

ASSESSMENT AND MONITORING OF PHYSICAL FITNESS USING WEARABLE TECHNOLOGY – AN OVERVIEW

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ABSTRACT

Living a healthy and fulfilling life or at least carrying on the daily activities inevitably depends on some physical activity in different scales. Therefore, measuring the physical activity is necessary to evaluate both healthy people and patients in order to plan their needs for wellbeing. Objective and accurate measurements can be made with wearable sensors and related technologies. Evaluating health and wellness, efficacy of treatment, safety, physical ability and disability are in the scope of monitoring physical activity with wearable technologies.

Keywords: Wearable technology, sensor, physical activity, disability

INTRODUCTION

Living a healthy and fulfilling life or at least carrying out daily activities inevitably depends on some physical activity in different scales. Therefore, measuring physical activity is necessary to evaluate both healthy people and patients in order to plan their needs for wellbeing. Simply, these activities include walking, sitting, sleeping, eating, talking, and hearing, looking, seeing and breathing. Each one of them can be elaborated on widely to include every aspect of daily living and professional activities. Moreover, understanding and treating disorders requires knowledge about the normal functioning of the body. Physical examination with laboratory and radiological investigations, audiovisual recordings may provide some of the necessary information. Even then, there may still be a vast amount of data missing.

Wearable sensors could improve data gathering in health and in disease during different environmental conditions and activities. The improvement of technology concerning sensors, communication and data analysis has broadened the remote monitoring scope and created a new field that may be called “telemedicine”. Therefore, the use of physiological monitoring could help patients with neurological, cardiovascular or pulmonary diseases such as epileptic seizures, asthma, cardiac insufficiency and, high blood pressure . Cardiac rhythm monitoring with portable devices is a well-known example of a wearable technology application which has been widely used for a long period of time and has almost become a usual part of cardiac examinations even if it has some limitations. Home based monitoring of movements has numerous benefits for individuals, family members and also for community health issues. Detecting or preventing falls in individuals in their own environment may increase the feel of self-sufficiency, independence and maximize social participation.

Core Technologies and Sensors

- **Motion Sensors:** Accelerometers, gyroscopes, and magnetometers are used to quantify training loads, detect movement direction, and measure physical activity intensity.

- **Physiological Sensors:** Photoplethysmography (PPG) is commonly used for continuous heart rate monitoring, while advanced sensors can track **blood oxygen levels (SpO2)**, **sleep patterns**, and even **electrodermal activity** for stress levels.
- **Specialized Biometrics:** Newer wearables integrate **sweat analysis** for lactate and glucose monitoring, or **biopotential sensors** (ECG, EMG) for deep muscular and cardiac assessment.

Key Assessment Metrics

- a. **Cardiorespiratory Fitness:** Monitored through resting heart rate, heart rate recovery (HRR), and estimated **VO2 max**.
- b. **Training Load:** Quantified via total steps, distance covered, and vertical jump height (critical for sports like volleyball).
- c. **Daily Activity Levels:** Categorised into sedentary, light, moderate, and vigorous physical activity (MVPA) minutes.
- d. **Biomechanical Performance:** Analysis of tilt angles, roll, and elevation using sensor fusion to understand movement efficiency.

Wearable Technology System

Wearable technology means a wearable device which presents information to users. With recent developments user interaction with voice or physical input is possible. The technologies needed to conduct these processes are the sensors, communication hardware and software, storage facilities and analyzing equipment. Present devices can be divided into two groups:

(i). Head mounted gadgets : Head mounted devices are usually visual systems which enable users to have hands free us. These visual systems are currently 33implemented in surgery, education and simulation and used as a navigation tool for partially sighted people.

(ii). Bodily placed instruments: Bodily placed instruments can be either wearable or portable. Present wearable technologies include accelerometers, gyroscopes, sole sensors, and barometric pressure sensors mounted over the body.

According to the purpose of the use, different body sensors have been developed with a capacity to monitor physiological and biochemical properties, posture and motion. Recent advances in microelectronics have provided a means to produce small flexible sensors which also include miniature circuits, microprocessors, and radio transmitters. These properties overcome some of the hurdles such as size and weight of devices which prevented adoption of wearable sensors for long-term monitoring. Innovations in fabric production have led to “e-textile” production. Current wearable technology integrates sensing capability into clothing. It is possible to collect electrocardiographic and electromyography data by weaving electrodes into the materials which garments are made of.

Wearable technology devices

Historically the first wearable device was a watch which gave information about time. It was worn as a necklace or carried in a pocket. Later on to keep hands unoccupied, watches were worn on wrists which became very fashionable at the beginning of the 20th century.

