**A COMPREHENSIVE ANALYSIS OF THE DESIGN PRINCIPLES AND FUNCTIONAL CAPABILITIES OF WEARABLE HEALTH MONITORING DEVICES**

**Ms. J. Christy Immaculate**

**Pharm D fourth year student, Swamy Vivekanandha College of Pharmacy, Elayampalayam, Tiruchengode - TK Namakkal District, Tamilnadu - 637 205.**

**Email id:** christyimmaculatepharmd2020@gmail.com

**INTRODUCTION:**

Wearable technology has become a significant trend in modern technology, particularly in the realm of tracking daily activities. Contemporary activity trackers have evolved from basic pedometers to sophisticated devices that offer advanced intelligence and accuracy. Unlike their predecessors, these modern trackers provide more comprehensive features, extending beyond mere distance measurement. Their popularity stems from their ability to deliver real-time data across various applications, including health management, fitness monitoring, dietary tracking, and aging assessments 1. Wearable monitoring devices play a crucial role in managing chronic conditions and monitoring vital signs such as heart rate, blood oxygen saturation, respiratory rate, and body fat percentage. These devices offer non-invasive sensing, local data processing, immediate user feedback, and communication capabilities. For instance, the Holter monitor is a type of wearable that records cardiac activity over a 24-hour period, capturing data during a patient's usual activities 2. With the increasing integration of technology into everyday life, consumers are turning to consumer-grade software and hardware for health management purposes. Smart wearables—such as smart watches, rings, and wristbands—are now popular consumer electronics that can be worn as accessories or incorporated into clothing. These devices boast significant processing power and advanced sensors, providing valuable health insights 3. Wearable sensors represent a leap forward in analytical technology, merging point-of-care system functionalities with mobile connectivity in standalone devices. They facilitate continuous, non-invasive, or minimally invasive monitoring of biometric data, allowing for the detection of subtle physiological changes over time. While devices like the Holter monitor have been available for decades, recent technological advancements have greatly improved their functionality and effectiveness 4-7. The primary objective of wearable health monitors is to deliver real-time health metrics, enabling proactive health management and the early identification of potential problems. The effectiveness and user acceptance of these devices depend heavily on their design and functionality, which include factors like comfort, accuracy, connectivity, and battery life. With technological advancements, these monitors are becoming increasingly sophisticated, offering a wider range of features and an enhanced user experience.

**HISTORY:**

The origins of wearable technology can be traced back to the 13th century with the invention of spectacles by English friar Roger Bacon. His 1266 work, \*Opus Majus\*, detailed the scientific principles of corrective lenses, making early glasses a precursor to modern smart glasses 8-9. The first portable mechanical watch, known as the Pomander or Bisamapfeluhr, appeared in the early 16th century 10. In the early 17th century Qing Dynasty, the Abacus Ring, a smart ring with a compact abacus, was created to aid traders 11-12. The development of portable cameras began with Julius Neubronner's Pigeon Camera in 1907 13. Early portable wireless systems were initially large and mounted on cavalry horses but were later redesigned for field communications 14. A major breakthrough in portable radio technology was the development of the "packset" or "walkie-talkie" by Donald Hings in 1937 15. Wristwatches became essential for planning and coordinating military operations, leading to their widespread use 16. Simultaneously, the first wired hands-free devices were incorporated into flight helmets for navy and pilots. After World War II, a notable advancement in wearable technology was the advent of VR 17. In 1960, Morton Heilig patented the "Stereophonic Television Head-Mounted Display," a pivotal moment in the history of wearable technology 18.

In 1961, MIT researchers Edward O. Thorpe and Claude Shannon developed a concealed timing device embedded in a shoe to predict roulette ball outcomes, marking the creation of the first wearable computer 19-20. This invention was publicly disclosed in 1998. Around the same period, Hugo Gernsback introduced TV glasses, weighing 140 grams and utilizing two battery-powered cathode-ray tubes for stereoscopic viewing 21-22. In 1972, Alan Lewis created a digital camera-case computer designed to predict roulette outcomes 23. The year 1998 also saw the introduction of wearable payment technology with devices like the mBracelet, a wrist-worn computer for ATM transactions, featuring interchangeable iButton buttons and a three-color LED grid 24. In 2001, Plantronics released the M1000 Wireless Headset, succeeded by the lighter M1500, which combined Bluetooth headset functionality with a mobile phone adapter. In early 2012, Eric Migicovsky founded Inpulse (later Allerta) and launched a smart watch that displayed messages from selected smartphones, known for its distinctive and innovative design 25.

**CURRENT MARKER AND INDUSTRY TRENDS IN SENSOR AND WEARABLE DEVICE:**

In 2016, the wearable technology market reached 33.9 million units. On World research predicts that in 2017, global shipments for sensors in wearable, implantable, and mobile health and fitness devices will surge to 515 million, up from 107 million in 2012, marking a 552% increase. These devices are projected to make up over 80% of the mobile health and fitness market. Additionally, On World forecasts that by 2017, 18.2 million health and wellness wireless sensor network systems (excluding sports and fitness) will be shipped worldwide, generating $16.3 billion in annual revenue, with cloud-connected services expected to contribute 53% of this revenue over the next five years 26.

**CLASSIFICATION OF WEARABLE DEVICE:**

Wearable devices can be broadly categorized into four main types based on their applications and usage.

**Lifestyle and Healthcare:**

Wearable technology includes devices such as sports and activity monitors, like smart bands and Lark sleep sensors, which track movements during sleep and other sleep disorders, as well as physical activities 27.

**E-Textiles:**

E-textiles, also known as smart garments, smart clothing, smart textiles, or smart fabrics, integrate digital components such as batteries, lights, and computers. These smart textiles are categorized into aesthetic and performance-enhancing types. Aesthetic textiles include features like light-up elements and color-changing fabrics, while performance-enhancing textiles are designed for sports and military applications, offering benefits such as body temperature regulation, wind resistance reduction, and muscle vibration control 28.

**E-Patches:**

E-patches are another form of wearable technology that adhere to the skin to deliver specific doses of medication transdermally. Predicting human activities is crucial in sports, exercise, and healthcare. Researchers at the University of California, San Diego, have developed a flexible wearable sensor and patch that can measure blood alcohol levels through sweat using a temporary tattoo applied to the skin. This data can be transmitted via Bluetooth from the patch sensor. Additionally, wearable multi-sensing patches can periodically measure lactate levels in sweat, as well as other metabolites, electrolytes, and temperature, transmitting this data in real-time for analysis 29.

**Smart Eyewear:**

Smart eyewear represents a notable category of head-mounted wearable technology. Google Glass, an early entrant, was designed to assist children with autism. Vuzix smart glasses enable email access, YouTube streaming, voice prediction, and touch-pad control. SOLOS glasses provide cyclists with real-time metrics such as speed, cadence, heart rate, and power zones. Eyesight Raptor glasses offer mapping and heart rate data. The ODG R7 AR Glasses feature 720p lenses for transparent video display, while the SAFILO X line includes a range of sensors (3-axis accelerometer, gyroscope, magnetometer, UV, temperature, and pressure) for tracking exercise, brain activity, and meditation. VUE glasses, launched in 2017, added functionality for managing calls and music 30.

