

Advancements in Wearable Biomedical Sensors for Continuous Health Tracking using Machine Learning Algorithm

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Abstract

Over time, a clear pattern has appeared that an increasing number of people are taking their health seriously and are tracking it on a daily basis. Wearable medical devices are becoming popular. These small and lightweight gadgets can be worn on your wrist. These sensors are attached to many body parts and continuously monitor the heart rate, body temperature, oxygen saturation, blood pressure, and everyday activities. In brief, they offer a fast overview of our health status. The best aspect is that these gadgets make it easy to collect and share our health information, so we don't have to go to the doctor all the time. When the continuous data is used with machine learning and then it becomes even more powerful. It can find small health changes that we might miss and warn us about problems before they get serious. It's almost like having a personal health assistant that learns about us and helps us to maintain our body healthy and fit. At the same time, scientists and technologists are giving doctors the tools they need to discover health concerns early without having to see the patient in person. Small wearable sensors—such, as cutting-edge smartwatches or discreet patches—are being used to keep an eye on a person's health. For anyone dealing with ailments, like diabetes or heart disease these gadgets are very helpful. They streamline getting the care required to trim down expenses and let people to maintain their overall health without the stream of doctor appointments.

Keywords: *Wearable sensors, Biomedical devices, Health monitoring, Continuous tracking, Machine learning, Artificial intelligence.*

1. Introduction

Healthcare is one of the major industries that has benefited from the sophistication and comfort that technology has brought to our lives. Wearable biomedical sensors have made it easy to track many things at home and when in the past, people had to visit hospitals to check their health conditions. These are small devices that can be worn on our body, such as watches, bracelets, and patches [1]. Many biological signs including body temperature, heart rate, oxygen saturation, and even sleep patterns can be measured by these devices. These devices allow people to check their health regularly without even seeing the doctor. These sensors are mainly employed for ongoing health monitoring[2]. These sensors are helpful continuously capture data instead of regularly evaluating your health. This makes it easier to identify health issues early and take prompt action.

For instance, the sensor can promptly notify the user or physician if a person's heartbeat becomes irregular. People with cardiac issues, the elderly, and those who wish to maintain an active lifestyle will all benefit a lot from such biomedical sensors for overall health. When we combine these sensors with machine learning methods, the system becomes even more intelligent. Machine learning makes assumptions after analyzing all of the data collected by the sensors. It can detect the change in physical activity that a person may not even be aware of. It is helpful in identifying the problem in our body before it becomes worse[3][4].

