International Journal of Science Academic Research
Vol. 04, Issue 08, pp.6058-6061, August, 2023
Available online at http://www.scienceijsar.com
ISSN: 2582-6425

Research Article

ON-SKIN, WEARABLE HEALTH-CARE MONITORING SYSTEM ENABLED BY MULTI-FUNCTIONAL SENSORS

***Seoyeong, Lee**

Fayston Preparatory School, South Korea

Received 20th June 2023; **Accepted** 25th July 2023; **Published online** 30th August 2023

Abstract

The wearable electronics as emerging technology has paved the way for the development of on-skin, wearable healthcare monitoring systems. These systems leverage multi-functional sensors to provide real-time monitoring and analysis of various health parameters. The integration of various devices, ranging from mechanical sensor, vibrational sensor to temperature sensor, into wearable platform allows for continuous and non-invasive health monitoring, offering numerous benefits in terms of convenience, early detection of health issues, and personalized healthcare. Here, we review an overview of on-skin, wearable healthcare monitoring systems enabled by multi-functional sensors. We discuss the widely used sensor components for health-care monitoring system, including strain-gauge, electrocardiogram (ECG), vibrational sensor and temperature sensor. With data processing of signals obtained from these sensors, we could monitor the current status of health more accurately. Furthermore, we explore the potential applications of these systems in healthcare, highlighting their use in monitoring vital signs, tracking physical activity, and assessing skin health.

Keywords: Skin, Wearable, Multi-functional sensors.

INTRODUCTION

The integration of wearable technology into healthcare has brought about significant advancements in the field of remote patient monitoring and personalized healthcare. One of the key developments in this research field is the emergence of on-skin, wearable healthcare monitoring systems enabled by multi-functional sensors (1-3). These systems offer the capability to monitor various health parameters in real-time, providing valuable insights into an individual's health and allowing for early detection of potential risk.Traditionally, healthcare monitoring involved periodic visits to medical facilities or the use of bulky monitoring equipment, limiting the frequency and duration of data collection. On-skin, wearable healthcare monitoring systems overcome these limitations by incorporating multi-functional sensors that can be directly applied to the surface of the skin. In general, the human skin has curve-linear surfaces, which is not compatible with rigid and bulky devices (4). Current medical devices are rigid and bulky structure that might limit our movement including exercising, walking when it attached on our body. To minimize this limitation, deformability of devices enables continuous and non-invasive monitoring, giving individuals the ability to track their health in real-time and make informed decisions about their lifestyle and medical interventions even during dynamic movements (Figure 1). The key advantage of multi-functional sensors is their ability to detect a wide range of physiological signals from the body. These sensors are designed to measure parameters such as heart rate, blood pressure, body temperature, electrocardiogram (ECG), respiratory rate, oxygen saturation, electrodermal activity (EDA), and more (5-7). By collecting and analyzing these data points, healthcare professionals and individuals can gain insights into various aspects of their health, including cardiovascular function, sleep patterns, stress levels, and physical activity.

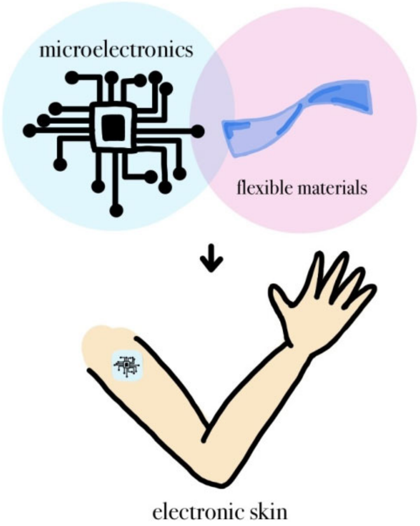

Figure 1. Miniaturized flexible shape of electronic skin

The on-skin nature of these wearable systems is made possible by the use of flexible and stretchable substrates that conform to the contours of the body, ensuring a comfortable user experience. The sensors are often integrated into wearable devices such as smartwatches, patches, or adhesive strips, allowing individuals to wear them throughout the day without impeding their daily activities. In addition to the sensor technology, data processing and communication infrastructure are vital components of these monitoring systems. Advanced algorithms and machine learning techniques are employed to process the sensor data, filter out noise, identify patterns, and detect abnormalities (8,9). The processed data can be displayed on the wearable device itself or transmitted wirelessly to a smartphone or cloud-based platform for further analysis and storage. This seamless integration with digital platforms provides individuals with tracking their health trends over time, sharing data with healthcare professionals, and receiving personalized recommendations from doctors.