**DESIGN OF WEARABLE DEVICE:**

Modern wearable technology has advanced to a point where its measurement accuracy rivals that of regulated medical devices, effectively blurring the line between consumer and medical-grade instruments. Initially, wearables like watches, shoes, and headsets focused on biophysical monitoring, tracking parameters such as physical activity, heart rate, and body temperature 31-33. With the success of these first-generation wearables, the focus is now shifting towards non-invasive or minimally invasive biochemical and multi-modal monitoring, marking a move towards personalized healthcare 32. Second-generation wearables include innovative designs such as on-skin patches, tattoos, tooth-mounted films, contact lenses, textiles, microneedles, and injectable devices. These advanced devices typically utilize bio-fluids and biorecognition elements to detect specific analytes and produce measurable signals. While many of these technologies remain in the prototype stage, some, like the Freestyle Libre glucose monitoring system and the Gx Sweat Patch, have achieved commercial success 31. Wearable biochemical and biophysical sensors are increasingly being utilized in disease management and wellness 34. Additionally, these devices are now being used in animal health monitoring, benefiting both pets and livestock 35.

**WEARABLE DEVICE IN HEALTH MONITORING:**

**a) Motion Trackers:**

The measurement of human movement through motion tracking has numerous valuable applications across fields such as sports, medicine, and other studies. These include assessing fall risk, quantifying sports exercises, studying human habits, and monitoring the elderly. Wearable trackers are becoming increasingly popular for two primary reasons: they can motivate users to exercise more during their daily workouts and provide activity measurement data via smartphones, eliminating the need for manual calculations 36. To accurately monitor human motion, 3-axis accelerometers, magnetometers, and gyroscope sensors are used, each serving a unique purpose. Additionally, these sensors are useful in the domain of ubiquitous computing for human activity recognition 37.

**1) Motion measurement in body tracking:**

A novel design introduced by Bertolotti et al. 38 facilitates objective measurement of trunk and limb movements for evaluating human body balance and control capabilities. This system incorporates a 72 MHz, 32-bit CPU (STM32F303VC; STMicroelectronics, Geneva, Switzerland) featuring a high-performance ARM Cortex-M4, 32-bit RISC core, capable of interfacing with multiple sensors via high-performance SPI and I2C modes. The sensors used in this study (STMicroelectronics sensors) possess a linear range and sensitivity suitable for accurately measuring body movements. The system performs online processing, including data acquisition from various sensors, filtering, and data generation, at frequencies up to 72 MHz. Body movements are tracked using 9DoF sensors, which consist of an accelerometer, a magnetometer, and a gyroscope. The full-scale values of these sensors can be adjusted through specific commands from the microcontroller 39-40. The entire device, encompassing the circuit board, Bluetooth module, and battery, measures 60 mm × 35 mm × 20 mm and is encased in transparent plastic to facilitate the observation of LED indicators. The device supports three types of movement monitoring: short-term, long-term, and full-body. For short-term monitoring, the device connects to a PC for real-time result observation. In long-term monitoring, data is both observed and stored locally. The third type involves a body network where multiple units are placed on the subject's body and connected to a gateway unit. This gateway can have local memory or a wireless connection to a PC or handheld device, enabling comprehensive body movement monitoring during exercises 41.

**2. Commercially available user devices applied in research papers:**

Long-term monitoring is essential in healthcare, as it enables ongoing data collection for enhanced diagnostic capabilities. This process requires devices to temporarily store data in memory before transmitting it to a cloud server or medical station for permanent storage. Effective data buffering necessitates both SD memory and RAM. Additionally, compatibility with Bluetooth and Wi-Fi is critical for data transmission. While many devices come with proprietary software, some allow for custom application development, though this is not universal. Firmware also plays a crucial role, especially for customizing development kits, but not all manufacturers provide this capability. This study reviews nine research devices, focusing on their significant features. Key constraints for wearable devices include size, battery life, weight, and the ability to integrate additional sensors. Real-time data visualization is a common user demand, making accurate fitness tracking a pivotal aspect in device selection. Device performance can vary significantly based on component quality and software integration. Conducted in Korea, this study evaluates the accuracy and user-friendliness of four wearable devices selected from the top ten on the market, providing detailed information on each device's commercial name, country of origin, capabilities, and cost 32.

**b) Vital Signs Measurement:**

Numerous wearable devices have been developed for monitoring vital health metrics, often focusing on specific parameters like ECG, EEG readings, or skin temperature. Recent advancements have sought to produce multi-functional wearables for comprehensive vital signs monitoring. Despite the availability of various remote ECG monitoring solutions—both in academic literature and industry—challenges persist regarding their implementation, power consumption, and overall performance efficiency.

**1) Body-worn smart clothing:**

To create a comprehensive health monitoring system, a recent study introduced the concept of ‘smart clothing,’ which integrates various physiological signals into a unified data center. Effective implementation of such systems requires the integration of smartphones, mobile apps, cloud computing, and big data analytics. Although many research approaches have been proposed and implemented, existing solutions often fall short for long-term health monitoring. Traditional methods, which typically capture a limited set of physiological signals, are inadequate for chronic disease management in a comprehensive health system 42. Smart clothing differs from conventional wearable devices primarily in its sensor deployment. In smart clothing, sensors are seamlessly embedded into the textile, which requires careful consideration of sensor quality, placement, flexible cable design, signal acquisition, low-power wireless communication, and user comfort. The fabric must be comfortable for the wearer while focusing on monitoring essential vital signs 43

**2) Wire-based wearable devices: limited physiological and environmental parameters measurement**

Sanfilippo and Pettersen proposed an innovative wire-based medical monitoring approach that integrates multiple vital sign measurements. Their system utilizes the e-Health Sensor Platform V2.0, a biometric shield for Arduino and Raspberry Pi, which, although not officially licensed for medical monitoring, allows for extensive research in health measurement. This platform employs ten sensors to track EEG, ECG, body temperature, and includes an emergency push button, facilitating detailed health monitoring and investigation 44.

**BIOENGINEERING PRINCIPLES OF WEARABLE DEVICE:**

Physical activity has a well-established inverse relationship with adverse cardiovascular events and overall mortality, making it a key component of the American Heart Association's 'Life’s Simple 7' recommendations for heart health. Traditionally, physical activity levels were often self-reported during clinic visits, a method limited by inadequate detail, recall bias, and a lack of objective measurement in everyday settings. For example, a common self-reported activity like "I walk five times a week for 30 minutes" fails to provide essential information such as intensity, distance, and periods of inactivity. With advancements in digital health technology, these outdated subjective reporting methods are being replaced. Wearable devices and smartphones now utilize various sensors to accurately monitor physical activity and energy expenditure. A primary tool in these devices is the triaxial accelerometer, which measures linear acceleration across three planes. Another important sensor is the gyroscope, which tracks angular motion 45.

Wearables also incorporate the Global Positioning System (GPS) and barometers to further refine physical activity tracking accuracy. GPS operates through a network of at least 24 satellites that transmit signals to determine their precise positions and timing using highly accurate atomic clocks. By applying complex calculations that include signal emission times, the speed of light, and principles from Einstein’s relativity, a GPS receiver calculates distances from at least four satellites. GPS effectiveness can be influenced by factors such as satellite positioning, signal obstructions, reflections from buildings, atmospheric conditions, and the design of the receiver. Conversely, barometers estimate the number of stairs climbed and detect falls by measuring changes in altitude, as atmospheric pressure decreases with altitude. However, barometric measurements can be inaccurate due to natural variations in temperature and pressure, which might be misinterpreted as altitude changes. While the integration of multiple sensors into wearables improves the precision of physical activity and energy expenditure estimates, it can also increase the demand on battery life 46.