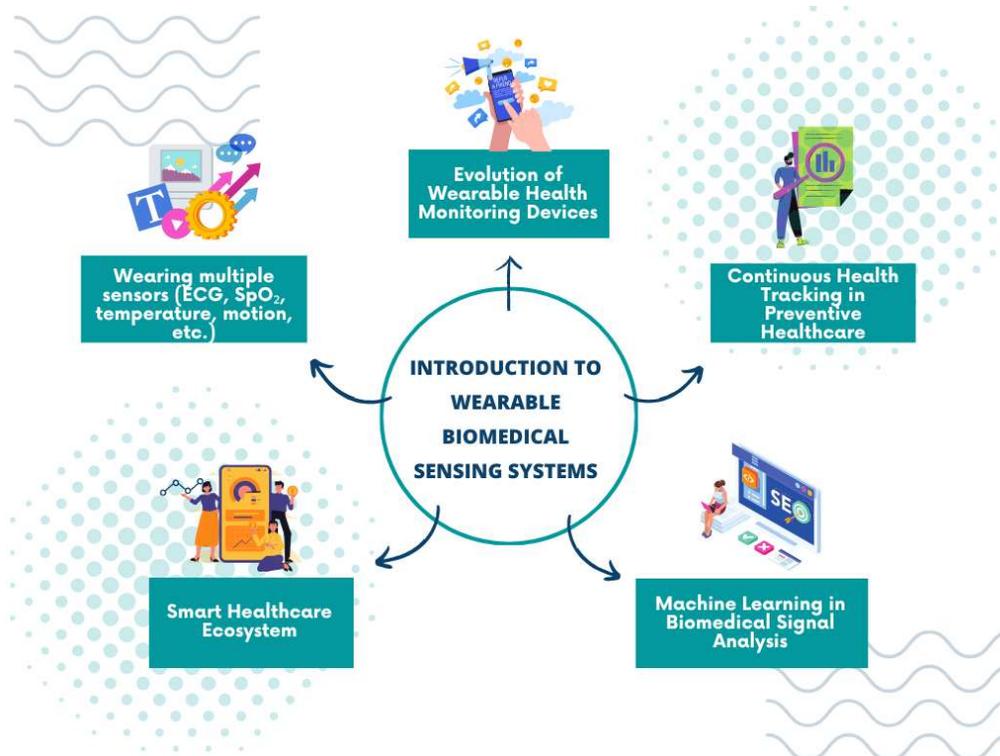


Figure 01: Introduction to Wearable Biomedical Sensing Systems

A machine learned from patterns in data and also improving the ability to perform particular task without even being programmed for every situation .It Gives exact predictions based on the data they collect. In conclusion, wearable biomedical sensors and machine learning are transforming how we manage our health. They speed up, improve, and modify medical care[5-6].

2. Evolution Of Biomedical Sensors

The development of biological sensors has changed drastically over time. At initially, the use of large connected devices for health checking was limited to hospitals. Doctors could take fundamental data like blood pressure, body temperature, and heart rate but the equipment was big, expensive, and did not suit for daily use. People may only have their health checked during hospital visits, making continuous health monitoring impossible[7]. As technology developed over time,

especially in the fields of electronics and communication, these devices became very small, more portable, and cheaper. The earliest wearable gadget was a simple fitness tracker that could count daily walking steps or measure heartbeats. After that, advancement in microchips, sensors, and wireless technology tend to the development of more advanced biomedical sensors that also could check numerous health signals[8].

The invention of Bluetooth and Internet of Things (IoT) made it possible for sensors to send data directly to smartphones or computers. This was the big step forward because people could now check their health status at any time and share this with doctors easily. The coming of smartwatches and health bands made wearable sensors a part of our daily life. Wearables can provide a key early warning system about the likelihood of COVID-19 infection, but their use can potentially go beyond in infection surveillance. There have been wearable devices introduced in the literature that not only make physiological measurements, but also focus on contact tracing applications to reduce the disease[9][10].

Now, with the help of machine learning and artificial intelligence, wearable biomedical sensors can not only collect data but also analyse it and learn from it and predict possible health issues before they arrive.

At end, biomedical sensors have risen from big hospital machines to small smart devices that can be easily worn on our body parts. This evolution is made healthcare faster and more accurate by giving people better control to their own health.

3.Types Of Wearable Biomedical Sensors

Wearable biomedical sensors come in various types, depending on what part of your body you want to monitor and what kind of data you want to collect. Each sensor has a specific function and plays an important role in monitoring health. Below are some of the most common and useful types of wearable biomedical sensors used today:

1. Heart Rate (ECG) Sensors

These sensors track the heart's electrical activity, which helps to check heart related problems including an irregular pulse or a rapid heartbeat. these days, many smartwatches have ECG features that will notify people if their rhythm is unusual.

2. Muscle Activity (EMG) Sensors

EMG sensors are used to track muscle activity and movement. They are often used by athletes and physicians to study muscle performance or injury recovery.

2. Temperature Sensors

Throughout the day, these sensors check body temperature. When it comes to detecting fever, illnesses, or changes in physical state, so that they are quite useful. Temperature sensors are used in some wearable watches and patches to provide early health signals.

4. Motion Sensors (Accelerometers and Gyroscopes)

These sensors measure how the body moves. It helps in tracking physical activity like walking, running, or sleeping patterns. Motion sensors are most commonly used in fitness bands to count daily walking steps and check sleep quality.