Corresponding Author:** ***Seoyeong, Lee
Fayston Preparatory School, South Korea

In this review, we will focus on novelty of wearable multi-functional sensor system in terms of non-invasive and continuous health-care monitoring. The potential applications of on-skin, wearable healthcare monitoring systems are vast. They can be utilized in various healthcare settings, including personal wellness management, chronic disease management, postoperative care, elderly care, and remote patient monitoring. By enabling continuous monitoring and early detection of health issues, these systems have the potential to reduce healthcare costs, improve patient outcomes, and enhance overall well-being. We will highlight the principle and structure of each sensors which could be integrated with wearable health-care platform.

Design strategies for wearable sensor technology

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 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.

Electrocardiogram (ECG) for monitoring of heart activity

Heart has conduction mechanism referring to the electrical system within the heart that coordinates and controls its rhythmic contractions. The heart's conduction system consists of specialized cells that generate and transmit electrical impulses, ensuring that the heart contracts in a synchronized manner. Medical device could detect those signals from electrocardiogram (ECG) to check the heart activity. Before design the ECG in wearable form, we need to understand the basic conduction mechanism of heart. Heart conduction system includes the following key components including sinoatrial (SA) node, atrioventricular (AV) node, bundle of His, bundle branches and Purkinje fibers. Firstly, the SA node is often referred to as the "natural pacemaker" of the heart. It initiates each heartbeat by generating an electrical impulse, causing the atria to contract. The SA node sets the heart's basic rhythm and determines the heart rate. Second, AV node, situated between the atria and ventricles, serves as a gatekeeper for the electrical signals. It receives the impulses from the SA node and slightly delays them, allowing the atria to complete their contraction before the ventricles receive the signal. After passing through the AV node, the electrical impulses travel down the bundle of His, which is a collection of specialized fibers located in the septum, the wall dividing the ventricles. The bundle of His divides into two branches, the right bundle branch and the left bundle branch, to distribute the electrical signals to their respective ventricles. The bundle branches further divide into smaller fibers called Purkinje fibers. These fibers spread throughout the ventricles, delivering the electrical impulses to the muscle cells of the ventricles, resulting in their contraction.

Most of the heart diseases originate from malfunction of those electrical conduction mechanism of heart. ECG is a widely used medical diagnostic tool to assess the electrical activity of the heart. It is a non-invasive procedure that provides valuable information about the heart's rhythm, rate, and overall cardiac health. In an ECG, the peaks represent specific electrical events that occur during each cardiac cycle. There are typical waveforms in ECG measurement, providing the standard of normal condition: P wave, QRS complex and T wave (Figure 2). The P wave is the first positive deflection seen in the ECG waveform. It represents the depolarization (contraction) of the atria, which occurs as an electrical signal spread across the atria and stimulates their contraction. Following waveform is QRS Complex consisting of three distinct deflections: Q, R, and S. It represents the depolarization of the ventricles. The Q wave is the first downward deflection, followed by the R wave, which is the first upward deflection, and finally the S wave, which is a downward deflection. The QRS complex indicates the contraction of the ventricles, which pump blood to the rest of the body. At last, T wave is a positive deflection following the QRS complex. It represents the repolarization (recovery) of the ventricles as they prepare for the next heartbeat.

