International Journal of Science Academic Research
Vol. 04, Issue 07, pp.5959-5962, July, 2023
Available online at http://www.scienceijsar.com
ISSN: 2582-6425

Research Article

WEARABLE ELECTRO-MECHANICAL SENSOR FOR THE DETECTION OF COLD SYMPTOMS

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Received 25th May 2023; **Accepted** 14th June 2023; **Published online** 30th July 2023

Abstract

In the ongoing battle against seasonal flu and infectious diseases, wearable sensors have emerged as innovative tools that offer valuable insights into individual health and public health monitoring. These wearable devices, equipped with advanced sensing technologies, provide continuous real-time monitoring of various physiological parameters associated with flu-like symptoms. By tracking vital signs, such as body temperature, heart rate, respiratory rate, and oxygen saturation, wearable flu sensors offer early detection, prompt intervention, and proactive management of flu cases even in daily lives. In this article, we will review the mechanical sensors, specifically about the key features, working principles, and potential applications of wearable mechanical sensors, highlighting their significant role in revolutionizing personal health monitoring and contributing to global efforts in flu prevention and control.

Keywords: Wearable sensor, Electro-mechanical, Stretchable, Real-time, Health-care, Flu.

INTRODUCTION

The diagnosis of flu is a crucial step in managing and controlling the spread of this contagious respiratory illness. Accurate and early diagnosis enables healthcare professionals to provide appropriate treatment, implement preventive measures, and monitor the progression of the disease. Traditionally, diagnosing flu involved clinical evaluation based on symptoms and, in some cases, laboratory testing. However, advancements in technology and medical research have led to the development of more sophisticated diagnostic methods. Among these technologies, wearable sensors have emerged as transformative technologies that enable continuous monitoring of various physiological and environmental parameters in real-time (Figure 1). These sensors, typically integrated into devices that can be worn on the body, have revolutionized the fields of healthcare, fitness, sports, and beyond. Wearable sensors provide valuable insights into an individual's well-being, performance, and overall quality of life by collecting and analyzing data on vital signs, movement patterns, environmental conditions, and other relevant metrics. There have been many demonstrations of wearable type of sensors by using various kinds of working principles. In terms of reliability, cost and fabrication, the electromechanical sensorshave drawn intensive attention for wearable health-care monitoring. Another indispensable technology for integrating these sensors to the body, which has irregular and curve-linear surfaces, is flexible or stretchable electronics. In general, human skin has irregular and curve-linear surfaces, on which the commercial sensors could not be attached conformally. Stretchable electronics is a research field at the intersection of materials science, engineering, and electronics, which focuses on the development of electronic devices that can be stretched, bent, or deformed without compromising their functionality. Unlike traditional rigid electronics, stretchable electronics offer unique capabilities and possibilities for applications in wearable technology, healthcare monitoring, soft robotics, and more (1-5).

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By incorporating flexible and elastic materials, such as polymers and nanomaterials, stretchable electronics allow for conformable, skin-like integration with the human body or other curvilinear surfaces (6,7). By combining sensor technology and stretchable platform, we could develop the advanced type of medical health-care devices, which could be used in daily life by attaching on our body. In this article, we will firstly explore the principles of mechanical and electrical sensors (Termed "electromechanical sensor"). Next, we will review the strategies in stretchable and flexible technology for integrating these sensors on our body. Finally, we will show the health-care parameters related to flu, which could be detected with wearable electric, mechanical sensors.

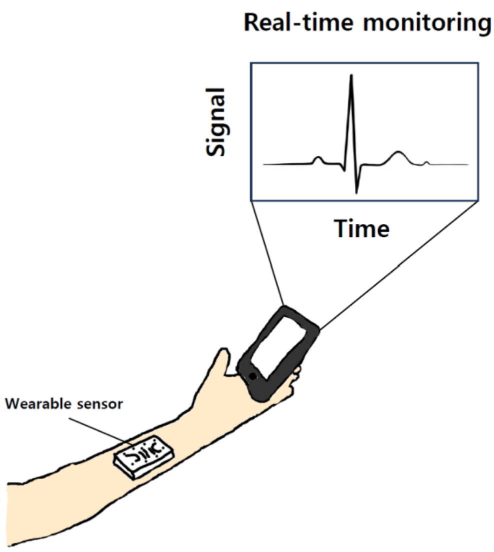

Figure 1. Schematic showing real-time monitoring of bio-signal from wearable device

