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Research Article

NON-INVASIVE REAL-TIME COLD MONITORING TECHNOLOGY ENABLED BY MULTI-FUNCTIONAL WEARABLE SENSOR SYSTEM

***Shue Park**

Dubai American Academy, United Arab Emirates

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Abstract

Wearable technology has become increasingly important in recent years, offering innovative solutions for monitoring various aspects of human health monitoring. Starting from prevalent disease, many sensors have been developed to detect how patients feel pain or stress during cold symptoms. This paper introduces a novel "Wearable Cold Detection Sensor" designed to enhance personal comfort and safety for daily lives of patients. Basically, the system has multi-functionality to enhance the accuracy of diagnosis. Typical types of sensors widely used for cold symptom are thermal sensor, bio-sensor and mechanical sensor. It incorporates highly sensitive temperature sensors capable of accurately measuring and comparing body and ambient temperature. Moreover, new class of sensor including mechanical sensor for vibrati.onal signal detection would be promising candidates for wearable medical system. This innovative wearable technology has applications in various fields, including outdoor activities, sports, healthcare, and occupational safety. It empowers individuals to make informed decisions to protect themselves from cold-related risks, ultimately enhancing their comfort and well-being in cold environments. Future developments may involve integrating additional environmental sensors and expanding compatibility with other smart devices to create a comprehensive wearable weather monitoring system.

Keywords: Cold monitoring, Technology

INTRODUCTION

In the modern world, people are becoming more reliant on technology, and technology is becoming more and more ingrained in people's daily lives. As a result of technology's tendency to get faster and smaller, new wearable technologies like smart watches, smart glasses, and smart contact lenses have emerged. Furthermore, with the appearance of Covid-19, the need for real-time monitoring has increased greatly as the current diagnostic methods are inconvenient, invasive, and inadequate for daily usage. The use of electronic sensors, such as epidermal tattoos, contact lenses, textiles, face masks, wristbands, and patches, can help gather physical and biochemical signals that were formerly unattainable. Utilizing the data from these sensors could also lessen the influence of environmental, behavioral, and other outside factors on diagnosis. Therefore, without having to access a huge training dataset, this strategy could increase the diagnostic performance via manipulating the established correlations between biomarkers and the physiological condition of the body. The analyte or physical quantity of interest and the intent of the measurement determine the complexity of each wearable sensor. When human bodies expose to health issues, they emit distinct vibration signals that show abnormality status of body. However, interpreting these signals through human eyes can be challenging, so mechano-acoustic sensing is employed as an alternative approach. Mechano-acoustic sensors fabricated in wearable platform could capture a range of vibration signals, such as blood pressure, heart rate, respiration, and vocal changes from our body (Figure 1). Various kinds of body signals could be detected from the skin-device interface, including cardiac information, temperature, hormones, which is vital standards for detection of diseases.

