Enhancing Quality of Life: Advanced Wearables for Patient and Elderly Monitoring

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***Abstract*—In the realm of advancing health care technology, the Health - Internet of Things (H-IoT) plays a crucial role, particularly through a smart wearable device designed for patient and elderly monitoring. This paper proposes a device, equipped with heart rate and ECG monitoring, fall detection, steps counter, activity monitoring and an alert system, as a game-changer in remote health care delivery and continuous patient monitoring outside traditional settings. Integrating advanced hardware with software solutions like Arduino Cloud and Twilio, it empowers individuals and health care providers to proactively manage health and enhance patient safety. This paper explores the impact of H-IoT on current healthcare systems, the trustworthiness of IoT technologies, and the transformative potential of these innovations in healthcare. It also delves into the design methodology and machine learning algorithms of the wearable device, illustrating the synergy between technology and healthcare.**

***Index Terms*—Arduino cloud, ECG Monitoring System, Fall Detection, Health Internet of Things (HIoT), Internet of Things (IoT), Internet of Medical Things (IoMT), Heart rate, Machine health monitoring, Machine learning, Remote health Monitoring.**

I. Introduction

In the ever-evolving landscape of technology, the Internet of Things (IoT) has emerged as a transformative force, weaving a seamless fabric of connectivity across the digital realm. It has led to a paradigm shift that reflects the connected whole and can be accessed by anyone, anywhere, and at any time [2]. It is a combination of several fields, including microelectronics, medicine, computer science, and a network of connected devices, mechanical and digital machines, or objects with unique identifiers that can transfer data over a network or internet without requiring human-to-human or human-to-computer interaction. Moreover, cloud computing services play a crucial role in IoT applications. They are employed to construct accurate composite services by combining pre-existing individual services. This process enhances the functionality of IoT service-based applications [3]. The global count of IoT devices is anticipated to reach 15.14 billion in 2023 and is projected to steadily rise, approaching 29 billion by 2030—almost doubling the 2020 figure of 15.1 billion [4]. China is anticipated to host the highest number of devices, reaching approximately 8 billion. These devices serve diverse industries and consumers, constituting 60% of all IoT devices in 2020.

The healthcare sector's primary goal is to make healthcare more affordable and accessible for all. A key player in this mission is the Internet of Things (IoT), whose cutting-edge innovations are vital in shaping the future of wellness. The global IoT healthcare market, as reported by Allied Market Research, was valued at $113.751 billion in 2019 and is expected to surge to $332.672 billion by 2027. This impressive growth rate of 13.20 % from 2020 to 2027 underscores the growing recognition of IoT's potential to enhance patient care, optimize resource use, and revolutionize traditional healthcare models.

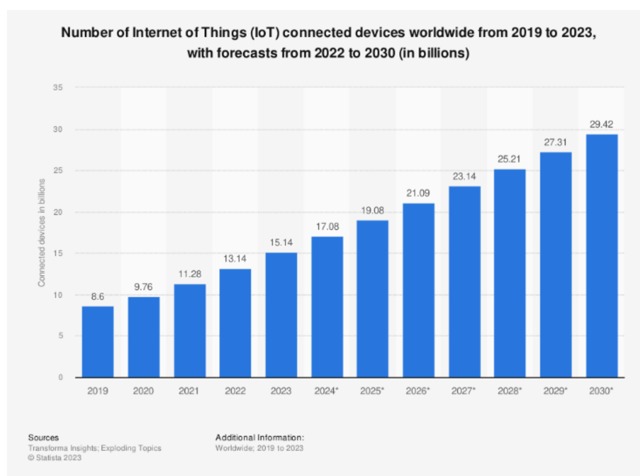

Fig. 1. The number of IoT connected devices worldwide from 2019 to 2023, with forecasts from 2022 to 2030 (in billions).
Adopeted from [4]

The concept of Health - Internet of Things (H-IoTs), first introduced in Health 2.0 focused on a healthcare system that enabled active patient participation, providing more accessible and comprehensive care. The H-IoT has open ways to new groundbreaking possibilities for preventive care, personalized medicine, and real-time health monitoring. These Internet of Things (IoT) devices, which range in size from small consumer portable devices to large hospital medical equipment, enable medical therapies, real-time diagnostics, and remote monitoring worldwide.

We are experiencing a change in the way we deliver care as technology continues to become more prevalent in the healthcare industry. This new stage of development, known as "health 4.0," introduces the Internet of Medical Things (IoMTs) by fusing technology and patient-centered methodologies. IoMTs is a broader term that combines medical equipment with the Internet of Things and is a future of current healthcare systems where every medical device will be connected and monitored over the Internet by the healthcare professionals.

The evolution in healthcare responds to the sector's dynamic nature and the transformative role of IoT. Each stage, from Health 2.0's focus on participatory models and social media use to Health 3.0's emphasis on holistic care and personalized medicine and has built upon its predecessor. Now, Health 4.0 brings together artificial intelligence, IoT, big data analytics, and blockchain to create a highly interconnected ecosystem. This latest stage prioritizes data-driven decision-making and real-time monitoring, aiming to optimize healthcare delivery and improve patient outcomes.

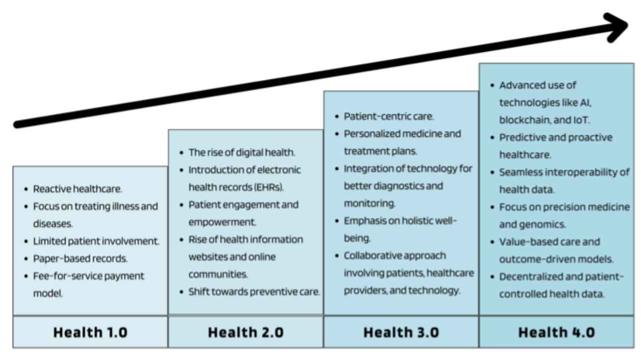

Fig. 2. The key characteristics of the evolution of health care

The prototypes of IoMT applications, such as wearable devices, empower individuals like patients, the elderly, or those with chronic diseases to remotely monitor their health. In emergency situations, these IoT applications can promptly alert caregivers or physicians about the health status of an elderly person, establishing a swift and efficient means of communication [3]. As we explore the IoT's impact on healthcare, the synergy between technological advancements and the art of healing emerges as a compelling narrative, one that holds the promise of a more interconnected and patient-centric approach to well-being.

Within the context of the HIoT, wearable devices are invaluable for real-time health monitoring, tracking metrics like heart rate and blood pressure. Remote patient monitoring is enabled by the seamless integration of IoT technologies, allowing healthcare providers to monitor patients' well-being without continual physical presence. This is especially advantageous for those with chronic diseases since it allows for tailored treatment regimens while minimizing the demand on healthcare institutions. Furthermore, the data collected by these wearables contributes to the field of data-driven customized medicine, allowing healthcare professionals to adjust therapies to specific health trends.

A. Motivation

In the rapidly evolving landscape of healthcare, which now integrates internet and IoT technologies, this paper introduces a solution: a wearable patient and elderly monitoring system, which we call 'VitalGuard'. It is essential to first understand the challenges it seeks to overcome. The current healthcare sector, despite advanced technological integration, grapples with critical issues. These issues include limited access to continuous health monitoring for vulnerable groups such as the elderly, patients with chronic conditions, and athletes. This gap in continuous care increases the risk of delayed detection and treatment of health issues. Moreover, geographical barriers further intensify disparities in healthcare access. Additionally, the security and privacy of digital health data and the complexities of assimilating new technologies into established healthcare infrastructures pose significant challenges. These pressing concerns highlight the dire need for a transformative approach.

In the midst of these technological advancements, our proposed wearable device emerges as a great solution. It offers features like activity monitoring, fall detection, steps counter, heart rate monitoring, and ECG capabilities, catering to a diverse range of individuals including the elderly, patients, athletes, and more. This device is not confined to mere monitoring; it marks a significant leap towards personalized healthcare. By analyzing collected data, healthcare providers can craft individualized treatment plans, thereby optimizing health outcomes. The real-time tracking and alert system function as a vigilant guardian, enabling prompt response to any abnormalities in vital parameters. This capability for immediate intervention not only enhances patient safety but also raises the standard of healthcare delivery.