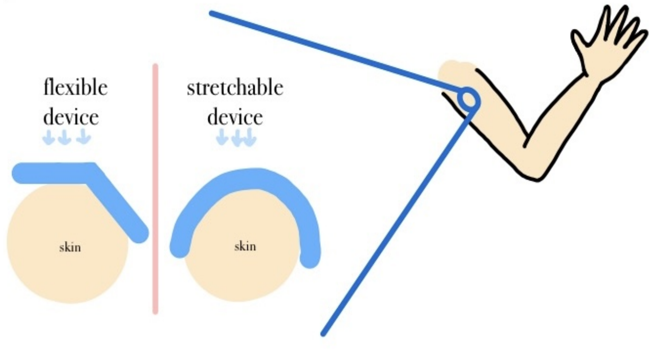

Figure 2. Comparison of flexibility and stretchability for skin electronics

One of the significant advantages of ECG is that it is a non-invasive and painless procedure. Electrodes are placed on the patient's chest, arms, and legs, which record the electrical signals of the heart. This makes ECG a safe and widely accessible diagnostic tool, suitable for individuals of all ages. Comparing with current ECG device, flexible/stretchable technology have changed the ECG technology to enhance the accuracy and comfortability to patient by using advanced materials. Wearable ECG device could monitor our heart activity in real-time during the daily activity of patients. In the future, understanding of medical parameters and corresponding device electronics will pave the way to develop the non-invasive, patient-oriented medical system.

Detection of seismocardiography (SCG) from vibrational sensor

One of recent technology for monitoring heart activity is seismocardiography (SCG), which detects the vibrational signal resulting from open/close of valve in the heart. For this measuring method, flexible wearable sensors which is typically called “mechanoelectric techniques”, focusing on subtle vibrations. These sensors can be categorized into several types: resistive, capacitive, piezoelectric, and triboelectric sensors. Despite having different underlying mechanisms, these sensors share similar configurations, typically comprising an active sensing component sandwiched between two electrodes. In all cases, the active sensing components respond to strain or pressure, leading to changes in resistance, capacitance, or electrical output. While resistive and capacitive sensors require external power for sensing, self-powered piezoelectric and triboelectric sensors can directly convert pressure or strain into electrical signals. Additionally, resistive sensors employ conductive networks as their active sensing components, with variations in resistance occurring due to geometric changes, crack propagation, disconnection mechanisms, etc. In contrast, capacitive, piezoelectric, and triboelectric sensors use dielectric materials as their active components, where changes in their geometry in response to pressure or strain cause variations in capacitance and transferred charges (10).

Based on these technologies, we could detect the vibrational pattern of signal cause by heart activity. These mechanical signal features various of peaks. From the graph, SCG provides valuable information about various aspects of cardiac function, including cardiac timing, output left ventricle function and heart sound. Specifically, SCG can help determine the timing of different events in the cardiac cycle, such as the opening and closing of heart valves. This information is crucial for assessing the heart's efficiency and identifying any abnormalities in its rhythm. In terms of output, SCG can provide an indirect measure of cardiac output, which is the amount of blood pumped by the heart per minute. Changes in the amplitude and frequency of the seismocardiographic signals can be indicative of alterations in cardiac output.The left ventricle is the main pumping chamber of the heart. SCG can offer insights into the contractility and function of the left ventricle, aiding in the assessment of heart health. Moreover, SCG allows for the study of heart sounds, which are produced by the flow of blood and the closure of heart valves. Analyzing these sounds can provide information about the heart's condition and potential abnormalities. SCG is still considered a relatively novel and developing field of research. It is promising method as a non-invasive and cost-effective method for cardiac monitoring and assessment. However, further studies and advancements are needed to fully establish its clinical utility and integration into routine medical practice.

Temperature sensor for skin health

Temperature sensor also provides important vital information, which enables monitoring the current health. The principle of a temperature sensor is based on the relationship between temperature and a physical property of a material that changes with temperature. The sensor is designed to detect and quantify this change, converting it into an electrical signal that can be measured and interpreted. Typically, thermistor is used for detection of skin temperature change. Thermistors are temperature sensors made from semiconductor materials with a highly temperature-dependent resistance. They exhibit a large change in resistance with temperature and can be of two types: Positive Temperature Coefficient (PTC) thermistors, where resistance increases with temperature, and Negative Temperature Coefficient (NTC) thermistors, where resistance decreases with temperature. Those sensors require intimate contact on skin and reducing thermal mass to minimize the effect of air temperature and leakage of heat, which need to be transferred to temperature sensor.