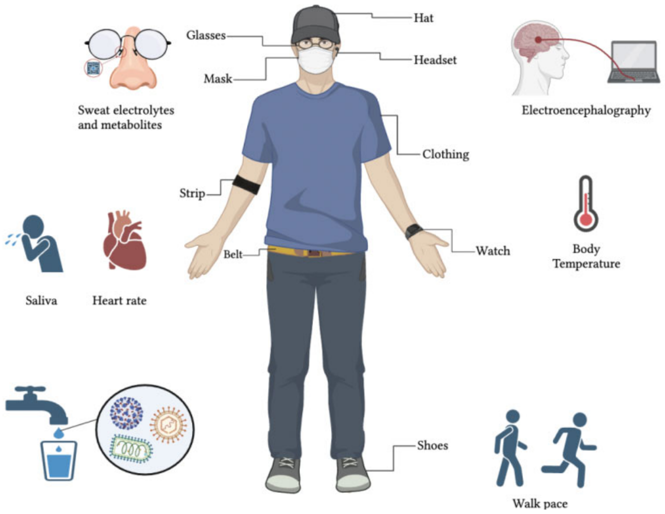

Figure 1. Wearable health-care system for body signal

These sensors comprehensively measure all the signals at once and subsequently differentiate these signals, eliminating the need for multiple sensors. Because wearing numerous sensors at one time is impractical, a system's performance can be increased by adding additional transducers or multiplexing the evaluation of multiple analytes. As technology advances, wearable devices have changed from large or bulky to flexible, thin or stretchable from. To ensure mechanical stability, researchers have focused on materials used in creating these wearables. The new devices are incredibly thin, with bending radii as small as tens of microns, and they employ high-strength materials like carbon nanotubes and graphene to enhance durability. Some studies have found that these wearable devices can function as an epidermal system, with self-healing conductors and electronic skins that mimic the flexibility and thinness of human skin. Structural design also

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Corresponding Author:** ***Shue Park
Dubai American Academy, United Arab Emirates.

plays a significant role in improving the thickness and performance of these wearable devices. By incorporating inorganic semiconductors, conductive metals, and soft substrates, more effective wearables can be produced. These structures allow for flexibility without fragility, making the devices resistant to mechanical damage even during repetitive strains caused by frequent movement. One effective design strategy called "island bridges" uses conductive traces as bridges along with rigid conductive traces to reduce stiffness and strain. This ensures long-term durability and functionality of the devices. Electronic properties are crucial in determining the performance of wearable devices. While organic materials show promise, they have limitations in electrical mobility and semiconductor stability, hindering their effectiveness. Inorganic materials, including semiconductors, dielectrics, and conductors, perform exceptionally well in wearable devices. One-dimensional and two-dimensional materials also exhibit great electrical and mechanical properties, but more research is needed to fully harness their potential in flexible and stretchable systems. For skin interfacing, materials like gold, platinum, and copper are commonly used for electrodes due to their chemical inertness and low contact impedance. Liquid metal alloys encapsulated in soft elastomers offer an alternative for stretchable interconnects and antennas. Integrating wearable devices onto the skin can be achieved through three main approaches: temporary epidermal tattoos, hard-soft integration, and functional substrates. Each method is based on different ways of attaching the devices and their potential functionalities. Early epidermal electronics used silicone materials, similar to tattoo ink, to achieve optimal conformal skin-device contact, adhesion, and transpiration. These "fabricated tattoos" are laminated onto the skin for electrophysiological measurements and other applications.We will review of material and clinical aspect for wearable cold monitoring system using mechano-acoustic devices to achieve patient-oriented future clinical system.

Soft materials for developing wearable system

When it comes to creating sophisticated wearable electronic devices, electronic properties are as important as mechanical properties. Since organic materials are biocompatible, they are promising candidates as a natural option when interacting with biological tissues, and can now be produced on a wide scale thanks to commercial printing methods. However, the realization of rapid circuitry and stable operation has been limited by the low electrical mobility and chemical instability of organic semiconductors. On the other hand, a variety of inorganic materials, such as semiconductors, dielectrics, and conductors, present the possibility of producing high-performance functional active devices. Although there are a few examples of one- and two-dimensional inorganic materials used in stretchable and flexible functional systems, such as carbon nanotubes (CNTs), graphene, and transition-metal dichalcogenides, they are still in the early stages of development. By incorporating conductive nanoparticles into soft polymeric matrix, highly conductive composite materials can be designed as advanced conductive materials for providing electrical functions as well as mechanical softness. Composite conductors provide the adaptability to modify their electrical and mechanical characteristics to meet particular needs. They are useful for creating electronic components with custom features because of their tunability. Furthermore, liquid metal alloys enclosed in soft elastomers have been studied as possible substitutes for device modules and stretchy interconnects. Stretchable electronic systems can benefit from these materials' ability to maintain mechanical integrity while offering the necessary flexibility and conductivity.

One of parameter, which is one of essential properties is modulus. Young’s modulus is expressed as below

Modulus = Stress / Strain

Young's modulus, also known as the modulus of elasticity, is a measure of the stiffness of a material. It describes how a material deforms when subjected to axial (tensile or compressive) stress. It is generally accepted standard for expecting the softness and deformability of soft materials. Furthermore, mechanical modulus affects conformability of materials, which is very critical character for wearable health-care devices. Particularly, hydrogel material is one of low modulus material for biocompatible wearable electronics. However, hydrogel embeds water, which makes entire material soft, however, it hinders formation of electrically conductive pathways in side of the material. If we develop the material design, considering both electrical functions and mechanical modulus, wearable medical system might go step forward to next generation personalized medical system.