It is like magining a world where health monitoring surpasses physical limitations. This innovative device enables caregivers, doctors, and coaches to remotely monitor an individual's health, breaking down demographic and geographical barriers. Its capability for real-time tracking and remote monitoring is especially beneficial for those with chronic conditions, reducing the need for frequent and often burdensome clinic visits. The elderly, in particular, can benefit from the comfort of home monitoring, avoiding the challenges of long queues and travel.

To ensure the highest standards, several non-functional requirements must be addressed. These include a compact form factor for sensors, stringent data security, fault tolerance, Quality of Service (QoS) considerations such as low latency with high data integrity, and interoperability. Addressing these requirements is crucial for the successful implementation and widespread adoption of this innovative healthcare monitoring solution.

B. PAPER STRUCTURE

The structure of the paper unfolds as follows: Following the introduction in Section I, Section II delves into the literature review, which provids an in-depth exploration with a specific emphasis on background and related work. Section III outlines the proposed system, offering a comprehensive overview of its design and functionality. Moving forward, Section IV discusses the research methodologies used to test the hypothesis and Section V engages in a detailed discussion encompassing the entirety of the project and its associated hypotheses. The ensuing Section VI addresses the challenges encountered during the project's development, presents countermeasures employed, and outlines avenues for future work. The paper concludes in Section VII, summarizing key findings and implications drawn from the study.

II. LITERATURE REVIEW

Conducting a comprehensive literature review is a crucial step in any project which provides a foundational understanding of current works and debates within a specific field. This process provides insights and highlights various perspectives on the topic, presenting valuable information and revealing conflicting ideas. Through reviewing numerous studies, we aim to build a solid understanding of wearable devices and validate pertinent information for our project.

A. Background and Foundation

An electrocardiogram (ECG) is a test that tracks the heart's electrical activity by measuring the impulses generated during the heart's contraction and relaxation cycles. By placing electrodes on the body, it captures changes in electrical voltages over time, resulting in a detailed graph. This data, including specific parameters like the PR interval and QRS complex, helps specialists in detecting and diagnosing various heart-related conditions [6].

Moreover, heart rate is an integral part of the information that can be derived from an ECG. Heart rate is a vital sign that measures the number of times your heart beats per minute. It's an important indicator of your heart health and overall physical condition. As American Heart Association [7] mentions that the heart rate can vary from person to person and can be influenced by factors like age, fitness level, activity level, and the presence of any medical conditions. The following table from American Heart Association shows target heart rate zones for different ages. However, the maximum heart rate is about 220 minus the person age [7].

TABLE I
CHARACTERISTICS OF THE HEART RATE BY AGE GROUP

Age	Target HR Zone 50-85%	Average Max. Heart Rate, 100%
20 years	100-170 bpm	200 bpm
30 years	95-162 bpm	190 bpm
35 years	93-157 bpm	185 bpm
40 years	90-153 bpm	180 bpm
45 years	88-149 bpm	175 bpm
50 years	85-145 bpm	170 bpm
55 years	83-140 bpm	165 bpm
60 years	80-136 bpm	160 bpm
65 years	78-132 bpm	155 bpm
70 years	75-128 bpm	150 bpm

There are some similar researches, Mohammed Yusuf Ansari et al., 2022 focused on the development and implementation of an IoT-based health monitoring system designed for Covid-19 patients. This system is particularly relevant in scenarios where resources are limited or there's a high risk of infection. The technology enables medical staff to remotely monitor vital signs like blood saturation, heart rate, pulse rate, and body temperature using specific sensors and a Biosensor Module MAX3100. Additionally, the system measures room temperature and humidity, with all data processed by an ESP32 Arduino and displayed on a smartphone or PC. The system, which has been tested and found effective, allows healthcare professionals to safely track multiple patients simultaneously, reducing the risk of virus transmission [8].

In a similar study, Ali I. Siam et al., 2022 discussed the design and implementation of a versatile and portable health monitoring system, a reflection of the significant advancements in remote healthcare and telemedicine driven by Internet of Things (IoT) technology. This system is capable of monitoring a range of medical parameters including heart rate, blood oxygen saturation, body temperature, photoplethysmography (PPG) signals, electrocardiography (ECG) signals, as well as environmental factors like room temperature and humidity. The data collected by this system can be displayed directly on its built-in screen or transmitted via Wi-Fi to a mobile app for local monitoring or to cloud storage for remote observation. This technology is particularly beneficial for continuous monitoring of individuals' health in their everyday environment, making it easier to manage their care without disrupting their daily routines. The system's accuracy has been rigorously tested, showing a maximum error percentage of 2.67%, 2.04%, and 1.58% for heart rate, blood oxygen saturation, and body temperature, respectively, when compared to commercial devices. Additionally, statistical tests have confirmed a high level of agreement with reference measurements, underscoring the system's reliability and potential for widespread application in daily medical monitoring.[9].

Md Julhas Hossain et al., 2022 concentrate on the role and advancements of IoT (Internet of Things)-based smart health monitoring systems in healthcare, emphasizing their growing importance globally, especially during the COVID-19 pandemic. They explore how IoT, with its network of sensors and communication devices, has transformed healthcare by enabling remote monitoring of vital parameters like blood pressure, heart rate, and blood glucose levels. This technology has not only minimized patient movement during the pandemic but also enhanced healthcare across all age groups, linking patients and doctors more effectively. The paper reviews the use of digital technology, including medical sensor devices and web-based apps, for transmitting health data to medical portals, with smartphones serving as a central hub for smooth operation. It highlights the economic and practical benefits of IoT in healthcare, including reducing direct contact to prevent virus spread, and emphasizes the significance of wearable real-time health tracking devices, particularly for the elderly. The review aims to demonstrate how IoT-based systems can efficiently monitor patients both in hospital settings and remotely, potentially reducing hospital operating costs and improving the quality of health services, while discussing the latest technologies, their benefits, and challenges in this rapidly evolving field.[10].

B. Trust Factors

The usage of an IoT application - a wearable patient and elderly monitoring device - encompasses several elements that contribute to the creation of trust among the numerous stakeholders involved in the process's success. As a result, extensive research endeavors have been undertaken to determine the critical factors that influence the use of IoT applications in general.

a) Users' Experience: With the rapid development of IoT into our lives today, many IoT applications have become a part of our everyday life. The experience of users using IoT applications is critical to the general adoption and success of IoT technology. A pleasant and positive user experience starts with simplicity of setup and use, since people value simple setups and user-friendly interfaces. User satisfaction is dependent on dependable functioning, efficient performance, and data privacy. Personalization features, as well as device settings management, improve the user experience by allowing users to adjust IoT applications to their tastes. IoT applications' efficiency and time-saving features make daily chores easier, while strong and robust data security measures encourage trust. Effective customer service, instructional materials, and scalability further enhance a great user journey. Moreover, Consistent value delivery encourages long-term engagement, and compatibility with other IoT devices improves automation and control [11].