**Heart rate and rhythm sensors:**

Heart rate (HR) measurements, both at rest and during activity, are key indicators of cardiovascular disease risk. Elevated resting HR in healthy individuals is linked to higher risks of coronary artery disease and mortality. In heart failure (HF) patients, high resting HR correlates with worse outcomes, and poor HR recovery post-exercise is associated with increased adverse cardiovascular events. HR variability (HRV) is also an important marker for cardiovascular risk in both healthy individuals and those with HF and reduced ejection fraction. Commercial wearables often use electrocardiography (ECG) or photoplethysmography (PPG) to monitor HR and heart rhythm, measuring beat-to-beat intervals and applying rhythm classification algorithms 47. ECG sensors, available in various forms, are the gold standard for accurate HR and rhythm measurement. While chest-strap monitors and ECG patches provide precise continuous monitoring, they can be bulky and less functional than smart watches. Some smart watches can record single-lead ECGs by placing a finger on the device, aiding in diagnosing common arrhythmias like atrial fibrillation (AF), although single-lead ECGs may not suffice for diagnosing complex arrhythmias or myocardial infarctions (MI) without additional techniques. PPG sensors track changes in microvascular blood volume by converting pulse waves into tachograms, typically used continuously during exercise and intermittently during rest and sleep to save battery. Combining PPG tachograms with single-lead ECG can help identify arrhythmias 48-49.

**Blood pressure sensors:**

Hypertension, a significant global health concern, can be more accurately screened using consumer wearables that provide precise blood pressure (BP) measurements. These devices are particularly useful in detecting conditions such as nocturnal or exercise-induced hypertension, which are associated with negative health outcomes. The Heart Guide wristwatch (Omron, Japan), featuring a built-in cuff, was compared with an ambulatory BP device. In office settings, BP was measured twice with each device at alternating intervals. In ambulatory settings, patients used the Heart Guide alongside an upper-arm BP monitor that recorded BP every 30 minutes over a 24-hour period 50.

**Biochemical sensors:**

Biochemical sensors in wearables measure electrolytes in body fluids via electrochemical transducers, providing data on plasma volume and analyte levels. Accuracy can be affected by factors such as skin temperature, contamination, and hair density. Continuous glucose monitors, though clinically validated, are difficult to integrate into consumer wearables and are usually standalone devices. Non-invasive sensors for sweat and saliva are promising but need further evaluation for widespread use. Biomechanical sensors in clothing or footwear, like ballistocardiograms and seismocardiograms, aim to continuously monitor cardiac output, lung fluid volume, and weight, which could aid in managing heart failure. Emerging technologies, such as flexible microfluidic sensors that resemble tattoos, offer potential for non-invasive, continuous hemodynamic monitoring but require significant clinical validation 51-52.

**POLYMERS USED IN BIOSENSORS:**

Polymers used in biosensors can be divided into thermoplastic polymers, thermosetting polymers, elastomers, liquid crystalline polymers, polymer gels, piezoelectric polymers, intrinsically conductive polymers, and polymer composites, etc.

**Elastomers:**

Elastomers, known for their rubber-like elasticity, include polydimethylsiloxane (PDMS), which is widely used in applications such as microfluidics, micropumps, electronic skin, and wearable sensors 53-54. PDMS is highly valued for its chemical inertness, thermal stability, tunable mechanical properties, transparency, and ability to form selective bonds under ultraviolet light, crucial for attaching electronic components to substrates. Flexible sensors made from PDMS often incorporate conductive materials like silver nanowires, silver nanoparticles, graphene, reduced graphene oxide, carbon nanotubes, and carbon black. Zhang et al. created an adhesive wearable sensor for use on hairy scalps, developing a CNT-PDMS composite sensor with conical microstructure arrays to enhance attachment to the scalp 55.

**Thermosetting polymers:**

These materials are created through the irreversible curing of a viscous polymer. Polyimide (PI) film is well-regarded for its excellent thermal stability, resistance to strong acids and bases, and high mechanical strength, making it suitable for various processing methods and foundational for sensor technology. However, PI typically lacks transparency and performs poorly under high pressure, limiting its application in flexible, transparent wearable sensors. The development of colorless polyimide (CPI) has expanded the potential for creating high-performance, flexible sensors 56.

**Thermoplastic Polymers:**

Thermoplastic polymers, like thermoplastic polyurethane (TPU), are distinguished by their reversible transition between solid and liquid states. TPU offers excellent elasticity, chemical resistance, processing ease, and cost-efficiency, and it pairs well with various carbon and metal nanomaterials. When combined with cellulose nanocrystals (CNCs), TPU's properties are further enhanced, resulting in sensors with improved tensile strength, broad sensing capabilities, high electrical conductivity, and heightened sensitivity. Additionally, incorporating a porous, cracked bionic structure into TPU can further amplify sensor sensitivity 58.

**Liquid crystalline polymers**:

Liquid crystalline polymers (LCPs) exhibit both fluid and solid-like anisotropy, enabling them to modulate light in response to external stimuli. This property makes them ideal for optical sensors such as ionic skin, photon skin, and electronic skin. Bai et al. created a dual-sensing ionic skin (DSI-skin) inspired by chameleon skin, which combines electromechanical and mechanochromic features. This advanced material, enhanced with Al3+ ions for increased ionic conductivity and cholesteric liquid-crystal structures within a PASCA hydrogel matrix, also offers antibacterial properties and an antifreeze energy source. Furthermore, polymer-dispersed liquid crystal (PDLC) devices, which switch between transparent and opaque states under voltage, are promising for smart displays 59.

**Polymer Gels***:*

Polymer gels, first introduced in 1978, are cross-linked polymer networks that swell in solvents and exhibit reversible volume changes in response to environmental factors like pH, temperature, or solvents. These adaptive properties have inspired research into their use in wearable technology for drug delivery, motion tracking, and altering tissue adhesion characteristics. The combination of gels with pressure-sensitive polymers (e.g., PVDF, PLA) can lead to high-performance strain and pressure sensors 60.

**Intrinsically Conducting Polymers and Piezoelectric Polymers:**

Intrinsic conductive polymers (ICPs), including polyacetylene (PA), polypyrrole (PPy), polyaniline (PANi), polythiophene (PTh), and PEDOT , possess conjugated double bonds or aromatic rings, granting them metal-like electrical, magnetic, and optical characteristics. These polymers, including PEDOT and its derivatives, are particularly valued for their high transparency in the visible spectrum, making them ideal for flexible, transparent electrodes in wearable devices 61-62.

**TYPES OF BIOSENSOR:**

**1. Movement Sensors:**

**a) Pedometers:**

Pedometers are commonly used movement sensors that count steps by detecting vertical acceleration when it surpasses a certain sensitivity threshold. Many fitness programs advocate for specific daily step goals, as achieving these targets often aligns with recommended physical activity levels. Pedometers are effective in promoting physical activity, especially among children and those with obesity, serving as a useful introductory tool for fitness tracking. However, while they offer reliable step counting in daily activities, they are less suitable for competitive sports due to their limitations in tracking directional changes and accurately measuring energy expenditure 63-65.

**b) Accelerometers/Gyroscopes:**

Accelerometers and gyroscopes provide detailed performance data that allows for precise exercise program adjustments. These devices combine mechanical movement sensors with microchips that process their signals. Advances in micro electro-mechanical systems (MEMS) now enable these sensors to integrate multiple transducers, allowing for multi-dimensional movement detection. Accelerometers, in particular, can estimate energy expenditure by analyzing vertical acceleration over time 66-67.

**c) Global Positioning Satellite:**

Global Positioning System (GPS) devices offer an alternative to accelerometers for tracking positional data in sports. They use signals from multiple satellites, synchronized by atomic clocks, to determine speed and location. The accuracy of GPS, especially in team sports, can be enhanced by using a stationary ground-based reference receiver to correct satellite timing errors, achieving precision within one meter. GPS technology is applied to monitor athlete speed and position across various sports such as football, orienteering, cross-country skiing, and field hockey. Wearable devices like Garmin's Vivofit and Vivoactive, Polar's M400, and Fitbit's Surge leverage GPS to provide real-time data on distance, steps, pace, caloric expenditure, altitude, and speed. This data can be analyzed to track performance and customize training programs for improved athletic results 69.