A similar phenomenon occurred when a smart watch came onto the market a century later. Sensors which were integrated into these devices can measure blood pressure and heart rate, count steps as well as storing data. Data can be shared via smart phones or personal computer

and can be analyzed offline. Smart phones can also be integrated with wireless sensors recording heart rate and send the relevant findings to a remote center. Small storage capacity and computational power of the phones do not allow long term monitoring yet.

Some other commercially available devices can measure vital signs such as blood pressure, heart rate, oxygen concentration continuously. Their accuracy of measurements may cause some concern in home based monitoring due to possible misplacement of electrodes. Small, flexible sensors that have integrated microprocessors and radio communication systems result in "System on Chips" implementation. These devices can perform laboratory tests such as lactate, glucose, sodium, potassium.

Sweat analysis and fatigue relation can be investigated with them. Motion sensors are mostly inert sensors that have accelerometer and gyroscope parts. These are relatively inexpensive small devices with low energy consumption. Accelerometers can detect change of direction and axis and also acceleration. Accelerometers and pedometers are used widely for measuring physical activity.

There are projects to develop smart garments for the safety of emergency rescuers such as firemen. These garments integrate sensors which detect environment temperature, oxygen levels, communication and GPS antenna, microphone, motion sensors.

Health and wellness monitoring in an aging population gain more importance especially in western countries. Older people with or without chronic conditions can remain in the home environment safely if reliable systems can be established. Accuracy of wearable sensors is widely investigated to classify activities of daily living. Monitoring vital signs, motion, and posture increases compliance to exercise and medication.

Potential uses of wearable technologies in medicine

The head-mounted devices, glasses worn by medical professional and wearable devices worn by patients can be used for medical education, patient interaction and consultation.

(i). Vital activity monitoring for congestive heart failure, dysrhythmia, and asthma is helpful for the assessment of the status of the patients. It can be used to evaluate efficacy of treatment. Motion sensors and posture detection devices will probably be very important in monitoring patients with balance problems, Parkinson's disease, patients in rehabilitation processes and sleep disorders. The motor symptoms of Parkinson's disease have hypokinetic and hyperkinetic features. The motor fluctuation is almost an inevitable complication of L-dopa treatment. Unexpected offs also become troublesome in the course of the disease. The autonomic involvement and loss of postural reflexes can be seen in the later stages of Parkinson's disease (PD) but it can be seen earlier in patients with atypical parkinsonian syndromes.

(ii). Multiple sclerosis (MS) affects young people in their productive age. Therefore, physical activity is very important for quality of life. There are several performance scales to measure different domains of physical activity such as gait, hand movements, fatigue, vision, and spasticity.

(ii). Prediction and prevention of falls have aspects involving the person and the environment. The ability of walking, vision and cognitive functions are patient characteristics that may affect falls. While slippery or irregular floors, poor lightening, cluttered spaces are environmental risk factors of falls. Thus the ideal system should have the ability to evaluate all of the aforementioned properties.

Handicaps of wearable technologies

Sensors placed over the body or deployed in garments may cause some discomfort and prevent natural movements. Therefore, almost half of the patients stop using these systems partially after one year. The accuracy of the collected data is a major concern especially for remote monitoring. The normal values are yet to be determined. False positive or false negative findings may create social and medico-legal problems. Continuous monitoring creates a huge amount of data waiting for offline or real time evaluation. Each one of them has its own difficulties. Safety and privacy of the information are important issues.

Physical fitness components assessed using wearables

Wearable technology assesses physical fitness through five primary health-related components. While most consumer devices excel at tracking **aerobic capacity** and **body composition**, specialized or research-grade sensors are required to measure **muscular strength**, **muscular endurance**, and **flexibility**.

1. Cardiorespiratory (Aerobic) Endurance

- **VO2 Max:** Advanced smartwatches and rings (e.g., Garmin, Apple, Gait Smart Ring) estimate peak oxygen consumption during exercise using heart rate and movement data.
- **Heart Rate Metrics:** Wearables monitor resting heart rate, heart rate variability (HRV), and heart rate recovery (HRR) to gauge cardiovascular efficiency and stress recovery.

2. Body Composition

- **Bioelectrical Impedance Analysis (BIA):** Some wrist-worn devices (e.g., Samsung Galaxy Watch) utilize BIA sensors to estimate body fat percentage and skeletal muscle mass by sending a low-level electrical current through the body.
- **BMI & Caloric Balance:** Apps integrated with wearables calculate BMI and energy expenditure (calories burned) by fusing data from accelerometers and heart rate sensors.