In the realm of health care, the user experience of IoT applications is very critical to empower individuals to take ownership of their well-being, improve adherence to treatment programs, and improve the efficiency and quality of healthcare services. These IoT applications can be used by patients and healthcare workers to monitor vital signs, manage chronic illnesses, and streamline healthcare processes. A smooth and user-friendly interface is especially important in healthcare, where simplicity of use can save lives. As IoT expands into these fields, providing a positive user experience is critical to fostering widespread acceptance and satisfaction with IoT solutions.

b) The Security and Design of IoT in Health Sector: The application of IoT in healthcare includes a variety of devices, systems, and applications implied to simplify operations, improve patient care, remotely monitor patients, and improve overall health outcomes. However, considering the sensitive nature of health-related data and the possible consequences connected with its breach, the security and architecture of IoT systems in healthcare require careful consideration. These devices gather, monitor, and analyze user-health data, which raises security concerns and may impact consumers' adoption of this technology, as well as trust issues.

c) Design Considerations: The design of IoT devices in healthcare is governed by a dual objective: functionality and user-centricity. These devices, ranging from wearable health monitors to smart hospital equipment, are engineered to ensure accuracy, reliability, and ease of use. The user-centric design is paramount, considering the diverse demographics of patients and healthcare professionals. This involves creating interfaces that are intuitive and accessible, catering to users with varying levels of technical proficiency and physical capabilities. It is important to note that the user must perform less number of actions as possible to perform a certain actions. Additionally, the design process must adhere to the regulatory standards and compliance requirements, such as those set by the Food and Drug Administration (FDA) in the United States or the European Union's Medical Device Regulation (MDR) which ensure that the devices meet safety and effectiveness criteria before being introduced to the market.

d) Security Challenges and Strategies: The proliferation of IoT devices in healthcare has significantly increased the attack surface for potential cyber threats. The sensitive nature of health data collected and transmitted by IoT devices makes them a lucrative target for cybercriminals. Data breaches can lead to severe consequences, including identity theft, financial loss, and compromised patient safety. To mitigate these risks, robust security measures are imperative. However, data protection is not merely a technical requirement but a cornerstone of ethical healthcare practice. It aims to ensure that medical staff, caretakers, and coaches have adequate access to patient information for effective treatment while upholding the sanctity of patient confidentiality [1].

This includes employing end-to-end encryption for data transmission, ensuring data integrity and confidentiality. Additionally, implementing strong authentication and access control mechanisms is vital to prevent unauthorized access to sensitive information. Qadri et al. mentions that the assurance of patient data security, as well as the patient's identity, is directly associated with the adoption rate of H-IoT [5].

C. Physiological Characteristics of Users

Trust is a key component of a user's physiological traits, which signifies opening oneself to be vulnerable based on a positive expectation or hopeful behavior of another party's future behavior. It may be viewed as an individual characteristic that is inextricably linked to an individual's bodily responses, and emotional sentiments, which helps maintain good relations and reduces the risk associated with the exchange [1]. This section focuses on the elements that influence trust relationships and what beliefs trust implies.

a) Beliefs: According to research conducted by Tao Zhou [2], three beliefs are frequently associated with trust.

First, there is ability, which denotes that service providers have the knowledge and skill set required to complete their tasks. Secondly, there is integrity, and finally, benevolence. Benevolence demonstrates that service providers care about users' interests as well as their own, whereas integrity shows that service providers uphold their pledges and do not deceive customers.

Every IoT application should have a clear privacy policy, disclaimer, and a terms and conditions section to inform and educate the user about some or all the ways the IoT application collects, uses, discloses, and controls data about the user. This helps users understand the scope of rights that must be exercised to avoid intentional or unintentional violations of any individual's rights, and the terms that the user must agree to in order to use the application.

b) Self-Efficacy: Self-efficacy refers to an individual's mindset, ability, and cognitive skills necessary to perform the behaviors required to achieve specific performance goals. In a study conducted by Tao Zhou [2], self-efficacy was defined as the belief in one's knowledge and expertise required to use a developing service. In the context of the paper, this service pertains to wearable patient and elderly monitoring IoT devices and online services. Self-efficacy significantly influences the initial trust that enables users to install and utilize the mobile application. According to social cognitive theory, individuals with high self-efficacy are more likely to have positive expectations about future outcomes. The likelihood of using the application increases as the user's sense of self-efficacy grows.

c) Desire to Self Development: The desire for self-development reflects an individual's drive to engage in personal growth and self-improvement, ultimately leading to enhanced long-term well-being. It drives them to continuously enhance their knowledge, skills, and personal growth, ultimately contributing to the long-term well-being and when the self-development is within the realm of IoT applications, it is paramount to driving innovation and ensuring the sustained relevance of this technology. Moreover, the willingness to self-improvement is positively correlated with self-esteem and success values [1]. The users will experience ease in using the IoT applications and therefore be more willing to invest in it. In the healthcare sector, this commitment results in the creation of more advanced and precise IoT applications, such as remote patient monitoring systems and smart medical devices. These applications not only provide healthcare practitioners with real-time data and insights for better diagnosis and treatment but also offer patients greater convenience and access to medical services.

d) Perception Autonomy: Perceived autonomy is a multifaceted concept that extends beyond personal freedom and self-determination. It refers to an individual's subjective perception or conviction that they have a certain degree of independence, control, and self-determination over their actions, decisions, and choices in a specific circumstance or setting that aligns with their intrinsic values and preferences. In the realm of healthcare, Tao Zhou [1] mentions that self-determined motivation favorably promotes physical practice participation, and perceived autonomy fosters healthy attitudes.

Furthermore, the influence of perceived autonomy extends into the realm of technology, as evident in recent studies focusing on the utilization of IoT (Internet of Things) applications in the treatment of chronically ill patients. One of these studies as mentioned by Tao Zhou [1] demonstrates that user autonomy is positively associated to the degree of use; the more connected patients are, the more independent and involved they become. As a result, patients value the autonomy provided by linked applications thereby improving their overall health outcomes and well-being.

D. Hypothesis

After a thorough review of existing literature and analysis of key physiological characteristics of users, we have formulated several hypotheses addressing the reliability and user trust in wearable IoT devices within the health sector. These hypotheses are crafted in the spirit of inquiry fostered by the work of Samhale[1], whose methodology in hypothesis formation has significantly influenced our approach. The hypotheses are as follows.

- **HYPOTHESIS ON BELIEFS**
  H1 The belief in the effectiveness of wearable health monitors positively influences the frequency and consistency of their use among individuals, especially elderly and patients.

- **HYPOTHESIS ON DESIRE FOR SELF-DEVELOPMENT**
  H2 Individuals with a strong desire for self-development are more likely to adopt and effectively use wearable health monitoring technologies.

- **HYPOTHESIS ON SELF-EFFICACY**
  H3 Higher self-efficacy levels in individuals with increased willingness and ability to utilize wearable health monitoring devices.

- **HYPOTHESIS ON HEALTH MONITORING EFFICANCY**
  H4 Higher self-efficacy levels in individuals with increased willingness and ability to utilize wearable health monitoring devices.

- **HYPOTHESIS ON TECHNOLOGY ACCEPTANCE**
  H5 Elderly individuals' acceptance of wearable health monitoring devices is significantly influenced by their perceived ease of use and perceived usefulness.

- **HYPOTHESIS ON EMERGENCY RESPONSE**
  H6 Caregivers using the data from the wearable monitors will be able to provide more efficient and timely care to their patients or individuals.

- **HYPOTHESIS ON CROSS-DEMOGRAPHIC USABILITY**
  H7 The effectiveness and usability of wearable health monitors are consistent across different demographic groups, including athletes, patients, and the elderly.

From a broader perspective, Hypothesis 4 (H4): 'Health Monitoring Efficiency,' emerges as particularly crucial when considering the impact and implications of our hypotheses. The primary reasons for this are:

a) Functionality and Innovation: Hypothesis H4 directly addresses the fundamental capabilities and innovations of the wearable device - motion detection, heart rate monitoring, and ECG capabilities. Demonstrating that these functionalities offer more comprehensive health monitoring than traditional methods is vital for justifying the device's adoption and technological advancement.

b) Impact on User Health: The effectiveness of these features plays a critical role in improving the health and well-being of users. Accurate and early detection of health issues by the device could notably enhance patient outcomes, particularly for the elderly and individuals with chronic conditions.

c) Foundation for Other Hypothesis: The reliability of health monitoring is foundational for other hypotheses. If the device fails to monitor health efficiently, related hypotheses concerning beliefs, behavioral changes, emergency response, and long-term health outcomes might lose relevance.

d) Broader Implications: The efficiency of the device holds significance beyond individual use. It could influence healthcare policies, insurance coverage, and broader adoption of wearable technologies in healthcare systems.