Soft sensor system for clinical detection

The development and implementation of soft sensor systems for clinical detection represent a transformative paradigm in healthcare technology, heralding a new era of precision diagnostics and patient monitoring. Soft sensors, often built upon flexible and pliable materials, seamlessly integrate with the human body, providing a non-intrusive means to collect real-time physiological data. These sensors hold immense promise in clinical settings, offering a host of advantages, including enhanced patient comfort, prolonged wear ability, and the potential for continuous, unobtrusive monitoring. The soft sensor systems are designed to capture a plethora of vital signs, ranging from heart rate and respiratory rate to skin temperature and sweat composition. Their conformable nature allows for placement on various parts of the body, ensuring a holistic monitoring approach. Moreover, the integration of advanced materials, such as stretchable electronics and biocompatible polymers, enables these soft sensors to accommodate the dynamic and intricate movements of the human body without compromising accuracy. The data obtained from soft sensor systems can be wirelessly transmitted to healthcare providers, facilitating remote monitoring and timely intervention. This innovation holds particular significance in chronic disease management, as soft sensors enable continuous tracking of key health parameters, empowering both patients and clinicians with actionable insights. As soft sensor technology continues to evolve, its potential applications in clinical detection are expansive, ranging from early disease detection to personalized treatment optimization, ushering in a new era of patient-centric and data-driven healthcare. With soft materials we reviewed above, researchers have designed wearable medical sensor platform, which could have intimate and conformal contact with our skin. Moreover, miniaturization of clinical device currently used in hospital enables health-care platform to be light-weight and portable. For instance, electrocardiogram (ECG) device needs many wires and has many noise signals even under subtle movement of body, which hinders accurate measurement under daily lives of patient. In contrast, seismocardiogram (SCG) is potential alternative for ECG. Device structure is very simple because of the simple detection mechanism (vibration), having potential candidate for highly miniaturized clinical system.

Detection mechanism of temperature, cardiac sensor

Cardiac information plays a central role in healthcare by enabling early detection, accurate diagnosis, effective treatment, and ongoing monitoring of heart-related conditions. It is indispensable for improving patient outcomes and advancing research in the field of cardiology. With next-generation wearable vibrational sensor, patient could detect cardiac disease in early stage. To understanding the mechanisms regarding detection of cardiac information via wearable devices, we need to consider two approaches: i) seismocardiogram (SCG) and ii) electrogardiogram (ECG). Basically, SCG is one of promising non-invasive method to detect the mechanical activity of the heart. It records the vibrations and movements of the chest wall generated by the heartbeat. It focuses on aspects like the opening and closing of heart valves (located in atrium/ventricle and ventricle/aorta) and the movement of blood within the heart. SCG is a non-invasive diagnosis technique, which involves attaching sensors to the chest to measure chest wall movements without the need for penetration or electrical connections. Comparing with SCG, ECG is commonly used in hospital to detect the electrical activity of heart. It records the electrical signals generated by the heart as it contracts and relaxes. It provides information about the heart's rhythm and can detect abnormal electrical patterns. SCG and ECG serve different but complementary roles in cardiology. SCG focuses on the vibrational signal of the heart's function, while ECG focuses on the electrical aspects. Both tests are valuable in diagnosing and monitoring heart conditions, and they are often used together for diagnosis the heart disease with high precision. As shown in Figure 2, the SCG and ECG is functionally matched, meaning that heart is well operated with synchronized rhythm. More specific explanation about this synchronized system, the comparison between Electrocardiography (ECG) and Seismocardiography (SCG) represents a pivotal exploration in the realm of cardiovascular diagnostics, shedding light on the distinctive attributes and complementary roles these two methodologies play in assessing cardiac function. ECG, a well-established and widely utilized technique, captures the electrical activity of the heart, providing invaluable insights into the depolarization and repolarization phases of the cardiac cycle. In contrast, SCG, a relatively novel approach, capitalizes on the detection of mechanical vibrations generated by the heart's contractions, offering a unique perspective on the mechanical aspects of cardiac performance. One notable distinction lies in the spatial domain, as ECG primarily focuses on electrical signals, while SCG delves into the mechanical forces and movements associated with cardiac muscle contraction. The temporal resolution of SCG is higher than that of ECG, allowing for a more nuanced analysis of subtle changes in cardiac dynamics. Moreover, SCG has the potential to unveil information about the contractile function of specific cardiac segments, providing a finer granularity in the assessment of regional myocardial activity. However, challenges such as signal noise and standardization of measurement protocols pose hurdles in the widespread adoption of SCG. Integrating the strengths of both modalities could present a comprehensive approach to cardiac monitoring, offering a synergistic interpretation of electrical and mechanical events. As research in this field progresses, the peak comparison between ECG and SCG not only enriches our understanding of cardiac physiology but also holds promise for enhanced diagnostic accuracy and personalized patient care in the realm of cardiovascular medicine. Moreover, temperature sensor helps to diagnosis cold symptom. Different from rigid type temperature sensors, wearable soft temperature sensor could be designed easily by using soft conductive composite. Basically, the dynamic movement of electrons in conductor increases as temperature increases, making entire conductivity of conductive composite higher. From this mechanism, skin temperature or core body temperature can be detected with high accuracy on the skin, maintaining intimate contact between skin and temperature sensor. Data analysis of dual parameter, measured by wearable cardiac and temperature sensor will enhance the diagnostic accuracy, realizing personalized and in-home health-care platform.

