Poster Abstract: TENG-enabled Self-powered Human-machine Interfaces for the Metaverse

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ABSTRACT

Human-machine interface (HMI) of high degrees of freedom (DoF) is one of the most critical bases of the metaverse. The ideal HMI for the metaverse should be cheap, robust, customizable, and ergonomically friendly. In light of this, we propose a triboelectric nanogenerator (TENG)-based sensing system. We developed a low-cost, soft, light, and customizable TENG sensor to collect data from the human body. We then used an artificial neural network (ANN) to obtain the corresponding human motion from collected sensory data. The effectiveness of the proposed system is demonstrated with experiments of a working prototype.

CCS CONCEPTS

• **Hardware → Sensor devices and platforms**.

KEYWORDS

Triboelectric nanogenerator, Human-machine interface, Metaverse

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1 INTRODUCTION

Metaverse is an immersive virtual world for people to conduct a large variety of activities as avatars [7, 8]. As a fundamental basis of the metaverse, the exemplary human-machine interface (HMI) should have six degrees of freedom, including forward-backward, up-down, left-right, pitch, yaw, and roll. [3, 9]. Traditional HMI, such as mouse, keyboard, and touchpad, are limited to merely 2 degrees of freedom in operation [2, 4]. To intuitively maneuver virtual reality (VR) technologies, the body movement of 6 degrees of freedom should be properly collected and processed. Moreover, by ergonomics, the wearable sensors should be soft, portable, customizable, and robust with high sensitivity in different strain ranges.

As an emerging mechanical-to-electrical conversion technology, triboelectric nanogenerator (TENG) has been considered a promising approach to constructing low-power and even self-powered sensors due to the special property of electrostatic induction [5, 10]. TENG has the advantage of diverse material options and simple structures. Therefore, TENG sensors could be soft, light, and cost-efficient with the proper choice of material and mold design. In fact, scholars have integrated TENG into various HMI or VR applications including smart keyboards, E-skin, artificial muscles, etc. [1, 6].

This paper presents a TENG-based sensing system to capture human motion of high degrees of freedom. First, we developed a series of customized TENG sensors to be deployed on human joints. The TENG sensors would generate voltage pulses in regard to the movements of the joint. We then reconstruct the human body movement in the virtual world. However, experiments show that, when the TENG-based sensor bends, the output voltage is not perfectly linear with respect to the bending angle. We therefore designed an artificial neural network (ANN) to recover the actual bending angle of the joints from the sensing data. Overall, we developed a TENG-based HMI prototype to perform real-time human movement reconstruction in the digital world.

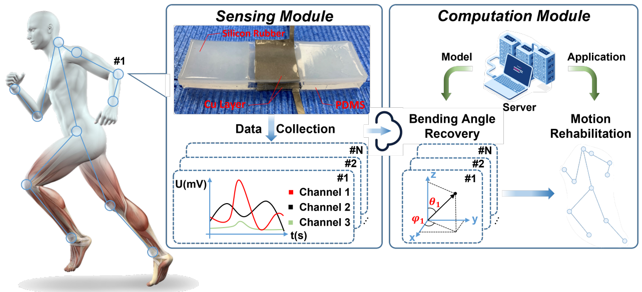

Figure 1: System Architecture

2 SYSTEM ARCHITECTURE

As shown in figure 1, the TENG sensors are deployed on the main joints of the human body. The collected data is fed into the computation module for human motion reconstruction. A voltage matrix produced by multiple TENG sensors could represent the human motion of high degrees of freedom.

2.1 Sensing module

The TENG sensor comprises a Polydimethylsiloxane (PDMS) layer and a silicon rubber layer with embedded Cu meshes, as shown in the sensing module in figure 1. Due to the difference in electronegativity of PDMS and silicon rubber, any bending motion would induce a unique voltage difference. In fact, such a property made the sensor purely self-powered in the process of data collection. Additionally, this set of TENG sensors is purposely designed to be thin, light, and soft. To make it ergonomically friendly, we carefully measured the size of the human joints before design and fabrication. With laser-cutting acrylic sheets-based mold, the TENG sensors become customizable.

2.2 Computation Module

Experiments showed that the data collected by the sensor are not perfectly linear. To cope with such nonlinearity, we introduce the ANN to process the sensing data due to its powerful modeling capability. The output voltage of the sensor varies with respect to different bending angles. The ANN is able to capture the relationship between different outputs and different bending angles. After completing the data collection of different outputs and different bending angles, we designed the ANN to fit the data. The ANN uses the output voltage of the sensor as input and the true value of the bending angle as the label to train the neural network. we repeatedly use linear motors to generate different bending angles for training data collection. We train the ANN with the output voltage values from different bending angles as inputs and the generated bending angles as labels. We use mean squared error (MSE) as the loss function, and stochastic gradient descent (SGD) as the optimizer. The training of the network lasted for 50 rounds. We use 80% of the collected data as the training data and the remaining 20% as testing data.

3 EVALUATION

We conducted preliminary evaluations of system performance using a TENG sensor customized for the human elbow. We deployed the sensor on the arm of the testees who were then asked to bend their arms.

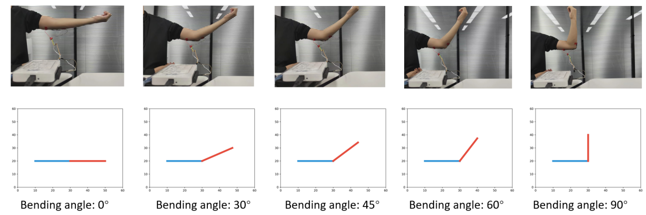

Figure 2: Experimental validation of the system on a human arm.

Figure 2 shows the experiment results from one testee. The first row in the figure shows the bending arm wearing the TENG sensor. The second row shows the reconstruction of the movement in the digital world. Experiments show that the system captures the bending movement of the human arm at different angles and maps such movements in the digital world.

4 CONCLUSION AND FURTHER DEVELOPMENT

In this paper, we propose a simple-structured TENG-based HMI system to approach high degrees of freedom. We developed ergonomically friendly TENG-based sensors to monitor the movement of human joints. A prototype deployed on the human arm showed successful motion monitoring. More comprehensive body movements of high degrees of freedom can be captured by deploying multiple TENG sensors onto different body parts. We would further design a more sophisticated neural network to approach whole-body motion monitoring.

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