III. Implementation of Proposed System

In this section, we delve into the implementation of our proposed system, outlining it through a design methodology. This approach categorizes the system's components into two main areas: hardware components and software components. We will provide detailed information about each component, emphasizing their roles and significance within the system. Additionally, we'll explore the interplay between these components, demonstrating how they integrate to form a cohesive and functional whole. Understanding both the individual elements and their synergistic operation is essential for grasping the full capabilities of our system. By breaking down the components and explaining their interactions, we aim to offer a clear and comprehensive view of how the system operates as an integrated unit, ensuring a thorough understanding of its design and functionality.

A. Hardware Components

The purposed system uses the following hardware components:

1) ARDUINO NANO RP2040 CONNECT
   At the heart of our system lies the Arduino Nano RP2040 Connect, which is an advanced microcontroller board that stands out in the realm of IoT and embedded systems development. At its heart is the Raspberry Pi RP2040, a potent dual-core ARM Cortex-M0+ processor clocked at 133MHz, complemented by 264KB of SRAM and 16MB of off-chip flash memory. It is the first RP2040 board to offer native Wi-Fi connectivity, achieved through the u-blox NINA-W102 radio module. This module not only facilitates Wi-Fi 802.11b/g/n connections but also supports Bluetooth and Bluetooth Low Energy v4.2, making the board a versatile choice for IoT applications [12]. .

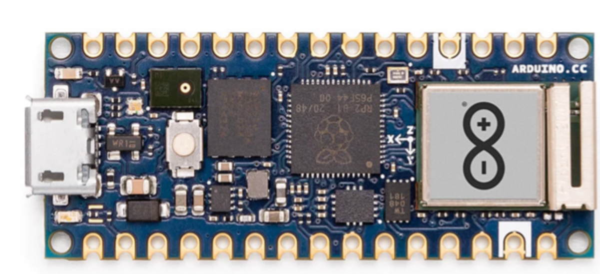

Fig. 3. Arduino Nano RP2040 COnnect

   The board is also having an array of built-in sensors. It includes a 6-axis IMU (LSM6DSOXTR) with a machine learning core, enabling sophisticated motion detection and analysis. This makes it suitable for applications like free fall detection, step counting, and other motion-related functionalities. The inclusion of an omnidirectional digital MEMS microphone (MP34DT06JTR) adds another layer of capability, allowing for sound activation, audio control, and even AI voice recognition tasks [12]. In terms of I/O capabilities, the Nano RP2040 Connect is well-equipped. It has 22 digital I/O pins, 20 of which support PWM, and 8 analog input pins. The board's versatile pin layout supports a variety of peripheral devices and sensors, making it highly adaptable for different project requirements.

2) PULSE SENSOR HW-827
   Central to our heart rate monitoring, the pulse sensor hw-827 is an electronic sensor designed for detecting heart rate or pulse. It is a low-power plug-and-play sensor that is typically used in various health and fitness applications, such as wearable devices, exercise equipment, and medical monitoring systems [13].
   On the front, it has a heart logo where you place your finger, and a tiny circular opening for a Kingbright's reverse mounted green LED. Below this opening is an ambient light photo sensor which is commonly found in phones and computers, which adjusts brightness based on surrounding light.
   The back side of the sensor houses an MCP6001 Op-Amp from Microchip, along with resistors and capacitors forming an R/C filter network, and a reverse

Fig. 4. Pulse Sensor

Fig. 5. Front Side of Pulse Sensor

protection diode to safeguard against incorrect power connection. The module operates on a DC power supply of 3.3 to 5V and consumes less than 4mA of current [13].

Fig. 6. Back Side of Pulse Sensor

It operates by measuring the volume of blood flow through the finger or earlobe, using a process called photoplethysmography (PPG). The PPG signal amplitude A_{PPG} can be roughly estimated using the formula:

$$A_{\text{PPG}} = \frac{I_{\text{LED}} \cdot A_{\text{blood}}}{d}$$

where I_{LED} is the LED intensity, A_{Blood} is the blood absorbance, and d is the distance between the LED and the photo detector. This data is crucial for determining heart rate and blood oxygen levels.

3) HEART MONITOR SENSOR ADB232
The ADB232 heart monitor sensor is an electronic sensor designed to measure the heart's electrical activity, producing an Electrocardiogram (ECG). ECG is primarily utilized in diagnosing a range of heart conditions. The sensor operates by detecting the electrical signals generated by the heart muscle during each beat, providing valuable insights into the heart's rhythm, strength, and timing[14]. This makes it useful for identifying and monitoring heart diseases and abnormalities. Its application is widespread in healthcare settings, ranging from hospitals to clinics, where accurate and real-time heart monitoring is essential. The ECG signal (V_{ECG}) can be represented as:

$$A_{\text{PPG}} = \frac{I_{\text{LED}} \cdot A_{\text{blood}}}{d}$$

Fig. 7. Heart monitor sensor

4) BUZZER
The buzzer, or the piezo, is a digital sound-generating component. It can be connected to any digital output, and it will emit a tone, when the output is HIGH. It is also compatible with analog pulse-width modulation outputs, allowing it to produce a variety of tones and effects. The component functions with both 3.3V and 5V power supplies and generates a sound output of 85 decibels. This feature makes it suitable for providing auditory feedback in applications, similar to the click sound of a button on a digital watch.

Fig. 8. A buzzer

5) BREADBOARD POWER MODULE MB102
The Breadboard Power Module MB102 is a versatile and essential component for electronic prototyping. It is designed to provide both 3.3V and 5V power supplies directly to a breadboard, making it extremely useful for powering a wide range of electronic components and circuits. This module also features a USB connector and a DC power jack, allowing for flexible power sourcing from either a USB port or an external power supply.

Additionally, it includes onboard voltage regulation, ensuring stable and safe power delivery to the components on the breadboard. The MB102 is widely favored in DIY electronics, robotics, and educational projects due to its ease of use and compatibility with standard breadboards, making it an ideal choice for hobbyists and students alike.

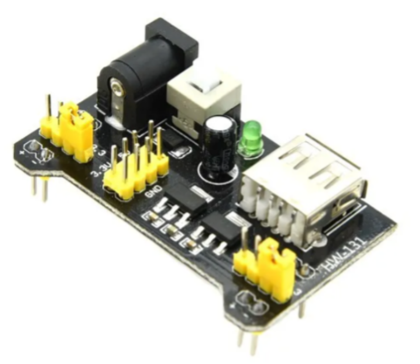

Fig. 9. Power Module MB102

B. Software Components

The purposed system uses the following software components:

1) ARDUINO CLOUD
Arduino Cloud is Arduino's cloud-based platform that offers a range of services that allow users to seamlessly connect their Arduino boards to the Internet. This platform is particularly useful for remote monitoring, control, and data logging of Arduino-based projects. A key component of Arduino Cloud is the Arduino Web Editor, a cloud-based Integrated Development Environment (IDE) that facilitates writing, compiling, and uploading Arduino sketches directly from a web browser. This feature enhances accessibility, allowing users to work on their projects from any device with internet access.

Additionally, Arduino Cloud enables effective remote monitoring and control of Arduino devices via a user-friendly web interface. It provides tools to visualize sensor data, control actuators, and interact with connected devices in real-time, regardless of the user's location. The platform is compatible with a wide range of Arduino boards and modules, making it a versatile choice for both beginners and experienced developers in IoT and other connected applications. Whether for home automation, environmental monitoring, or educational purposes, Arduino Cloud offers a scalable and efficient solution for bringing Arduino projects online and expanding their capabilities.

2) TWILIO SMS APPLICATION PROCESSING INTERFACE (API)
The device leverages Twillo, an online service, to send SMS without requiring a GSM module or a physical SIM card. This enables SMS sending from any microcontroller or any device, in general. Using this service is not free, but it offers a free trial which can be used for testing and purposes.