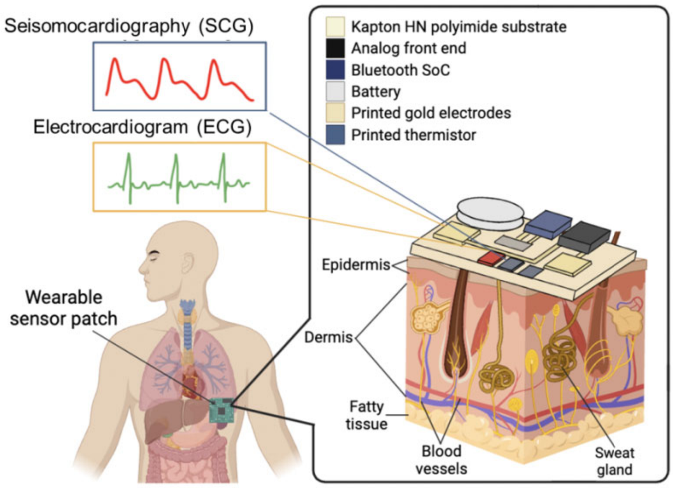

Figure 2. Seismocardiography and Electrocardiogram measured on skin

Conclusion

In conclusion, the advent of non-invasive real-time cold monitoring technology facilitated by a multi-functional wearable sensor system represents a significant leap forward in the realm of healthcare and personal well-being. The integration of such advanced sensor systems not only allows for the continuous tracking of environmental and physiological factors influencing cold exposure but also offers a nuanced understanding of individual responses to temperature variations. This technology holds promise for diverse applications, ranging from the optimization of thermal comfort in everyday settings to the prevention of cold-related health issues. The real-time nature of the monitoring provides timely insights, enabling individuals to make informed decisions about their activities and clothing choices, thereby mitigating the risks associated with cold exposure. Soft materials still have been researched from many groups and have many challenges in terms of long-term durability for practical application. Conductive composites embed conductive nanomaterials are promising candidates for next generation clinical device, however, the electrical performances such as conductivity change, recovery of conductivity are unstable due to permanent deformation (plastic deformation). Based on this materials, wearable medical device becomes softer, which makes intimate and durable interfaces between device and skin. Development of soft sensor platform integrated with SCG/ECG and temperature sensor enables monitoring of diverse status of cold symptoms.

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