5. Oxygen Level (SpO₂) Sensors

These sensors measure the total amount of oxygen in the blood. They are becoming very popular during the COVID-19 pandemic because when people used them to check their oxygen levels even at home. A normal SpO₂ level shows that person lungs are working properly.

6. Glucose Sensors

These sensors are especially useful for diabetic patients. They can continuously check the amount of sugar in the blood and signals that person when it became too high or too low. This helps manage diabetes more easily and safely. It is very helpful for those who can't even able to walk they can check their performance of daily basis on their bed.

4. Working Principles of Wearable Sensors

Wearable biomedical sensors work on a simple idea they sense what is happening in internal body or external body and translate that information into data that can be understood by computers or mobile devices. In easy words, these sensors change physical signals from our body (like heartbeat, temperature, or motion) into electrical signals that can be measured and evaluated.

Every wearable sensor has a few basic parts:

1. **Sensing Unit:** This part checks the actual body signal, such as heart rate, temperature, or oxygen level.
2. **Processor or Microcontroller:** This takes the raw data from the sensor and changes it into meaningful information.
3. **Communication Module:** It sends the data to smartphones, computers, and cloud servers using Bluetooth, Wi-Fi, and IoT technology etc.

4. **Power Source:** Many sensors work on small charging batteries that permit regular monitoring.

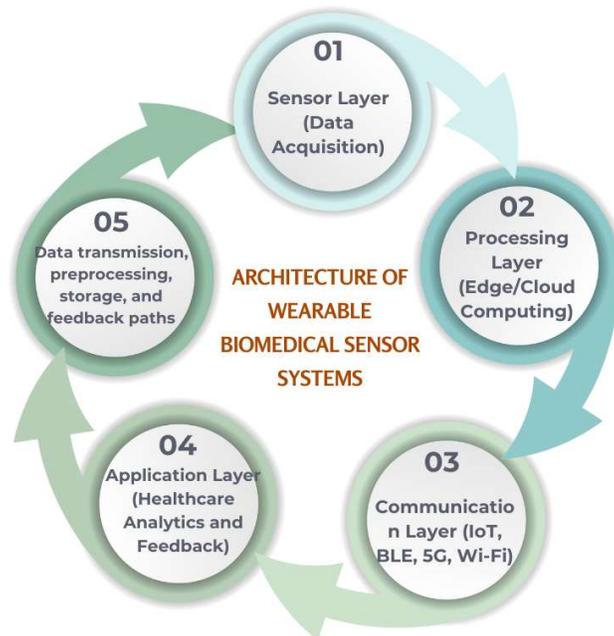


Figure 02: Architecture of Wearable Biomedical Sensor Systems

For instance, a smartwatch's tiny ECG sensor detects your pulse and converts it into electrical data. Your heart rate is shown on the screen after this data is processed by the watch's processor. You can keep the same information online or send it to your phone for later use. Certain sophisticated sensors even collaborate to collect information from various bodily parts. A comprehensive picture of your health can be obtained by combining data from many sensors, such as one that measures movement and another that measures oxygen levels. This data can be immediately shared with physicians or health apps anywhere in the world because to the Internet of Things (IoT).

Because wearable sensors have to function continuously, conserving energy is also important. Because of this, present-day sensors have been built to use quite little energy while yet collecting accurate data. Even self-powered sensors that can recharge themselves through motion or body heat are the subject of some recent studies. SO, in short, you know how a Fitness tracker works ?it's basically like a little detective on your body. And its constantly picking up clues from your body like your heartbeat and your daily walking steps and how we are sleeping. It gets those data or clues and turns them into numbers and data and then shoots that information to your phone super-fast . Because it's getting this constant update on you , it helps you to understand what's really going on your internal body parts how they work . They are working properly or not, and tells us everything about our body.

5. Integration of Machine Learning in Health Tracking

Machine learning is the brains beside modern health trackers. It is what makes our wearables smart devices and not just data gathering. In easy words, it teaches computers to find patterns in our health information and make predictions and almost like a doctor does, but it does it automatically and in a flash. Think about it, your watch is constantly gathering data like your heart rate, how you slept and your body movement. On itself, that data is just a bunch of numbers. But by adding machine learning algorithm in it, the device can now analyze every information to find what is really needed. So, if your heart rate and sleep patterns suddenly change then the device can notice something is not usual and give you a signal before it turns into a big issue.