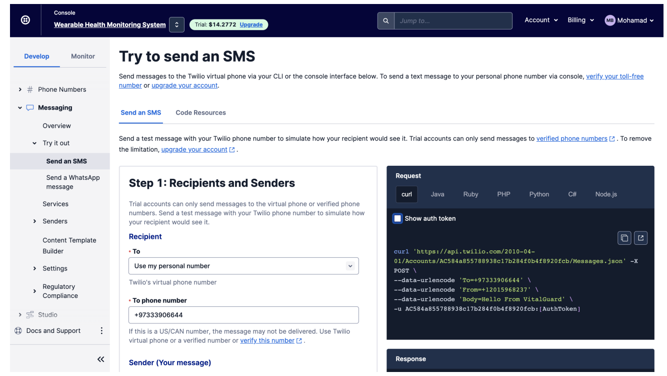

Fig. 10. API Tesring Screen in Twilio

C. Software Architecture

The architecture of the Advanced Wearable Monitoring Device is designed to ensure efficient data acquisition, processing, and communication for the purposes of patient and elderly health monitoring. The system is built around the Arduino Nano RP2040 Connect, that serves as the central processing unit, handling input from various sensors and managing outputs for notifications and alerts. The Figure 1 illustrates the architecture, which enables health observing and checking vital signs at any place through remote monitoring.

1) CENTRAL PROCESSING UNIT
Arduino Nano RP2040 Connect: The microcontroller is the core of the device, equipped with a six-axis smart IMU with AI capabilities, including an accelerometer and gyroscope. These features allow the device to process complex data and make intelligent decisions based on the sensor inputs.
The build-in IMU helps us detect the activity the person is performing with the help of Machine Learning Core Features. feature allows us to use a trained model with the IMU to identify motion activities based on labeled data sets. This is achieved without the need for external processors or additional sensors, enhancing the efficiency and responsiveness of our wearable device.
The activity detecting model is based on decision-tree logic model, which is a mathematical structure consisting of a series of decision nodes. Each node operates on a simple "if-else-then" principle, forming a hierarchical framework for data analysis. Our IMU is capable of running up to 8 decision trees in parallel, allowing for nuanced and comprehensive motion analysis. For feature extraction, the decision tree method analyzes the training data set to identify the most relevant features. The MLC of the IMU can be configured with up to 31 distinct

features, ensuring a detailed and accurate model for activity classification.

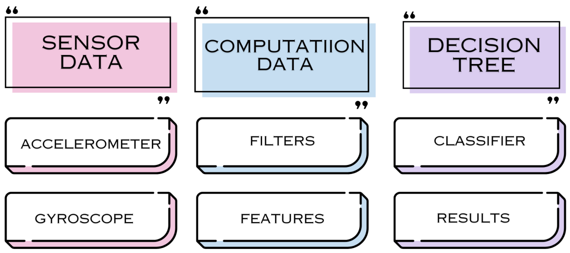

Fig. 11. The MLC blocks

The activity detecting model has 6 output classes: Stationary, Walking, Jogging, Biking, Driving Unknown. In addition, we have leveraged this model to implement a step counter, which is activated specifically when the wearer is Walking or Jogging. This step counting feature is seamlessly integrated into the device, providing users with real-time feedback on their physical activity levels. All of these data is shown on Arduino cloud dashboard For remote monitoring.
Similarly, we have incorporated fall detection in the device, which sends an alert on the dashboard and sends an SMS to doctors, caretakers, and/or relatives. It makes use of the accelerometer that detects sudden moments and compare it to the threshold that denotes the actual.

2) INPUT SENSORS

- Pulse Sensor:
  This sensor employs optical technology to detect the pulse waveform and calculate the beats per minute (BPM). Its signal is processed by the microcontroller to monitor heart rate variability and detect any sudden changes that could indicate a health risk.
- Heart Monitor Sensor:
  Utilizing electrodes, this sensor captures the ECG waveform, providing insights into the heart's electrical activity. The Arduino processes this data to identify patterns characteristic of arrhythmias or other cardiac conditions.

3) CLOUD CONNECTIVITY AND DATA MANAGEMENT

- Arduino Cloud:
  The microcontroller connects to the Arduino Cloud platform, which serves multiple functions: Secure data storage for historical health data analysis. Data processing backend to run more complex algorithms that are not feasible to run on the microcontroller. User interface for caregivers and healthcare professionals to monitor patient data in real-time or review historical data for long-term health tracking.

4) ALERT SYSTEM

- Notification for Doctor, Caretaker, and Relative:
  The system is configured with communication protocols to initiate alerts and notifications via the Arduino Cloud. It can be programmed to send different types of notifications based on the severity of the data received, such as:
  o Immediate SMS or push notifications for urgent medical conditions detected by the sensors.
  o Email summaries for regular health updates or less critical alerts.
  o Automated phone calls for emergencies, employing text-to-speech technology for direct communication with the concerned parties.
- Buzzer:
  This simple yet vital component serves as the first line of alert directly on the wearable device. The buzzer can be activated in various scenarios, such as, fall is detected by the IMU, or an abnormal heart rate or pattern is detected by the pulse or heart monitor sensors.

Overall, this architecture provides a comprehensive view of the system, ensuring that all components work synergistically to monitor, analyze, and communicate the health status of the wearer, thereby facilitating immediate and appropriate responses to potential health issues. This section can be summarized by the overview of the whole architecture as shown in Figure 13.

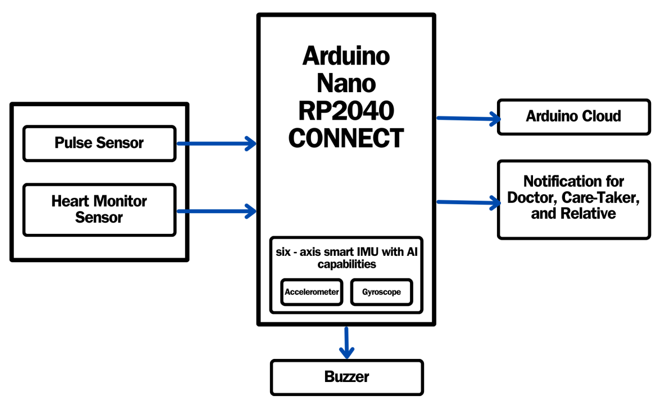

Fig. 12. System Architecture

Following with the price breakdown of the mentioned hardware and software in Table II

IV. Hypothesis Research Methodology

The study described is a cross-sectional survey conducted in December 2023 using Google Forms for its simplicity and browser compatibility. Invitations to participate were distributed via URL links sent to friends, communities, and

TABLE II
PRICE BREAKDOWN OF HARDWARE AND SOFTWARE.

Type	Name	Price	Purchased From
Hardware			
	ARDUINO NANO RP2040 CONNECT	19.960 BHD with shipping	Arduino Store
	PULSE SENSOR HW-827	5.200 BHD with Shipping	Amazon UAE
	HEART MONITOR SENSOR ADB232	3.000 BHD without Shipping	AliExpress
	ARDUINO STARTER KIY	12.000 BHD with Shipping	AliExpress
	BREADBOARD	1.000 BHD with Shipping	AliExpress
	BREADBOARD POWER MODULE MB102	1.000 BHD with Shipping	AliExpress
	2 * OLED Module	4.000 BHD with Shipping	AliExpress
Software			
	Arduino Cloud – 12 Months Maker Plan	27.140 BHD	Arduino Cloud
	TWILLO SMS	FREE – Trial Account	Twillo
TOTAL			73.300 BHD

family members. The primary methods of response collection involved using and posting a web-link on social media platforms.

A. *Contents of The Survey*

This survey is structured to assess various aspects of wearable health monitors among patients and the elderly, comprising eleven distinct parts. It starts by collecting demographic information such as age, gender, occupation, health status, and usage of wearable health devices. The survey then progresses through ten hypotheses: 1) Belief in the positive impact of these monitors on health understanding, 2) Self-efficacy in using technology, gauging confidence in device utilization, 3) Desire for self-development in health improvement methods, 4) Perception of autonomy influenced by real-time health data, 5) Acceptance of technology, focusing on ease-of-use and perceived benefits, 6) Efficiency of health monitoring, assessing trust in advanced monitoring features, 7) Emergency response capabilities, probing beliefs in quicker assistance and the importance of emergency alerts, 8) Long-term health outcomes from continuous monitoring and long-term device usage, 9) Cross-demographic usability, exploring the universal benefits and likelihood of recommending these devices, and 10) Behavioral changes, assessing the impact of regular feedback and the propensity to follow health advice from wearable devices. The survey employs a mix of five-point Likert scaled responses and binary questions, allowing for detailed data collection crucial for validating each hypothesis.