**2) Physiologic Sensors:**

**a) Heart Rate Monitoring:**

Sensors that track physiological responses during training and competition are vital for enhancing performance and reducing injury risks. Heart rate monitoring, a key metric for assessing exercise intensity and adaptation, is traditionally done with chest strap monitors that transmit data to a wrist display 54. Newer models, featuring optical sensors in wristbands or smartphones, measure heart rate from the wrist or fingertip. While these newer devices offer convenience, chest straps generally provide greater accuracy at high heart rates and are less prone to motion artifacts. Modern heart rate monitors from brands like Polar Electro and Suunto also assess heart rate variability, a critical fitness indicator 70. Heart rate’s linear relationship with VO2 allows for the estimation of VO2 and energy expenditure, making these monitors widely used in evaluating exercise intensity. They are often paired with kinematic analysis to gain insights into physiological responses and metabolic demands in sports such as basketball, rugby, and soccer 71.

**b) Temperature/Heat Flux Sensors:**

Monitoring core body temperature is essential in preventing hyperthermia, particularly in hot or humid conditions and during the initial adjustment to new sports activities. Accurate core temperature measurement in sports medicine is challenging, as external temperatures often do not correlate well with core temperature 72. Technological advances, such as ingestible telemetric sensors transmitting data via radiofrequency, have improved accuracy. However, these sensors can be affected by cold food or beverages. Additionally, skin-based sensors, including armbands, may cause irritation and may not reliably measure temperature or energy expenditure during intense exercise 73.

**c) Integrated Sensors:**

Multimodal integrated sensors are increasingly utilized in both individual and team sports to provide comprehensive physiological and movement data. Companies such as Catapult and Zephyr offer advanced devices combining GPS with various sensors. Catapult's sensor is a compact unit attached between the shoulder blades and fastened to a jersey or protective gear 74. Zephyr's devices, including the BioPatch, integrate respiratory rate and ECG monitoring, although the BioPatch requires a chest and shoulder strap for accurate readings, which may be inconvenient with safety gear 75.

**SYSTEM DESIGN 76-78**

The goal of this project is to create a compact, wearable healthcare monitoring system that enables patients to track their health metrics and allows physicians to remotely monitor patient well-being, reducing the need for in-person visits. By using widely available and affordable components, the project aims to keep development costs low. It also emphasizes the benefits of combining front-end physiological monitoring devices with mobile technology and standard networking methods to improve functionality and connectivity.

* Bluetooth connection
* Software implementation
* The mobile applications

**Bluetooth connection:**

During the implementation phase, we chose the MiniDragon + microcontroller platform due to its compact size (6 × 8 cm), affordability, and low power usage. This platform features the 9S12DP256 microcontroller with a 16-bit RISC architecture (Freescale Semiconductors, 2008), providing 256 Kb of Flash EEPROM, 12 Kb of RAM, and 4 Kb of EEPROM. It includes two asynchronous Serial Communications Interfaces (SCI), three Serial Peripheral Interfaces (SPI), an 8-channel enhanced capture timer, and two 8-channel, 10-bit Analog-to-Digital Converters (ADC), among other functionalities that suit our project's needs. We selected Bluetooth for communication technology as it meets essential requirements for our uses includes

* It is ideal for short-range data transmission, increasingly common in mobile devices, and
* It offers enhanced security through data encryption between the controller and the mobile device, ensuring greater protection for our system.

**Software implementation:**

After pairing the Bluetooth devices, the PDA application communicates with the microcontroller through virtual serial ports established via the Serial Port Profile (SPP). This application, developed with the Microsoft Visual Basic .NET Compact Framework, runs on the i-mate PDA2k. The PDA is powered by an Intel XScale PXA263 processor at 400 MHz, with Windows Mobile 2003 Second Edition for Pocket PC Phone Edition, 128 MB RAM, and 64 MB ROM. To manage Bluetooth functionalities, an external library compatible with the Microsoft Bluetooth Stack (WindComm) was used. This stack handles the Bluetooth connection processes and supports various protocols and services. The library provides access to SPP services, facilitating device discovery and connection management. The SPP, designed for continuous data streaming, supports reliable, bidirectional data transmission with sockets categorized as 'active' (initiating connections) and 'passive' (accepting incoming connection requests).

**The mobile application:**

The mobile unit's application, developed with Microsoft Visual Basic .NET (VB.NET) Compact Framework, manages system operations by utilizing standard .NET Compact Framework libraries along with additional components for Bluetooth connectivity. The application also employs the Smart Device Framework to enhance functionality, including

* Access to the virtual serial port,
* Importing patient records from a text file into the registry, and
* Enabling background operation.

The PDA application offers services in three main categories: administrative, patient-related, and communicative. These services include:

* Initial setup of application parameters
* Password management
* Graphical display features
* Bluetooth data transmission and reception from sensors
* Temporary data storage in system registry for later internet upload, enabled by the Smart Device Framework
* Continuous background operation, also supported by the Smart Device Framework
* Emergency SMS notifications to physicians, facilitated by the Smart Device Framework
* Scheduled data uploads using System.Net components with HTTP Web Request and HTTP Web Response
* Customization options for threshold values, SMS contacts, and update frequencies
* Database access
* Data uploads to a server via Active Server Pages (ASP) query strings

**WEARABLE HEALTH DEVICES AND THEIR APPLICATIONS:**

Wearable technology is revolutionizing healthcare by enabling the prediction and management of common health issues through the collection and analysis of physiological and environmental data. These devices allow users to turn personal, biological, and environmental information into actionable insights, facilitating real-time data exchange between individuals and healthcare providers. This enables informed decision-making and targeted interventions. Advanced sensors track long-term activity and exercise adherence, aiding in more effective medication management for chronic conditions, and assess motor tasks for customized rehabilitation. A recent pilot program by an American insurance company involves wearables to gather both invasive and non-invasive data, including vital signs. The integration of artificial intelligence in healthcare is enhancing diagnosis, treatment, monitoring, and prevention, leading to improved healthcare delivery.

**Personalization 79:**

With the assistance of software specialists, healthcare professionals can develop customized programs tailored to individual patient needs.

* **Early Detection:** Accurate medical metrics support the prompt identification of symptoms, allowing for timely interventions.
* **Continuous Monitoring:** Wearable devices enable real-time tracking of patient conditions, providing ongoing oversight.
* **Medication Compliance:** The system ensures patients follow their medication regimens and notifies healthcare providers of missed doses.
* **Data Management:** Real-time data recording facilitates thorough analysis and the creation of detailed patient reports for specialist review.
* **Informed Decision-Making:** Data analysis enhances clinical decision-making, leading to improved patient care quality.
* **Cost Efficiency**: Utilizing wearable devices for remote healthcare reduces the need for in-person visits, saving both time and resources.

Skin-based devices in healthcare applications can predict sudden medical events, detect genetic cancer syndromes, monitor heart rate and respiration fluctuations, identify early signs of vascular issues, manage body temperature, and use bio-sensing clothing. Wearable strain sensors, praised for their lightweight, reliable, flexible, and stretchable characteristics, are particularly suited for monitoring movement-related signals, such as heart and respiration rates, across various healthcare settings.