IMU and temperature sensor for electric, mechanical detection

IMU is a sensor technology that plays a crucial role in various fields, including robotics, virtual reality, motion tracking, and navigation systems. An IMU sensor is a combination of several sensors, typically including accelerometers, gyroscopes, and magnetometers, which work together to measure and track an object's orientation, position, and motion in three-dimensional space (8,9). By collecting data on acceleration, rotation, and magnetic fields, IMU sensors provide valuable information about an object's movement and spatial orientation. In particular, magnetometers gauge magnetic forces in reference to Earth's magnetic field through the principles of the Hall effect: if a current carrying conductor is deposited in a magnetic field, then a voltage is produced over the conductor perpendicular to the current and the magnetic field. Then electrodes inside the conductor are affected by the blockage of the magnetic field, resulting in the read voltage. Voltage reading also varies proportionately according to variation of applied force, affording the value and the direction of the magnetic field. This is displayed as an electrical quantity, which offers the orientation through the vector calculations. IMUs are easy to prepare and, more importantly, able to collect human movement data regarding the inertial motion, and 3D orientation of individual limb segments in unrestricted environments. Natural movement of our body yield mechanical signals, which are almost attenuated by the skin. Body motions, ranging from subtle vibration to large scale movement contain various important information for predicting status of human health. For example, cardiac signals originated from atrium/ventricular conduction mechanism contain 90-120 beats/minute (1.5-2 Hz in frequency) while respiratory rate has 15-18 breaths/minute (0.25-0.3 Hz) (10). In terms of body daily body motions, rather than camera-based systems which are disturbed by location, occlusion, and lighting issues, IMU systems can track sophisticated postures in the various environments through 'real-world' training. Moreover, IMUs are highly effective in assessing joint angles, comparable to marker-based systems. Because of these advantages, IMUs have been predominantly utilized for investigating components of lower limb exercises.

Monitoring skin temperature can provide valuable insights into an individual's health. Changes in skin temperature can be indicative of various conditions and can help detect potential issues. Firstly, elevated skin temperature is often associated with fever, which is a common symptom of infections and inflammatory conditions. Monitoring skin temperature can help identify the presence of a fever and track its progression. Moreover, circulation and blood flow could be detected through the on-skin temperature sensor (11). Skin temperature can be influenced by blood circulation and blood flow patterns. Poor circulation or vascular disorders can lead to abnormal skin temperature in specific areas. For example, cold or cool areas on the extremities may indicate reduced blood flow, while increased warmth may suggest inflammation or infection. A wearable temperature sensor is a device designed to measure and monitor body temperature conveniently and non-invasively. These sensors are typically integrated into wearable devices such as smartwatches, fitness trackers, or patches. They allow individuals to track their body temperature continuously or at regular intervals, providing valuable data for various applications, including health monitoring, fitness tracking, and fever detection. Resistance temperature detectors (RTDs), thermocouples, and thermistors are widely used temperature sensors. By using them, we can calculate the current skin temperature accurately. One of the temperature sensors, RTDs, are strong candidates for temperature sensors because they have high accuracy, linearity, and quick response properties. Moreover, they are suitable for a low-thickness profile produced by the deposition of a thin film of conductor on a substrate. To be specific, they utilize the temperature dependence of the material on electrical to calculate the temperature. When the temperature increases, electrical resistance also increases owing to electron vibration at higher temperatures, preventing the free flow of electrons in conductive material. The temperature coefficient of resistance (TCR) is a critical parameter in analyzing the temperature sensitivity of the Materials. The equation below defines the thermal response (TCR) of the Material for RTD applications.

$$\alpha = \frac{1}{R(T0)} * \frac{R(T) - R(T0)}{T - T0}$$

R(T) is the resistance at temperature *T*, $R(T_0)$ is the initial resistance *T* of the tested sample at 0 temperature, and T_0 is the initial temperature. The high TCR value indicates high precision. With optimization of these thermal parameters, we could devise the wearable temperature device for real-time on-skin temperature monitoring.

How to make the sensors in stretchable form?

"Skin-like" and "epidermal" describe devices which are ultrathin, soft, and comparable thermal masses, having almost same properties as epidermis. With these prominent properties, the devices can have intimate contact on the skin. Comparing with flexibility, stretchability provides superior conformality of device on irregular surfaces like skin (Figure 2).