V. SURVEY FINDING

In this section, we present all the results and analyze the factor loads that confirm the hypotheses put forward. The data analysis consists of two phases. In the first stage, we examined the demographic profile of respondents. The second step inspected the survey analysis in which we utilize different type of hypothesis testing tests.

The table 1 outlines the demographics of the study's participants, indicating a higher proportion of male respondents, as compared to female respondents. The majority are identified as students or employed individuals, and about half of the respondents fall into the 25 to 39 age range, with most reporting good health.

TABLE III
CHARACTERISTICS OF THE STUDY SAMPLE.

Gender	**Number**	**Percentage (%)**
Male	62	59%
Female	43	41%
Total	105	100%
Professional category	**Number**	**Percentage (%)**
Farmers, craftsmen, traders, entrepreneurs	4	3.8%
Executives and Intermediaries professions	18	17.1%
Employees, students, and workers	73	69.6%
Inactive	10	9.5%
Total	105	100%
Age	**Number**	**Percentage (%)**
Less than 25 years	41	39%
25–39 years	43	41%
40–54 years	14	13.3%
55 years and more	7	6.7%
Total	105	100%
Health status	**Number**	**Percentage (%)**
Good	75	71.4%
Fair	29	27.6%
Poor	1	1%
Total	105	100%

For analyzing the survey data, we used two different types of statistical tests on the sample size (N_S) = 105,

- One-Sample T-Test:
  A one-sample t-test is appropriate when we want to compare the mean score of a single sample to a known value (in this case, the neutral score of 3) to see if the sample mean is significantly different from the hypothesized value.

  The One-Sample T-Test is calculated as:

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}} \tag{1}$$

  Where:

- t is the calculated t-value,
- $\bar{x}$ is the sample mean,
- μ_0 is the hypothesized population mean (3 in this case),
- s is the sample standard deviation,
- n is the sample size.

- Chi-Square Goodness-of-Fit Test:
  This test is used to determine whether there is a significant difference between the expected frequencies and the observed frequencies in one or more categories. In our case, it was to see if the observed proportion of 'Yes' to 'No' responses was significantly different from what would be expected by chance (e.g., an even 50/50 split if there was no actual effect).

  The chi-square statistic is calculated as:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (2)$$

  Where:
  - χ^2 is the chi-square statistic,
  - O_i is the observed frequency for each category (Yes and No in this case),
  - E_i is the expected frequency for each category (which would be 52.5 for both Yes and No if no preference is assumed in a sample of 105 responses).

Now, We move onto testing our Hypothesis as follows,

- **HYPOTHESIS TEST ON BELIEFS**
  This hypothesis aimed at evaluating the beliefs of individuals regarding the efficacy of wearable health monitors.
  - **Question 1: Scale from 1-5**
    * **Null Hypothesis -** H_0: There is no strong belief that wearable health monitors can positively impact health.
    * **Alternate Hypothesis –** H_1: There is a strong belief that wearable health monitors can positively impact health.
  - **Statistical Analysis Results:**
    * Mean (Average) Rating: 3.61
    * Standard Deviation: 1.06
    * Sample Size: 105 responses
    * T-Statistic: 5.89
    * P-Value: < 0.0001 (4.82×10^{-8})
  - **Conclusion:** With a p-value significantly less than the conventional alpha level of 0.05, we reject the null hypothesis. The results indicate a strong belief among the survey participants that wearable health monitors can have a positive effect on their health, with a mean score notably greater than 3.
  - **Question 2: Yes/No Response**
    * **Null Hypothesis -** H_0: There is no significant belief that wearable health monitors can enhance understanding of health needs.
    * **Alternate Hypothesis –** H_1: There is a significant belief that wearable health monitors can enhance understanding of health needs.
  - **Statistical Analysis Results:**
    * Observed 'Yes' Responses: 91
    * Observed 'No' Responses: 14
    * Chi-Square Statistic: 56.57
    * P-Value: < 0.0001 (5.43×10^{-14})
  - **Conclusion:** The extremely low p-value rejects the null hypothesis, indicating a significant deviation from the expected neutral (50/50) response distribution. This suggests that the vast majority of participants agree that wearable health monitors can enhance the understanding of their health needs.

- **HYPOTHESIS ON DESIRE FOR SELF-DEVELOPMENT**
  This hypothesis focuses on the individual's motivation to use wearable health monitors for personal health development.
  - **Question 3: Scale from 1-5**
    * **Hypothesis -** H_0: There is no significant difference between the respondents' rated importance of actively seeking ways to improve their health and a neutral level of importance (mean = 3).
    * **Hypothesis –** H_1: Respondents rate the importance of actively seeking ways to improve their health significantly higher or lower than the neutral level of importance (mean $\neq$ 3).
  - **Results:**
    * Mean (Average) Importance Level: 4.01
    * Standard Deviation: 0.995
    * Sample Size: 105 responses
    * T-Statistic: 10.40
    * P-Value: 8.81×10^{-18})
  - **Conclusion:** The p-value is significantly lower than the alpha level of 0.05, leading to the rejection of H_0. The high mean importance level suggests that respondents place significant importance on actively seeking new ways to improve their health, supporting H_1.
  - **Question 4: Yes/No Response**
    * **Hypothesis -** H_0: The proportion of respondents who would use a health monitor as part of their personal health development strategy does not differ from what would be expected by chance (50/50 distribution).
    * **Hypothesis –** H_1: The proportion of respondents who would use a health monitor as part of their personal health development strategy differs significantly from a 50/50 distribution.
  - **Statistical Analysis Results:**
    * Observed 'Yes' Responses: 76 (rounded from 72.4% of 105)

- * Observed 'No' Responses: 29 (rounded from 27.6% of 105)
  * Chi-Square Statistic: 21.07
  * P-Value: 4.42×10^{-6})
- **Conclusion:** With the p-value being much lower than 0.05, H_0 is rejected. This suggests that a significant majority of participants would incorporate the use of a health monitor into their strategy for personal health development, aligning with H_1.

- **HYPOTHESIS ON SELF-EFFICACY**
  This hypothesis focuses on the participants' self-efficacy regarding the use of wearable health monitors.
  - **Question 5: Scale from 1-5**
    * **Hypothesis -** H_0: Respondents do not have a significant level of confidence in their ability to use technological devices such as a wearable health monitor (neutral mean = 3).
    * **Hypothesis –** H_1: Respondents have a significant level of confidence in their ability to use technological devices such as a wearable health monitor (mean $\neq$ 3).
  - **Statistical Analysis Results:**
    * Mean (Average) Confidence Level: 4.01
    * Standard Deviation: 1.00
    * Sample Size: 105 responses
    * T-Statistic: 10.30
    * P-Value: 1.47×10^{-17}
  - **Conclusion:** The p-value is significantly lower than the conventional alpha level of 0.05, which means we reject H_0. The high mean confidence level indicates that respondents have a significant level of confidence in their ability to use technological devices, supporting H_1.
  - **Question 6: Yes/No Response**
    * **Hypothesis -** H_0: Respondents do not feel comfortable learning to use a new health monitoring device on their own (50/50 distribution expected by chance).
    * **Hypothesis –** H_1: Respondents feel comfortable learning to use a new health monitoring device on their own (distribution different from 50/50).
  - **Statistical Analysis Results:**
    * Observed 'Yes' Responses: 92 (rounded from 87.6% of 105)
    * Observed 'No' Responses: 13 (rounded from 12.4% of 105)
    * Chi-Square Statistic: 59.38
    * P-Value: 1.30×10^{-14}
  - **Conclusion:** The p-value is extremely low, leading to the rejection of H_0. This suggests that the vast majority of participants are comfortable learning to use a new health monitoring device on their own, aligning with H_1.