Some examples of how ML helps in health tracking:

1. **Heart Disease Predict:** By studied heart rate and ECG data, Machine Learning can warn that there is a risk of a heart attack or irregular heartbeat.
2. **Diabetes and Blood Sugar Tracking:** Algorithms can study glucose levels and our daily activities to suggest us good diet and exercise charts.
3. **Sleep Analysis:** Machine Learning is helpful in understanding whether your sleep cycle is deep and light or disturbed, and gives suggestions for good beauty sleep.
4. **Activity Tracking:** This can also tell even you are moving, running, or resting and calculate calories burned more accurate.

The more and more data these devices are collect from us, the smarter they becoming. The real magic happened because these devices are always learning.

The machine learning software can also analyze information from thousands of other people to understand the difference between a normal reading and one that might be a reason for concern. This helps in personalized healthcare, where every person gets advice or alerts according to your body unique patterns. This is also changing healthcare in big smart ways. In the hospitals the doctors can use those smart systems to keep an eye on patients from a distance. That means people don't have to go to the clinic regularly and their care team gets a constant, real-time picture of how they are doing and also not just a snapshot from an appointment. So, by adding, we can think of machine learning as the brain behind the operation. It takes all the raw numbers from the sensors like the heartbeats and steps and turns them into genuinely useful health insights. These helps people to catch serious issues quickly and manage treatments more effectively.

8. Applications In Continuous Health Tracking

Now the wearable biomedical sensors are playing an important role in health system. Both doctors and regular checker are using these small and intelligent devices to closely monitor our health in real time. In the past years , people had to visit labs or hospitals to monitor their blood pressure and heart rate or blood sugar levels. Additionally, the wearable sensors have made it possible to measure all of these problems at our home itself. Heart and blood pressure monitoring is one of the most popular applications for wearable devices. The issues that can be related to the heart are detected by smartwatches and patches regularly control and monitor the pressure and heart rate. In a similar vein, sensors that measure blood sugar levels without causing painful finger pricks are gaining popularity among diabetes patients. Another important use is monitoring daily activity and fitness. Fitness bands count steps, calories, and the amount of time spent exercising. They promote leading healthy lives and leading active lifestyles. Sleep tracking that provides users with information on their sleeping habits, sleep length, and level of deep or disturbed sleep, is another crucial feature[11].

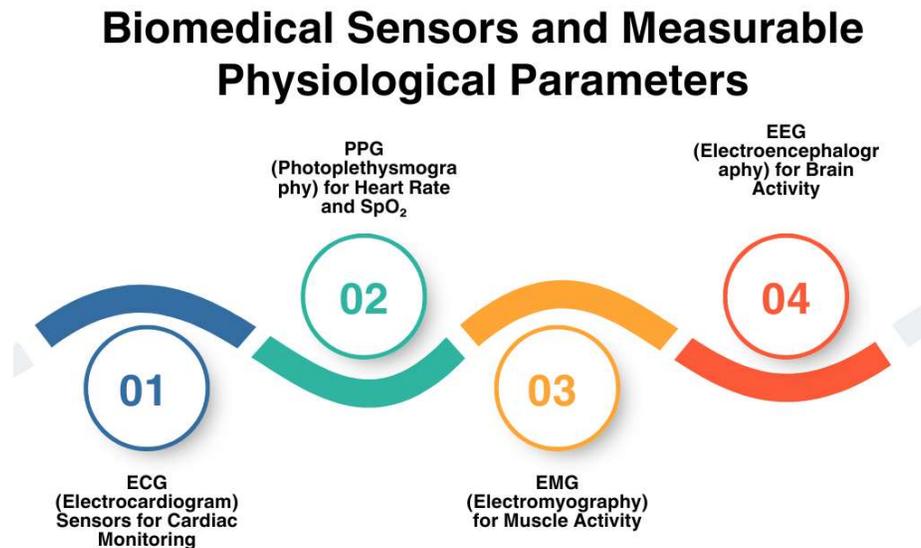


Figure 03: Biomedical Sensors and Measurable Physiological Parameters

Furthermore, wearable sensors are being used to track oxygen levels and breathing rates, which is especially useful for people with asthma, COVID-19, or respiratory conditions. Before suggesting breathing techniques and other relaxation techniques, some sensors even take skin temperature and heart rate readings to assess stress levels.