**Disease 80-81:**

Researchers have developed various wearable technologies aimed at managing and alleviating symptoms of different diseases. Here are some key applications:

* **Sleep Apnea**: This condition involves intermittent interruptions or reductions in breathing during sleep. Treatments range from lifestyle changes to surgery, depending on severity. A notable wearable solution is the DT oral device, which monitors therapy adherence by measuring temperature, movement, and head position through its spatial orientation.
* **Chronic Obstructive Pulmonary Disease (COPD)**: COPD is a lung disorder that leads to breathlessness, is managed through monitoring physical activity with an ear-worn device. This device allows patients to track their condition from home, potentially lowering healthcare costs for those who can be managed outside a hospital setting.
* **Diabetes Mellitus**: This chronic disease affects the body’s insulin production, necessitating precise blood glucose control. Wearable solutions include an artificial pancreas that monitors glucose levels and comprises a core system for insulin delivery, glucose sensing, and glucagon administration. Additionally, Google/Verily Life Sciences has developed a smart contact lens that tracks blood sugar levels.
* **Cardiovascular Diseases**: Various heart-related conditions, such as venous thrombosis and heart failure, are monitored using wearable sensors. For instance, a wireless blood pressure wrist monitor that connects to a smartphone provides real-time heart rate measurements, showing accuracy comparable to clinical standards.
* **Safety Monitoring**: The Vega GPS bracelet offers location tracking through GPS and mobile communications to ensure user safety. For epilepsy patients, the Embrace wristband monitors physiological signals and alerts family members during seizures.
* **Mosquito-Borne Diseases:** The Kite Patch is a wearable device designed to be attached to clothing, emitting compounds to repel mosquitoes and prevent diseases such as malaria and Zika virus.
* **Kidney Failure:** Wearable artificial kidneys offer a portable alternative to traditional dialysis, improving mobility and convenience for individuals with kidney failure.
* **Skeletal System Diseases:** Wearable sensors, equipped with gyroscopes, accelerometers, and magnetometers, provide pain relief for joint disorders and osteoporosis through transcutaneous electrical nerve stimulation and therapeutic exercises. Additionally, some devices help with posture correction by vibrating to alert users to incorrect posture.
* **Stress and Depression Detection:** Wearable wristbands that monitor heart rate variability can evaluate mental states and notify users of rising stress levels.
* **Sunburn Prevention**: Wearable UV sensors, available as bracelets or wristbands, monitor UV exposure to prevent skin damage and estimate vitamin D production.
* **Vein Finding**: Eyes-On technology, a smart glass wearable, utilizes multispectral 3D imaging and wireless connectivity to help healthcare providers locate veins through the skin quickly.

**Nutrition and dietetics: 82**

The field of nutrition and dietetics is undergoing a significant transformation with the introduction of real-time, effective, and affordable wearable technology and sensors. These innovations have the potential to address global nutritional issues by enabling rapid, precise, and cost-effective self-monitoring of dietary deficiencies or imbalances in various settings, including homes, workplaces, and healthcare facilities. Such advancements are critical for providing evidence-based guidance to individuals and vulnerable populations, facilitating informed dietary and lifestyle adjustments through wearable technology. These devices enhance the efficacy of nutritional programs by offering tailored interventions for specific conditions or groups, which is crucial in combating malnutrition and under nutrition. The evolution of wearable health and fitness technologies, combined with digital nutrition databases and informatics platforms, marks a significant shift in the field. These tools foster interactive communication between consumers, dieticians, and nutritionists, thereby enhancing the quality of interventions, management, and outcomes. Emerging technologies in nutrition, such as wearable sensors and implantable devices, offer new opportunities for enhancing health and resource management. These personalized tools ensure that essential resources are accessible and support positive dietary adjustments. By providing real-time monitoring and recommendations, these technologies help users balance their diets, particularly when transitioning to plant-based sources rich in unique phytochemicals and micronutrients. While their effectiveness in promoting healthy lifestyles is well-documented in developed countries, they are also vital in Africa for addressing food and nutrition challenges. These innovations enable accurate, cost-effective detection of nutritional issues, assisting individuals, vulnerable populations, and policymakers in crafting effective nutrition strategies and interventions, ultimately leading to improved health and well-being.

**Body dietary and energy balance 83:**

In a study examining daily total energy expenditure (TEE), researchers used a physical activity monitor and dietary assessments to investigate the relationship between TEE, activity levels, and energy intake. The monitor, placed on the left upper triceps, recorded TEE, sleep duration, and activity levels. Participants also logged their food and beverage consumption. The study found a positive correlation between TEE and BMI and body weight, while TEE was negatively correlated with sleep duration and time spent lying down. After adjusting for BMI, sleep duration, and time lying down in multiple linear regression, the correlation between TEE and energy intake weakened. These results emphasize the importance of body mass, activity, and sleep in determining TEE and suggest that wearable technology could be beneficial for real-time, personalized nutrition management to prevent unintended weight loss.

**CHALLENGES:**

|  |  |  |
| --- | --- | --- |
| **CONCEPT** | **ISSUES** | **SUGGESTIONS** |
| Precision and credibility | Inaccurate information can be more harmful than having no data at all. | To establish thorough assessment frameworks for medical devices akin to the one proposed by Coravos et al., it is essential to formulate comprehensive standards endorsed by medical societies. These standards should outline methodologies for evaluating devices, which often integrate multiple sensors and dynamic software algorithms. Additionally, it is crucial to define cohesive and consistent regulatory policies tailored to these devices to ensure their efficacy and safety. 84 |
| Criteria for Meaningful Use and Supporting Clinical Evidence | There are few meaningful use criteria and limited clinical evidence regarding wearables, with only a small number of studies assessing whether they improve clinical outcomes compared to their absence. | To ensure both efficacy and safety, it is essential to construct a robust body of evidence. This involves delineating criteria that distinguish valuable, actionable data from irrelevant information. The technology sector should emulate the pharmaceutical industry's approach by investing in extensive and methodologically sound randomized clinical trials with extended follow-up periods. This strategy will bolster trust among patients and healthcare providers. Additionally, incorporating training modules on wearable technology into telehealth education programs at various educational and postgraduate levels across different health disciplines is crucial. 85 |
| Behavioral change | Implementing and sustaining behavioral change is challenging, and some research raises doubts about the effectiveness of wearables in facilitating such changes. | Standardize the methodologies for developing behavioral change technique tools, as suggested by Hekler et al. 86. Create tools to address non-adherence issues in advance, following the approach of Zhou et al. 87. Innovate social and financial incentives by leveraging behavioral economics and cognitive psychology principles. Insurance rewards programs should prioritize data privacy, permit voluntary opt-outs without negative consequences, and accommodate individuals with limited financial resources or digital literacy 88. |
| Cost Structures and Payment Models for Hardware | Wearable technology may exacerbate health disparities, as usage rates are up to three times higher among individuals with higher socioeconomic status compared to those with lower socioeconomic status. | Research is essential to explore whether wearables might create new health disparities. Manufacturers should focus on developing affordable, clinical-grade devices. In the U.S., the Centers for Medicare and Medicaid Services, along with private insurers, should broaden reimbursement policies to include metrics such as physical activity and support for lifestyle interventions. As value-based reimbursement for wearables grows, healthcare providers could consider offering these devices to patients through loan programs or at a low co-pay 89 |
| Data Protection and Management Oversight | Sensitive wearable data is vulnerable to breaches, making it challenging to use for research or clinical purposes and resulting in unrealistic expectations from patients about data security. | De-identifying wearable data alone may not suffice for ensuring privacy, necessitating the development of advanced cybersecurity tools such as blockchain. Current HIPAA/HITECH regulations should be updated to encompass the expanding range of patient engagement technologies. Transitioning from opt-out to opt-in systems with transparent privacy policies could improve patient engagement. Clear data user agreements and addressing privacy concerns openly can help establish trust between patients and clinicians 90 |
| Data Administration | Data Integration, Traceability, and Preservation | Create policies to enhance semantic interoperability between wearables and other platforms. Establish regulations for data storage and provenance, and employ innovative technologies like block chain to ensure secure data integrity and traceability 91 |

**CONCLUSION:**

Wearable health monitors have seen remarkable advancements in design and functionality, offering a range of features for effective health tracking and management. These devices now incorporate advanced sensors, intuitive interfaces, and robust connectivity options, making them essential for personal health oversight. With ongoing technological progress, future wearable health monitors are expected to provide even more precise data, enhanced user experiences, and expanded applications in healthcare, fostering a more proactive and tailored approach to health management.