- **HYPOTHESIS ON HEALTH MONITORING EFFICACY**
  This hypothesis focuses on the belief that advanced wearable health monitoring devices, equipped with features like motion detection, heart rate, and ECG monitoring, provide more comprehensive health insights than traditional health monitoring methods.

  - **Question 7: Scale from 1-5**
    * **Hypothesis -** H_0: Respondents are neutral in their likelihood to trust the data provided by advanced health monitors (mean = 3).
    * **Hypothesis –** H_1: Respondents' trust in the data provided by advanced health monitors is significantly different from a neutral standpoint (mean $\neq$ 3).
  - **Statistical Analysis Results:**
    * Mean (Average) Trust Level: 3.47
    * Standard Deviation: 1.15
    * Sample Size: 105 responses
    * T-Statistic: 4.15
    * P-Value: 6.84×10^{-5}
  - **Conclusion:** With a p-value well below the threshold of 0.05, H_0 is rejected. Respondents generally have a higher level of trust in the data provided by advanced health monitors than the neutral level, supporting H_1.
  - **Question 8: Yes/No Response**
    * **Hypothesis -** H_0: A device with motion detection, heart rate, and ECG monitoring does not offer better health insights than traditional methods.
    * **Hypothesis –** H_1: A device with motion detection, heart rate, and ECG monitoring offers better health insights than traditional methods.
  - **Statistical Analysis Results:**
    * Chi-Square Statistic: 37.8
    * P-Value: 7.84×10^{-10}
  - **Conclusion:** The p-value is significantly less than 0.05, so we reject H_0. The data suggests that a large majority of respondents believe that a device with motion detection, heart rate, and ECG monitoring would offer better health insights than traditional methods, supporting H_1.

- **HYPOTHESIS ON HEALTH MONITORING EFFICACY**
  This hypothesis focuses on the belief that advanced wearable health monitoring devices, equipped with features like motion detection, heart rate, and ECG monitoring, provide more comprehensive health insights than traditional health monitoring methods.
  - **Question 7: Scale from 1-5**
    * **Hypothesis -** H_0: Respondents are neutral in their likelihood to trust the data provided by advanced health monitors (mean = 3).

    - **Hypothesis –** H_1: Respondents' trust in the data provided by advanced health monitors is significantly different from a neutral standpoint (mean $\neq$ 3).
  - **Statistical Analysis Results:**
    - Mean (Average) Trust Level: 3.47
    - Standard Deviation: 1.15
    - Sample Size: 105 responses
    - T-Statistic: 4.15
    - P-Value: 6.84×10^{-5}
  - **Conclusion:** With a p-value well below the threshold of 0.05, H_0 is rejected. Respondents generally have a higher level of trust in the data provided by advanced health monitors than the neutral level, supporting H_1.
  - **Question 8: Yes/No Response**
    - **Hypothesis -** H_0: A device with motion detection, heart rate, and ECG monitoring does not offer better health insights than traditional methods.
    - **Hypothesis –** H_1: A device with motion detection, heart rate, and ECG monitoring offers better health insights than traditional methods.
  - **Statistical Analysis Results:**
    - Chi-Square Statistic: 37.8
    - P-Value: 7.84×10^{-10}
  - **Conclusion:** The p-value is significantly less than 0.05, so H_0 is rejected. The data suggests that a large majority of respondents believe that a device with motion detection, heart rate, and ECG monitoring would offer better health insights than traditional methods, supporting H_1.

- **HYPOTHESIS ON EMERGENCY RESPONSE**
  This hypothesis suggests that wearable health monitors with emergency alert features are perceived to significantly enhance the speed and efficiency of care provided by caregivers during emergencies, indicating a strong belief in the technology's capacity to improve patient safety and emergency response.
  - **Question 9: Scale from 1-5**
    - **Hypothesis -** H_0: The importance of emergency alerts in health monitoring devices is at a neutral level (mean = 3).
    - **Hypothesis –** H_1: The importance of emergency alerts in health monitoring devices is significantly different from a neutral level (mean $\neq$ 3).
  - **Statistical Analysis Results:**
    - Mean (Average) Importance Level: 3.91
    - Standard Deviation: 0.97
    - Sample Size: 105 responses
    - T-Statistic: 9.64
    - P-Value: 4.29×10^{-16}
  - **Conclusion:** The p-value is significantly lower than the threshold of 0.05, which leads us to reject H_0. This indicates that the importance of emergency alerts is rated significantly higher than the neutral level by respondents, supporting H_1.
  - **Question 10: Yes/No Response**
    - **Hypothesis -** H_0: A wearable health monitor does not contribute to quicker assistance in an emergency.
    - **Hypothesis –** H_1: A wearable health monitor does contribute to quicker assistance in an emergency.
  - **Statistical Analysis Results:**
    - Chi-Square Statistic: 45.46
    - P-Value: 1.56×10^{-11}
  - **Conclusion:** Given the extremely low p-value, we reject H_0. The data suggests that a significant majority of respondents believe that wearable health monitors could help in getting quicker assistance in an emergency, supporting H_1.

- **HYPOTHESIS ON CROSS-DEMOGRAPHIC USABILITY**
  This hypothesis suggests that wearable health monitors with emergency alert features are perceived to significantly enhance the speed and efficiency of care provided by caregivers during emergencies, indicating a strong belief in the technology's capacity to improve patient safety and emergency response.
  - **Question 9: Scale from 1-5**
    - **Hypothesis -** H_0: The likelihood to recommend a health monitoring device for remote monitoring is at a neutral level (mean = 3).
    - **Hypothesis –** H_1: The likelihood to recommend a health monitoring device for remote monitoring is significantly different from a neutral level (mean $\neq$ 3).
  - **Statistical Analysis Results:**
    - Mean (Average) Likelihood Rating: 3.71
    - Standard Deviation: 0.98
    - Sample Size: 105 responses
    - T-Statistic: 7.49
    - P-Value: 2.40×10^{-11}
  - **Conclusion:** With a p-value well below 0.05, H_0 is rejected. This indicates that respondents are likely to recommend health monitoring devices for remote monitoring, suggesting a positive perception of their effectiveness, supporting H_1.
  - **Question 10: Yes/No Response**
    - **Hypothesis -** H_0: People of all ages and health statuses do not benefit from using a wearable health monitor.
    - **Hypothesis –** H_1: People of all ages and health statuses benefit from using a wearable health monitor.
  - **Statistical Analysis Results:**
    - Chi-Square Statistic: 33.16
    - P-Value: 8.47×10^{-9}

- **Conclusion:** The p-value is significantly less than 0.05, leading us to reject H_0. This indicates that a large majority of respondents believe people of all ages and health statuses can benefit from using a wearable health monitor, supporting H_1.

RESULTS

This section discusses the findings from the comprehensive analysis conducted to test the formulated hypotheses and evaluate the implementation of the proposed system. The hypotheses, developed based on the literature review were rigorously examined using survey data. This evaluation not only sheds light on the validity of the hypotheses but also provides critical insights into the practical implications and effectiveness of the newly implemented system. The following subsections detail the outcomes of each hypothesis and the observed impacts of the system's implementation.

If we focus on the findings, the collected data from the survey provides robust support for Hypothesis 1, showcasing a statistically significant belief among participants that wearable health monitors are instrumental in improving health and deepening understanding of individual health needs. This prevailing positive perception is not just a testament to the potential of these devices in enhancing health management; it also significantly contributes to their increased utilization. This positive correlation between belief in the efficacy of wearable health monitors and their usage frequency underscores the critical role of user perceptions in the development and implementation of health technologies, particularly those focused on patient monitoring and elderly care.

Turning to the concept of self-development, our statistical analysis aligns with Hypothesis 3, revealing a clear trend: individuals with a heightened desire for self-improvement are more inclined to integrate wearable health monitoring technologies into their personal health regimes. This finding is pivotal as it underscores the relationship between personal motivation for health enhancement and the effective adoption of health monitoring devices.

