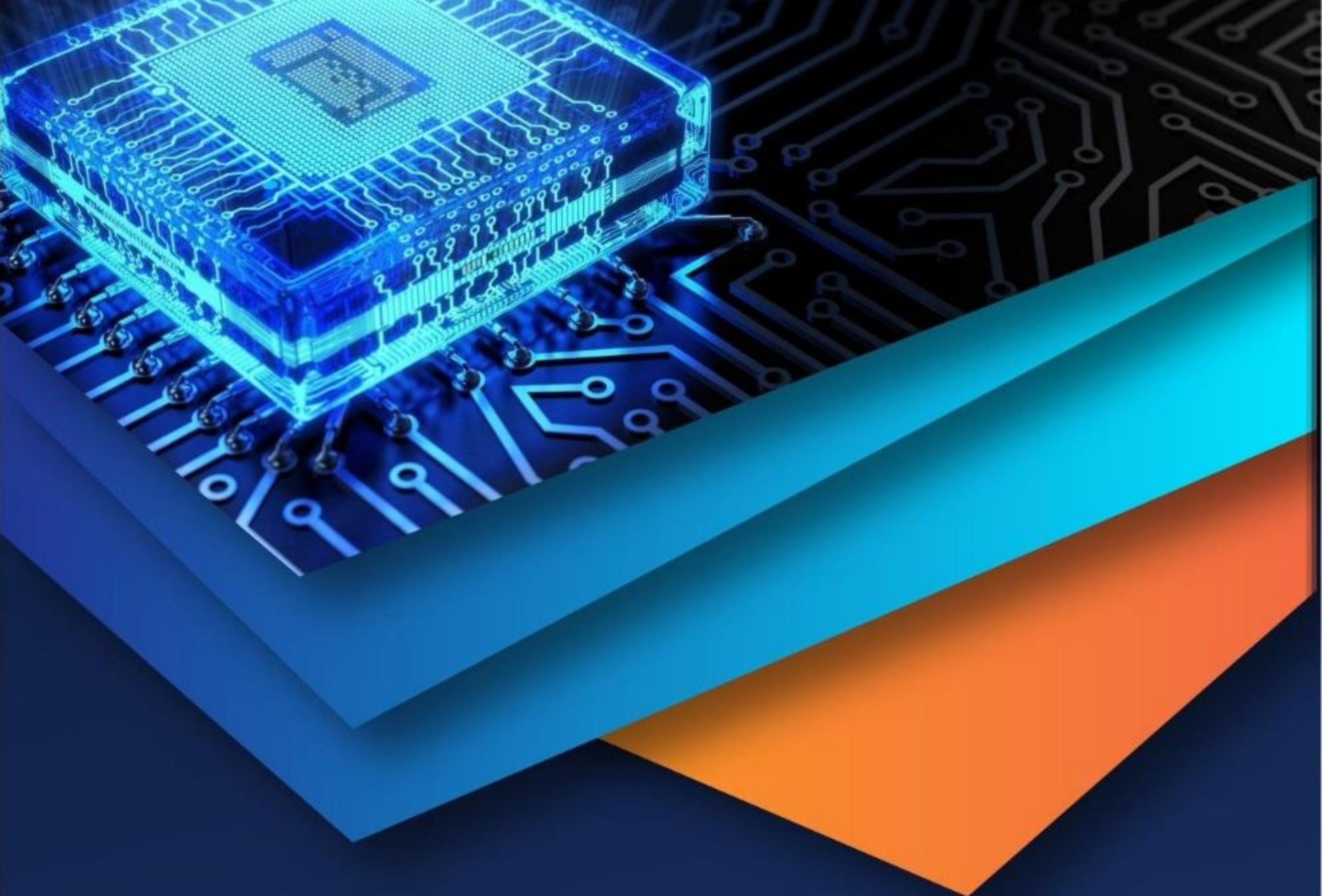

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