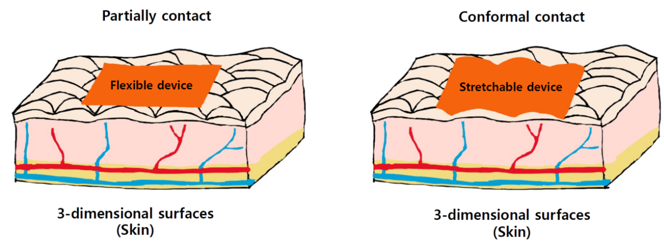

Figure 2. Schematic showing comparison between flexibility and stretchabiltiy

To utilize these devices, they must be able to bend and stretch during natural body motion, comparable to the epidermis which can deform up to 15% with an elastic modulus ranging from 10 kPa to a few hundred kPa. However, large mechanical mismatch occurs between biological tissues and the materials used as the functional layers in the electronic devices, causing malfunction or breakdown of electronic devices. Moreover, during this unintended process, skin could be easily exposed to inflammation. To overcome these limitations, many kinds of soft materials and strategies have been developed and reported. Firstly, elastomer, which has similar elastic moduli (~100 kPa) to those of the biological tissues, is a promising candidate for skin electronics. It has a very large degree of deformation, maintaining elasticity. In general, an electronics system consists of not only dielectric materials but conductors. For this reason, stretchable conductor is also required to operate entire system, however, the elastomer is not conductive. There are many strategies to form the stretchable conductor including mechanical design and conductive composite materials. Recent developments in nanotechnology and thin-film processing have facilitated the production and combination of ultrathin polymeric, metallic, and semiconducting materials to create conductive electronic devices. Due to the reduction in bending stiffness by several orders of magnitude, such combination enables bending to small radii of curvature without breaking. Moreover, fabrication of large organic and inorganic devices on ultrathin substrates also could be a great approach for developing stretchable electronic systems. These devices can have greatly small bending radii even though materials with large elastic moduli are used. Another candidate for establishing mechanical stability is to locate the devices in zero-strain plane (middle of the thickness) so that the device could be protected from external stress. Similar to this, structural design is important in enhancing mechanical stability of electronic devices. Combining inorganic semiconductors and conductive metals with soft substrates has developed stretchable electronic devices. The most prevailing strategy is "island-bridge" designs where conductive "bridges" interconnect robust functional "islands." Because the bridges have stretchability that could relax the stress, they can hold stretching of the whole system while mitigating strains in the islands. To be commercialized, these designs must endure consecutive strains from natural motion of the body and must be modified to deform only in usage. Specifically, bridge is fabricated by serpentine or wavy-shaped rigid materials or conductive elastomers. When entire system is stretched or bent, those bridge materials are deformed instead of islands, protecting island parts where the sensors or functional components are located.

The health-care applications for flu monitoring with wearable sensors

When we getflu, there are many symptoms in our body in terms of cardiac sound, temperature, respiratory pattern. Currently, medical approach could use electrocardiogram (ECG). Cardiovascular conditions can be assessed by analyzing signals generated during the rhythmic heartbeat. ECG signals are produced due to the heart's specialized electrical conduction system, composed of distinct cardiomyocytes. The sinoatrial node excites the cardiomyocytes, and the electrical signal propagates through the atria and ventricles in a specific path and sequence, ultimately creating the ECG signal on the body's surface. Heart sound signals are produced by the opening and closing of valves during each heartbeat. Additionally, pulse waves generated by the arteries, in conjunction with the cyclic contraction of the heart, carry various information about heart pumping activity and pressure waves along the arterial tree. Beyond this, by using the vibrational mechanic sensor could detect cardiac signals more accurately. The pumping of blood generates a complex and subtle force, resulting in the generation of seismocardiogram (SCG) signals based on the force and reaction force. SCG refers to a signal generated by the subtle vibrations caused by the mechanical forces associated with the heartbeat. It is a measure of the vibrational signals and accelerations produced by the heart's contraction and relaxation cycles. The SCG signal is captured using specialized sensors placed on the chest or body surface. The SCG signal provides information about the mechanical aspects of the heart's activity, including the timing and intensity of heart sounds, as well as the cardiac ejection and filling processes. By analyzing the SCG signal, researchers and healthcare professionals can gain insights into cardiovascular health, including the assessment of cardiac function, detection of abnormal heart rhythms, and evaluation of heart valve disorders. The measurement and analysis of SCG signals are still a developing field, and ongoing research aims to further understand its potential applications and clinical significance. SCG has the advantage of being non-invasive and can be used alongside other cardiovascular monitoring techniques to provide a more comprehensive assessment of heart health. With this technology, we could integrate the temperature sensor to support the accuracy of system. A wearable skin temperature sensor for real-time monitoring can be a valuable tool in assessing an individual's health status. During a flu infection, the body's immune system is activated to defend the viral infections. This immune response can cause various physiological changes, including an increase in body temperature. When the immune system detects the presence of a virus, it releases chemicals called pyrogens, which act on the hypothalamus in the brain. For this reason, monitoring the change on skin temperature could be a great standard to diagnose the health condition.

Conclusion

A wearable health-monitoring system using an electro-mechanical sensor has the potential to provide valuable insights and aid in the management of flu infections. By combining various sensors and technologies, such as temperature sensors, motion sensors, and possibly even respiratory rate monitors, a wearable device can continuously monitor relevant health parameters and provide real-time data for analysis and intervention. Such a system can offer several benefits, including early detection of flu symptoms, continuous monitoring of vital signs, and the ability to track the progression and severity of the infection with a non-invasive process. It can also assist healthcare professionals in remotely monitoring patients, enabling timely intervention and personalized care. Electrochemical based health-care systems can provide individuals with a better understanding of their health status, allowing them to take appropriate measures, such as seeking medical attention or practicing self-isolation to prevent the spread of the infection. These devices can also contribute to public health efforts by providing aggregated data on flu prevalence and trends, helping authorities respond effectively. As technology advances and wearable devices become more sophisticated, the potential for wearable health-monitoring systems for cold or flu symptoms to play a significant role in early detection, prevention, and management of flu infections continues to expand.

Acknowledgement

I would like to thank Sunny Kim for his guidance, and encouragement during the process of this review paper.

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