In hospitals, these sensors play a key role in remote patient monitor. Doctors can now see patients' health data from a distance with the help internet, without need them to visit the hospital every time .

That saves time, reduces hospital crowding, and helps patients recover in the comfort of their homes. For elderly people, sensors that can detect sudden falls or unusual movements are a big help, as they can send instant signals to family members or emergency services. In short, wearable biomedical sensors have made healthcare more personal, convenient, and continuous. They are not just tools for patients but also valuable helpers for doctors, creating a new age of smart and connected healthcare.

6. Challenges and Limitations

Even though wearable biomedical sensors have made great progress in modern healthcare, they still face several challenges and limitations that need to be improved in the future. These problems may affect their performance, comfort, and overall reliability. One major challenge is accuracy and reliability. Many wearable devices sometimes give wrong or inconsistent readings because of sweat, skin movement, and wrong position on device on the body. For example, when a person is running or sweating more , the sensor may not detect correct heart rate or oxygen levels. This can lead to wrong conclusions about health problems. Another limitation is battery life. Since wearable devices regularly track data, they need constant power. Most of them have small batteries that required frequent charging, which cannot be convenient for users to charge the devices every time or a whole time because charging points are not every time near to the patient and there is a loss of connection that can be find in many cases . Researchers are now working on self-powered sensors that use body temperature or movement for charging, but they are still in early stages.

Data privacy and security are also big concerns. Wearable sensors collect very personal and sensitive health information. If this data is not properly protected, it can be misused or stolen through hacking. Ensuring strong encryption and data protection methods is necessary to keep users health data safe. The cost of advanced wearable devices is another limitation. High-quality biomedical sensors are still very expensive, so that many people can't be able to purchase those sensors because of the high prices for many people. Comfort and design are further concerns. Many sensors are heavy or hard to wear for longer periods of time. In this the Common issues include like allergies or skin irritation are occur by frequent contact with this gadget. Wearing such devices constantly might be exhausting or irritating for anyone with sensitive skin like such as children or newborn babies. Lastly, wearable sensor technology lacks uniformity. Doctors found it challenging to compare or merge data from several devices since different brands employ different measurement techniques and data formats. This lowers the overall healthcare system effectiveness. In conclusion the wearable biomedical sensors have made it possible to measure health continuously. Moreover, in order to make them more efficient, accessible and comfortable

for all users the issues like proper accuracy of data and privacy need to be confidential in that case also there is an issue of battery life of the devices need to be resolved.

7. Conclusion:

Wearable biomedical sensors are totally changed our health how we think about our health and handle our health. We can see the movement of basic signals like temperature and blood oxygen level and heart rate at any time and from any location thanks to these small smart devices. Artificial intelligence and machine learning are now able to analyze huge number of health data and processing useful knowledge that is very helpful in early disease identification and for better treatment. These sensors have made healthcare more accessible, consistent, and customized. People can now take control on their own health instead of depending just on hospitals. Additionally, the doctors can also save time and deliver better care because of real time patient monitoring. However, several problems still need attention that is accuracy, data privacy, and battery life. As technology develops, researchers are working to solve these issues and increase wearable sensor usefulness, comfort, and affordability that a normal person can buy these devices and take care of their health because health should be our first priority. Wearable biomedical sensors are like to play an important role in everyday life in the future, much like cell phones. They will help people to stay healthier and detect illnesses early, and increase everyone access to healthcare. In the end , wearable biomedical sensors and machine intelligence are helpful in transforming the future of smart and connected, and also preventive healthcare.

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