**REFERENCES:**

1. Tehrani, Kiana and Michael A. Wearable Technology and Wearable Devices everything you need to know. In: Wearable Devices.com. 2014. <http://www.> wearabledevices.com/what-is-a-wearable-device. [cited 2024 Jul 30].

2. Fotiadis DI, Glaros C, Likas A. Wearable Medical Devices. Wiley Encyclopedia of Biomedical Engineering. 2006 Apr 14; 3816-3827 doi:10.1002/9780471740360.ebs1326

3. Blond K, Brinkløv CF, Ried-Larsen M, Crippa A, Grøntved A. Association of high amounts of physical activity with mortality risk: a systematic review and meta-analysis. Br J Sports Med. 2020 Oct;54(20):1195-1201. doi: 10.1136/bjsports-2018-100393.

4. Iqbal SMA, Mahgoub I, Du E, Leavitt MA, Asghar W. Advances in healthcare wearable devices. npj Flex Electron. 2021 Apr 12;5(1): 9.

5. Brophy, K. et al. The future of wearable technologies. Brief. Pap. 8, 1–20 (2021).

6. Ates HC, Brunauer A, von Stetten F, Urban GA, Güder F, Merkoçi A, et al. Integrated Devices for Non‐Invasive Diagnostics. Adv Funct Materials. 2021 Apr;31(15):1-9.

7. Heikenfeld J, Jajack A, Rogers J, Gutruf P, Tian L, Pan T, et al. Wearable sensors: modalities, challenges, and prospects. Lab Chip. 2018;18(2):217-48.

8. The history of Spectacles [Internet]. [cited 2024 Jul 30]. Available from: https://www.college- optometrists.org/the-british-optical-association-museum/the-history-of-spectacles

9. Cashell GT. A short history of spectacles. Proc R Soc Med. 1971 Oct;64(10):1063-4.

10. G. Oestmann, The Origins and Diffusion of Watches in the Renaissance: Germany, Comune di Cremona, 2016, pp. 141–143.

11. Zolfagharifard E. Is this the first wearable computer? 300-year-old Chinese abacus ring was used during the Qing dynasty to help traders [Internet]. Associated Newspapers; 2014 [cited 2024 Jul 30]. Available from: https://www.dailymail.co.uk/sciencetech/article-2584437/Is-wearable-computer-300-year-old-Chinese-abacus- ring-used-Qing-Dynasty-help-traders.html

12. Engineering I. The smart ring: From the 17th Century wearable abacus to today [Internet]. 2017 [cited 2024 Jul 30]. Available from: https://interestingengineering.com/innovation/smart-ring-17th-century-wearable-abacus- today

13. Dr Julius Neubronner’s Miniature Pigeon Camera [Internet]. [cited 2024 Jul 30]. Available from: <https://publicdomainreview.org/collection/dr-julius-neubronner-s-miniature-pigeon-camera>

14. The National Archives. Fighting talk: First World War Telecommunications [Internet]. The National Archives; 2016 [cited 2024 Jul 30]. Available from: [https://www.nationalarchives.gov.uk/first-world- war/telecommunications-in-war/](https://www.nationalarchives.gov.uk/first-world-%20war/telecommunications-in-war/)

15.Donald L. Hings - walkie talkie inventor [Internet]. [cited 2024 Jul 30]. Available from: <http://www.dlhings.ca/>

16. Myre G. From wristwatches to radio, how World War I ushered in the modern world [Internet]. NPR; 2017 [cited 2024 Jul 30]. Available from: https://www.npr.org/sections/parallels/2017/04/02/521792062/from- wristwatches-to-radio-how-world-war-i-ushered-in-the-modern-world

17. Magazine S. A partial history of headphones [Internet]. Smithsonian Institution; 2013 [cited 2024 Jul 30]. Available from: <https://www.smithsonianmag.com/arts-culture/a-partial-history-of-headphones-4693742/>

18. B. Ticknor, Virtual Reality and the Criminal Justice System: Exploring the Possibilities for Correctional Rehabilitation, Lexington Books, 2018.

19. E.O. Thorp, Beat the Dealer: A Winning Strategy for the Game of Twenty One, Vol. 310, Vintage, 1966.

20. E. Kurland, History of VR, in: Virtual Reality Filmmaking, Routledge, 2017, pp. 7–17.

21. E. Ackerman, The Man Who Invented VR Goggles 50 years Too Soon, IEEE Spectr. (2016).

22. S.D. Guler, M. Gannon, K. Sicchio, A Brief History of Wearables, in: Crafting

Wearables, Springer, 2016, pp. 3–10.

23. D. Papadopoulos, MBracelet (1999): New York, New York, USA & London, UK with the Knowledge Lab, NCR, 2019, [Online] http://www. fashionabletechnology.org/press/photosbook/hi-res/ft-book-p117.pdf (cited 2024 Jul 30).

1. Plantronics, An Industry Pioneer Reflects on a Decade’S Worth of Achievements To Honour the 10th Anniversary of Bluetooth Headsets, 2010, [Online] <https://newsroom.poly.com/press> release/consumer/plantronics-celebrates-10- years-bluetooth-headset-innovation (cited 2024 Jul 30).
2. T. Jowitt, Tales in Tech History: Pebble Smartwatch, 2017, [Online] https:// www.silicon.co.uk/mobility/tales-tech-history-pebble-smartwatch-220973 (cited 2024 Jul 30).
3. Al-Shorbaji N. Improving Healthcare Access Through Digital Health: The use of Information and Communication Technologies. Healthcare Access. 2022 Feb 9; doi:10.5772/intechopen.99607
4. Kye S, Moon J, Lee T, Lee S, Lee K, Shin S, et al. Detecting periodic limb movements in sleep using motion sensor embedded wearable band. 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC) 2017. https://doi.org/10.1109/smc.2017.8122756.
5. Applications of Smart and Interactive Textiles". Textile Learner. Saddamhusen Jamadar.

29. Sawh M, Stables J. 2017 in Review: The year in fitness trackers [Internet]. 2017 [cited 2024 Jul 30]. Available from: <https://www.wareable.com/fitness-trackers/2017-review-year-in-fitness-trackers-5532>

30. Andrew Williams [Internet]. [cited 2024 Jul 30]. Available from: <https://www.wareable.com/author/a.williams>

31. LeHong H, Velosa A. Hype cycle for the Internet of Things, 2014 [Internet]. Stamford (CT): Gartner Inc.;

2014 [cited 2024 Jul 30]. Available from: https://www. gartner.com/doc/2804217/hype-cycle-internet-things-.

32. Gao W, Emaminejad S, Nyein HY, Challa S, Chen K, Peck A, et al. Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis. Nature 2016;529(7587):509-14.

33. Wilson J. Infonetics survey unveils businesses’ plans for mobile security, Internet of Things, wearables [Internet]. London: HIS Inc.; 2015 [cited 2024 Jul 30]. Available from: https://technology.ihs.com/527159/infoneticssurvey-unveils-businesses-plans-for-mobile-securityinternet-of-things-wearables. 1996. p. 317-26.