3. Muscular Strength and Endurance

- **Training Load & Repetitions:** Movement sensors (Inertial Measurement Units or IMUs) track exercise volume, repetition counts, and "velocity-based training" metrics to assess power output and muscular fatigue.
- **Electromyography (EMG):** Smart clothing (e.g., Athos) uses embedded EMG sensors to measure muscle activation intensity and balance during resistance training.

4. Flexibility and Range of Motion (ROM)

Joint Angle Tracking: Specialized wearable IMU networks (placed on the ankle, thigh, or lower back) measure joint range of motion and biomechanical symmetry, identifying potential abnormalities in movement.

5. Motor-Related Skills

- **Balance & Stability:** Sensors track postural sway and static/dynamic balance, which are critical for injury prevention and rehabilitation monitoring.

- **Agility & Reaction Time:** High-frequency accelerometers measure speed, agility, and reaction time in response to stimuli, primarily used in elite sports settings.

Role in injury prevention and rehabilitation

Wearable technology plays a critical role in injury prevention by providing real-time biomechanical and physiological monitoring that identifies risk factors before an injury occurs. These devices track metrics such as gait symmetry, joint loading, and fatigue levels through sensors like accelerometers and electromyography (EMG), allowing athletes and clinicians to detect abnormal movement patterns or overtraining signs early. In the rehabilitation phase, wearables facilitate a safer return-to-activity by offering objective data on recovery progress, such as range of motion and muscle activation, which enables highly personalized exercise prescriptions. Furthermore, these technologies support remote monitoring and virtual rehabilitation, which have been shown to increase patient engagement and adherence to physical therapy protocols, ultimately reducing hospital readmission rates and improving long-term outcomes.

Data analytics and AI

In the realm of physical fitness, AI and data analytics transform the raw data collected by wearables into actionable health intelligence. Advanced machine learning algorithms process massive datasets to identify hidden patterns in heart rate and movement, enabling early detection of cardiovascular issues or metabolic shifts. For fitness enthusiasts, AI-driven platforms provide personalized coaching by adjusting workout intensity in real-time based on recovery scores and fatigue levels. Furthermore, predictive analytics assist in injury prevention by flagging biomechanical deviations and overtraining syndrome before physical symptoms arise. In clinical settings, big data analysis across large populations helps researchers establish more accurate health benchmarks and validate the efficacy of specific rehabilitation protocols.

Future trends in wearable fitness technology

Future trends in wearable fitness technology are shifting from simple activity tracking to creating "Health Operating Systems" that provide clinical-grade insights and personalized coaching.

- Hydration and Sweat Analysis:** New sensors can analyze biomarkers in sweat, such as lactate and cortisol, to monitor fatigue, hydration, and stress levels in real-time.
- Clinical Indicators:** Devices are integrating blood pressure monitoring and arrhythmia detection (ECG) as standard features for proactive heart health management.
- Holistic Wellness Coaching:** Generative AI is transforming devices into virtual health coaches that provide conversational feedback and adjust training loads based on daily "Readiness" scores.
- Predictive Analytics:** AI algorithms use long-term biometric data to predict potential injury risks or the onset of illness before symptoms appear.
- Smart Clothing (E-Textiles):** Sensors woven into fabric (e.g., Hexoskin biometric shirts) will provide full-body biomechanical data and muscle activation monitoring.
- Smart Rings & Jewelry:** Discreet devices like smart rings are gaining popularity for 24/7 recovery tracking without the bulk of a smartwatch.

- g. **Augmented Reality (AR):** Smart glasses will offer hands-free, visual workout instructions and real-time form correction overlays.
- h. **Connected Ecosystems:** Wearables will sync seamlessly with smart home systems (e.g., adjusting room temperature based on sleep data) and Electronic Health Records (EHR) for direct physician updates.
- i. **Energy Harvesting:** To solve battery issues, future devices may use kinetic or solar charging to power themselves through body movement.

Implementation Challenges

- **Data Accuracy:** Variations in reliability between brands (e.g., Fitbit vs. Garmin) can affect the consistency of longitudinal data.
- **Privacy and Ethics:** High-level monitoring in sports raises concerns regarding **data security** and athlete privacy

CONCLUSION

Wearable technology has fundamentally reshaped physical fitness monitoring by shifting from simple step counting to providing a comprehensive, data-driven view of human health. By integrating advanced AI analytics and multi-sensor arrays, these devices now bridge the gap between consumer fitness and clinical diagnostics, offering vital insights into injury prevention, rehabilitation accuracy, and personalized physiological optimization. As the industry moves toward non-invasive bio sensing and predictive health models, wearables are poised to become indispensable tools for proactive wellness, empowering individuals to manage their physical well-being with unprecedented precision.

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