Conclusion

A wearable health-monitoring system utilizing various sensorsfor offering valuable insights and support in managing flu infections. By integrating various sensors and technologies like temperature, cardiac sensor, this wearable device can continuously track essential health parameters, providing real-time data for analysis and intervention. Importantly, vibrational signal, which includes vital information, showing heart activity, could be used as standard for diagnosing the diseases like flu. The benefits of such a system are manifold, including early identification of flu symptoms, ongoing monitoring of vital signs, and the ability to assess the infection's progression and severity in a non-intrusive manner. Additionally, it facilitates remote patient monitoring, enabling healthcare professionals to intervene promptly and deliver personalized care. Wearable healthcare systems empower individuals with a deeper understanding of their health status, prompting them to take appropriate actions like seeking medical attention or practicing self-isolation to prevent infection spread. Moreover, these devices contribute to public health initiatives by providing aggregated data on flu prevalence and trends, assisting authorities in making effective responses. As wearable technology evolves and becomes more advanced, the potential for wearable health-monitoring systems to play a pivotal role in the early detection, prevention, and management of flu infections continues to grow.

Acknowledgement: I would like to thank Sunny Kim for his guidance, encouragement during process of this review paper

REFERENCES

1. Xu K., Y. Lu, K. Takei, (2019) Multifunctional Skin-Inspired Flexible Sensor Systems for Wearable Electronics. *Adv. Mater. Technol.*, 4, 1800628.
2. Yao S., P. Swetha, Y. Zhu, (2018) Nanomaterial-Enabled Wearable Sensors for Healthcare. *Adv. Healthcare Mater.,*7, 1700889.

3. Rodgers M. M., V. M. Pai, R. S. Conroy, (2015) Recent Advances in Wearable Sensors for Health Monitoring. *IEEE Sensors Journal*., 15 (6), 3119-3126.
4. Oh J. Y., Z. Bao, (2019) Second Skin Enabled by Advanced Electronics. *Adv. Sci.,*6, 1900186.
5. M. M. Baig, H. Gholamhosseini, M. J. Connolly, (2013) A Comprehensive survey of wearable and wireless ECG monitoring systems for older adults. *Med Biol Eng Comput*, 51, 485-495.
6. Jin H., Y. S. Abu-Raya, H. Haick, (2017) Advanced Materials for Health Monitoring with Skin-Based Wearable Devices. *Adv. Healthcare Mater*., 6, 1700024.
7. Oh J. H., S. Y. Hong, H. Park, S. W. Jin, Y. R. Jeong, S. Y. Oh, J. Yun, H. Lee, J. W. Kim, J. S. Ha, (2018) Fabrication of High-Sensitivity Skin-Attachable Temperature Sensors with Bioinspired Microstructured Adhesive. *ACS Appl. Mater. Interfaces*, 10, 7263-7270.
8. Ozdemir A. T., B. Barshan, (2014) Detecting Falls with Wearable Sensors Using Machine Learning Techniques. *Sensors*, 14, 10691-10708.
9. Adans-Dester C., N. Hankov, A. O'Brien, G. Vergara-Diaz, R. Black-Schaffer, R. Zafonte, J. Dy, S. I. Lee, P. Bonato, (2020) Enabling precision rehabilitation interventions using wearable sensors and machine learning to track motor recovery. *npj Digital Medicine*, 3, 121.
10. Lin J., R. Fu, X. Zhong, P. Yu, G. Tan, W. Lei, H. Zhang, Y. Li, L. Zhou, C. Ning, (2021) Wearable sensors and devices for real-time cardiovascular disease monitoring. *Cell Reports Physical Science*, 2, 100541.

****