34. Foerster F, Smeja M, Fahrenberg J. Detection of posture and motion by accelerometry: a validation study in

ambulatory monitoring. Comput Human Behav 1999; 15(5):571-83.

1. Miyazaki S. Long-term unrestrained measurement of stride length and walking velocity utilizing a piezoelectric gyroscope. IEEE Trans Biomed Eng 1997;44(8):753-9.

36. Anliker U, Ward JA, Lukowicz P, Troster G, Dolveck F, Baer M, et al. AMON: a wearable multiparameter medical monitoring and alert system. IEEE Trans Inf Technol Biomed 2004;8(4):415-27.

37. Gas sensor developer kit [Internet]. Newark (CA): SpecSensors; c2015 [cited 2024 Jul 30]. Available from: https://www.spec-sensors.com/product-category/gassensor-developer-kits/.

38. Misfit Shine Fitness + Sleep Monitor [Internet]. Burlingame (CA): Misfit; 2015 [cited 2024 Jul 30]. Available from: http://misfit.com/products/shine?locale=en.

39. STMicroelectronics. Ultra-compact high-performance eCompass module: 3D accelerometer and 3D magnetometer [Internet]. Geneva: STMicroelectronics; 2013 [cited 2024 Jul 30]. Available from: http://www.st.com/content/ccc/resource/technical/document/datasheet/56/ec/ac/de/28/21/4d/48/DM00027543.pdf/files/DM00027543. pdf/jcr:content/translations/en.DM00027543.pdf.

40. STMicroelectronics. MEMS motion sensor: ultra-stable three-axis digital output gyroscope (L3G4200D) [Internet]. Geneva: STMicroelectronics; 2010 [cited 2024 Jul 30]. Available from: http://www.st.com/content/ccc/resource/technical/document/datasheet/04/46/d6/00/be/d9/46/ae/CD00265057.pdf/files/CD00265057.pdf/ jcr:content/translations/en.CD00265057.pdf.

41. Bertolotti GM, Cristiani AM, Colagiorgio P, Romano F, Bassani E, Caramia N, et al. A wearable and modular inertial unit for measuring limb movements and balance control abilities. IEEE Sens J 2016;16(3):790-7.

42. Spinelle L, Gerboles M, Villani MG, Aleixandre M, Bonavitacola F. Field calibration of a cluster of low

cost available sensors for air quality monitoring. Part A: Ozone and nitrogen dioxide. Sens Actuators B Chem 2015;215:249-57.

1. Chen M, Ma Y, Song J, Lai CF, Hu B. Smart clothing: connecting human with clouds and big data for sustainable health monitoring. Mob Netw Appl 2016;21(5):825-45.

44. Sanfilippo F, Pettersen KY. A sensor fusion wearable health-monitoring system with haptic feedback. 2015 11th International Conference on Innovations in Information Technology (IIT). 2015 Nov; 262-266. doi:10.1109/innovations.2015.7381551

45. American Heart Association. Life’s Simple 7. [Internet]. [cited 2024 Jul 30]. Available from: https://www.heart.org/-/media/files/professional/workplace-health/detailed-overview-whs-with-ls7-journey-1218.pdf?la=en&hash=9D16F77814743A12695010D025065588CD1F9A44

46. Muralidharan K, Khan AJ, Misra A, Balan RK, Agarwal S. Barometric phone sensors. Proceedings of the 15th Workshop on Mobile Computing Systems and Applications. 2014 Feb 26; 12; 1-6. doi:10.1145/2565585.2565596

47. Fox K, Ford I, Steg PG, Tendera M, Robertson M, Ferrari R; BEAUTIFUL investigators. Heart rate as a prognostic risk factor in patients with coronary artery disease and left-ventricular systolic dysfunction (BEAUTIFUL): a subgroup analysis of a randomised controlled trial. Lancet. 2008 Sep 6;372(9641):817-21. doi: 10.1016/S0140-6736(08)61171-X.

48. Perez MV, Mahaffey KW, Hedlin H, Rumsfeld JS, Garcia A, Ferris T, Balasubramanian V, Russo AM, Rajmane A, Cheung L, Hung G, Lee J, Kowey P, Talati N, Nag D, Gummidipundi SE, Beatty A, Hills MT, Desai S, Granger CB, Desai M, Turakhia MP; Apple Heart Study Investigators. Large-Scale Assessment of a Smartwatch to Identify Atrial Fibrillation. N Engl J Med. 2019 Nov 14;381(20):1909-1917. doi: 10.1056/NEJMoa1901183.

49. Dagher L, Shi H, Zhao Y, Marrouche NF. Wearables in cardiology: Here to stay. Heart Rhythm. 2020 May;17(5 Pt B):889-895. doi: 10.1016/j.hrthm.2020.02.023.

50. Kario K, Shimbo D, Tomitani N, Kanegae H, Schwartz JE, Williams B. The first study comparing a wearable watch-type blood pressure monitor with a conventional ambulatory blood pressure monitor on in-office and out-of-office settings. J Clin Hypertens (Greenwich). 2020 Feb;22(2):135-141. doi: 10.1111/jch.13799.

51. Bailey TS. Clinical Implications of Accuracy Measurements of Continuous Glucose Sensors. Diabetes Technol Ther. 2017 May;19(S2):S51-S54. doi: 10.1089/dia.2017.0050.

52. Seshadri DR, Li RT, Voos JE, Rowbottom JR, Alfes CM, Zorman CA, et al. Wearable sensors for monitoring the physiological and biochemical profile of the athlete. npj Digit Med. 2019 Jul 22;2(1): 72.

53. Chen J, Zheng J, Gao Q, Zhang J, Zhang J, Omisore O, et al. Polydimethylsiloxane (PDMS)-Based Flexible Resistive Strain Sensors for Wearable Applications. Applied Sciences. 2018 Feb 28;8(3):345.

54. Sun Y, Rogers JA. Structural forms of single crystal semiconductor nanoribbons for high-performance stretchable electronics. J Mater Chem. 2007;17(9):832-840.

55. Zhang A, Shyam AB, Cunningham AM, Williams C, Brissenden A, Bartley A, et al. Adhesive wearable sensors for electroencephalography from hairy scalp. Advanced Healthcare Materials. 2023 Jun 9;12(22): e2300142. doi:10.1002/adhm.202300142

56. Lin J, Peng Z, Liu Y, Ruiz-Zepeda F, Ye R, Samuel EL, Yacaman MJ, Yakobson BI, Tour JM. Laser-induced porous graphene films from commercial polymers. Nat Commun. 2014 Dec 10;5:5714. doi: 10.1038/ncomms6714

57. Zhang Y, Zhao Y, Zhai W, Zheng G, Ji Y, Dai K, et al. Multifunctional interlocked e-skin based on elastic micropattern array facilely prepared by hot-air-gun. Chemical Engineering Journal. 2021 Mar;407:127960.

58. Chen T, Xie Y, Wang Z, Lou J, Liu D, Xu R, et al. Recent Advances of Flexible Strain Sensors Based on Conductive Fillers and Thermoplastic Polyurethane Matrixes. ACS Appl Polym Mater. 2021 Nov 12;3(11):5317-38.

59. Bai L, Jin Y, Shang X, Jin H, Zhou Y, Shi L. Highly synergistic, electromechanical and mechanochromic dual-sensing ionic skin with multiple monitoring, antibacterial, self-healing, and anti-freezing functions. J Mater Chem A. 2021;9(42):23916-28.

60. Peng Y, Peng H, Chen Z, Zhang J. Ultrasensitive Soft Sensor from Anisotropic Conductive Biphasic Liquid Metal-Polymer Gels. Adv Mater. 2024 Feb;36(8):e2305707. doi: 10.1002/adma.202305707.

61. 1. Li Y, Lu D, Wong CP. Intrinsically conducting polymers (ICPS). Electrical Conductive Adhesives with Nanotechnologies. 2009 Aug 14;361–424. doi:10.1007/978-0-387-88783-8\_8

62. Farrell TP, Kaner RB. Conducting polymers. Encyclopedia of Polymeric Nanomaterials. 2013;1–8. doi:10.1007/978-3-642-36199-9\_2-1

63. Chen KY, Janz KF, Zhu W, Brychta RJ. Redefining the roles of sensors in objective physical activity monitoring. Med Sci Sports Exerc. 2012;44(suppl 1):S13-S23.

64. Crouter SE, Schneider PL, Karabulut M, Bassett DR Jr. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. Med Sci Sports Exerc. 2003;35(8):1455-1460.

65. Rowlands AV, Eston RG, Ingledew DK. Relationship between activity levels, aerobic fitness, and body fat in 8- to 10-yr-old children. J Appl Physiol. 1999;86(4):1428-1435.

66. Mineta T, Kobayashi S, Watanabe Y, et al. Three-axis capacitive accelerometer with uniform axial sensitivities. J Micromech Microeng. 1996;6:431.

67. Scheeper P, Gulløv JO, Kofoed LM. A piezoelectric triaxial accelerometer. J Micromech Microeng. 1996;6(1):131-133.

68. Larsson P. Global positioning system and sport-specific testing. Sports Med. 2003;33(15):1093-1101.

69. Larsson P, Henriksson-Larsén K. Combined metabolic gas analyser and dGPS analysis of performance in cross-country skiing. J Sports Sci. 2005;23(8):861-870.

70. Matthew D, Delextrat A. Heart rate, blood lactate concentration, and time– motion analysis of female basketball players during competition. J Sports Sci. 2009;27(8):813-821.

71. Strath SJ, Swartz AM, Bassett DR Jr, O’Brien WL, King GA, Ainsworth BE. Evaluation of heart rate as a method for assessing moderate intensity physical activity. Med Sci Sports Exerc. 2000;32(suppl):S465-S470.

72. Moran DS, Mendal L. Core temperature measurement. Sports Med. 2002;32(14): 879-885.

73. Sparling PB, Snow TK, Millard-Stafford ML. Monitoring core temperature during exercise: ingestible sensor vs. rectal thermistor. Aviat Space Environ Med. 1993;64(8):760-763.

74. Portas MD, Harley JA, Barnes CA, Rush CJ. The validity and reliability of 1-Hz and 5-Hz global positioning systems for linear, multidirectional, and soccerspecific activities. Int J Sports Physiol Perform. 2010;5(4):448-458.

75. Varley MC, Fairweather IH, Aughey RJ. Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. J Sports Sci. 2012;30(2):121-127.

76. Sagahyroon A, Raddy H, Ghazy A, Suleman U. Design and implementation of a wearable healthcare monitoring system. Int J Electron Healthc. 2009;5(1):68-86. doi: 10.1504/IJEH.2009.026273.

77. Standing S, Standing C. Mobile technology and healthcare: the adoption issues and systemic problems. IJEH. 2008;4(3/4):221-235.

78. Thulasi Bai V, Srivatsa SK. Design of wearable cardiac telemedicine system. Int J Electron Healthc. 2007;3(3):303-16. doi: 10.1504/IJEH.2007.014550.

79. Jin H, Jin Q, Jian J. Smart materials for wearable healthcare devices. Wearable Technologies. 2018 Oct 3; doi:10.5772/intechopen.76604

80. Aliverti A. Wearable technology: Role in respiratory health and disease. Breathe. 2017;13(2):e27-e36

81. Tambo E, Ngogang JY. Wearable nutrition and dietetics technology on health nutrition paradigm shift in lowand middle-income countries. International Journal of Nutrition and Metabolism. 2018;10(5):31-36. DOI: 10.5897/IJNAM2016.0207

82. Javadi B, Calheiros RN, Matawie KM, Ginige A, Cook A. Smart Nutrition Monitoring System Using Heterogeneous Internet of Things Platform. Internet and Distributed Computing Systems. 2018;19(1): 63–74. https://doi.org/10.1007/978-3-319-97795-9\_6.

83. Murakami H, Kawakami R, NakaeShow S, Miyachi M. Accuracy of wearable devices for estimating Total energy expenditure: Comparison with metabolic chamber and doubly Labeled water method. JAMA Internal Medicine. 2016;176:702-703. DOI: 10.1001/jamainternmed.2016.0152

84. Coravos A, Doerr M, Goldsack J, Manta C, Shervey M, Woods B, Wood WA. Modernizing and designing evaluation frameworks for connected sensor technologies in medicine. NPJ Digit Med. 2020 Mar 13;3:37. doi: 10.1038/s41746-020-0237-3. Erratum in: NPJ Digit Med. 2020 Apr 2;3:52. doi: 10.1038/s41746-020-0263-1

85. Haibe-Kains B, Adam GA, Hosny A, Khodakarami F; Massive Analysis Quality Control (MAQC) Society Board of Directors; Waldron L, Wang B, McIntosh C, Goldenberg A, Kundaje A, Greene CS, Broderick T, Hoffman MM, Leek JT, Korthauer K, Huber W, Brazma A, Pineau J, Tibshirani R, Hastie T, Ioannidis JPA, Quackenbush J, Aerts HJWL. Transparency and reproducibility in artificial intelligence. Nature. 2020 Oct;586(7829):E14-E16. doi: 10.1038/s41586-020-2766-y.

86. Hekler EB, Michie S, Pavel M, Rivera DE, Collins LM, Jimison HB, Garnett C, Parral S, Spruijt-Metz D. Advancing Models and Theories for Digital Behavior Change Interventions. Am J Prev Med. 2016 Nov;51(5):825-832. doi: 10.1016/j.amepre.2016.06.013.

87. Zhou M, Fukuoka Y, Goldberg K, Vittinghoff E, Aswani A. Applying machine learning to predict future adherence to physical activity programs. BMC Med Inform Decis Mak 2019;19(1). https://doi.org/10.1186/s12911-019-0890-0

88. Fitbit launches Fitbit Care, a powerful new enterprise health platform for wellness and prevention and disease management [Internet]. 2018 [cited 2024 Jul 30]. Available from: <https://www.businesswire.com/news/home/20180919005234/en/Fitbit-Launches-Fitbit-Care-A-Powerful-New-Enterprise-Health-Platform-for-Wellness-and-Prevention-and-Disease-Management>

89. Yang WE, Spaulding EM, Lumelsky D, Hung G, Huynh PP, Knowles K, Marvel FA, Vilarino V, Wang J, Shah LM, Xun H, Shan R, Wongvibulsin S, Martin SS. Strategies for the Successful Implementation of a Novel iPhone Loaner System (iShare) in mHealth Interventions: Prospective Study. JMIR Mhealth Uhealth. 2019 Dec 16;7(12):e16391

90. Sarpatwari A, Choudhry NK. Recalibrating Privacy Protections to Promote Patient Engagement. N Engl J Med. 2017 Oct 19;377(16):1509-1511.

91. Slotwiner DJ, Tarakji KG, Al-Khatib SM, Passman RS, Saxon LA, Peters NS, et al. Transparent sharing of digital health data: A call to action. Heart Rhythm. 2019 Sept;16(9): 95-106. doi:10.1016/j.hrthm.2019.04.042