In the realm of self-efficacy, the survey results offer compelling support for Hypothesis 2. A notable majority of respondents expressed confidence in their technological proficiency and comfort with adopting new health monitoring devices. This high level of self-efficacy among individuals suggests a greater propensity to embrace wearable health monitoring technologies, highlighting the potential of self-efficacy as a critical factor in the effective adoption and usage of health technology.

Regarding the efficiency of health monitoring, the data from both survey questions points to a strong preference for advanced health monitoring devices, particularly those offering features like motion detection, heart rate, and ECG monitoring. These devices are perceived as providing superior health insights and garnering higher trust compared to traditional methods. This aligns with the hypothesis that higher self-efficacy in individuals is linked to a greater willingness to adopt advanced health monitoring devices, emphasizing the importance of both efficiency and trust in technology for their wider acceptance.

The analysis of technology acceptance, especially among elderly individuals, reveals a significant correlation with their perceptions of the ease of use and benefits of wearable health monitoring devices. This finding is crucial as it suggests that usability and perceived health advantages are key determinants in the acceptance and adoption of wearable health technology by older adults.

In the context of emergency response, the survey analysis indicates a strong belief in the efficacy of caregivers utilizing data from wearable monitors to provide more efficient and timely care, particularly in emergency scenarios. The high value placed on the capability of wearable health monitors for quick assistance and emergency alerts underscores their potential role in enhancing the effectiveness of emergency responses.

Lastly, cross-demographic usability analysis suggests that wearable health monitors are favorably perceived across various demographic groups, reflecting their broad appeal and potential for recommendation. This supports the hypothesis that the effectiveness and usability of these monitors are consistent across different ages and health statuses, reinforcing their versatility and widespread applicability.

To conclude the focus area of findings, we can say that the survey data provided compelling evidence for the growing acceptance and potential of wearable health monitors across various facets of healthcare, emphasizing their role in enhancing patient autonomy, proactive health management, and emergency care.

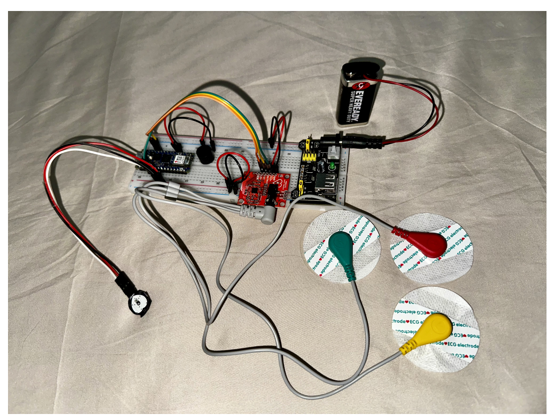

Fig. 13. Implemented of the "VitalGuard" Device

In the context of the proposed device, we implemented all the mentioned features as per the gained information from the literature review and the survey. It has shown effective results in health monitoring. Its ability to measure heart rate and ECG, along with an easy-to-use Arduino cloud dashboard, has made it more user-friendly. The device can be adjusted to suit different health monitoring needs, making it versatile. In urgent medical situations, it has proven to be efficient, helping caregivers respond quickly and effectively. The device appeals to a wide range of users and encourages them to actively manage their health.,

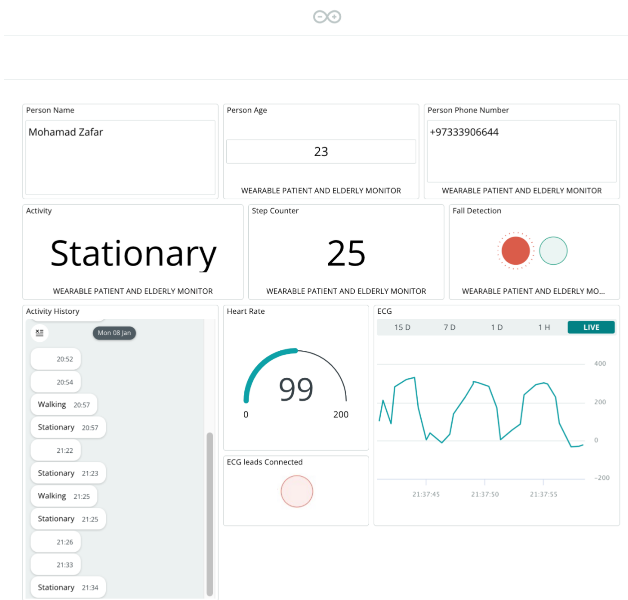

Fig. 14. Arduino Cloud Dashboard of "VitalGuard" Device

The cloud dashboard that was created on Arduino cloud as seen in Fig 14, which symbolizes a comprehensive tool for monitoring health and activity. The dashboard, clearly displaying the person's name, age, and a contact phone number, is divided into several widgets. Each widget offers vital information: one shows whether the person is stationary, indicating rest or inactivity; another logs activity history, recording times and types of movement; there's also a step counter, a fall detection system, and a heart rate monitor. The ECG section is presents a live heart rhythm chart along with an indicator confirms whether the ECG leads are connected or not. This layout allows caregivers or medical personnel to efficiently monitor and respond to the patient's physical status and cardiac health in real time..

Moreover, If any abnormality in BMP or ECG is detected or a fall is detected, the buzzer on the device goes off along with an SMS alerts on the given number. in case the number is not given, the notification goes to issuing party.

Challenges, Countermeasures, and Future Work

The development of a wearable elderly and patient monitoring device marked a huge step forward. This device, equipped with an ECG, pulse sensor, steps and activity monitoring, fall detection, and an alert system, provided as with foundation for more advanced devices and research. However, its journey was not without challenges.

One of the primary obstacles was the reduction of noise in the ECG and pulse sensor readings. Achieving accuracy in these measurements was crucial, as they were the cornerstone of reliable health monitoring. To address this, we need to implement more advanced filtering techniques to the data to

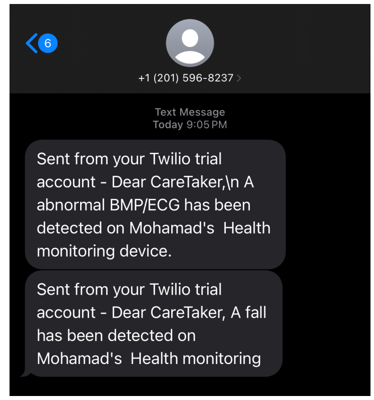

Fig. 15. SMS Alerts Send via Twilio SMS API

isolate and remove external noise factors. This may include the use of adaptive filters that adjust according to the signal characteristics, ensuring cleaner data.

Additionally, sourcing components from the Kingdom of Bahrain proved to be a very costly. While the intention was to support local businesses, the financial implications were considerable.. To mitigate this, we evaluated international suppliers to identify more cost-effective and reliable alternatives. As a result, the components were ordered from China. A major setback occurred when parts ordered from China arrived late and damaged. This not only delayed the project but also raised questions about proper implementation of the project, quality assurance and the reliability of international supply chains.

Looking ahead, the future of this device is bright with ambitious enhancements. We plan to integrate a body temperature sensor, along with external temperature and gas sensors. These additions aim to provide a more comprehensive health overview for the elderly and patients. Furthermore, a pivotal upgrade is envisioned where components like the ECG will be wirelessly connected to the Arduino NANO RP2040 CONNECT board, thereby enhancing the device's efficiency and user experience.

Conclusion

Our research into advanced wearable technologies for patient and elderly monitoring has significantly advanced our understanding of their role in healthcare. This challenging journey has yielded valuable insights into how technology can enhance health management and the quality of life.

A key finding is the potential of wearable technologies to support and complement current healthcare practices. The proposed system, a product of our research, marks a notable advancement by integrating sophisticated features like ECG and pulse rate monitoring, thus offering precise and accessible health data to users and providers. It's crucial to recognize, however, that this system is part of an evolving healthcare technology landscape. Integral to our system is the Arduino cloud dashboard, a central platform displaying vital health indicators. This dashboard, focused on improving data accessibility and user interaction, exemplifies where technology and user experience converge for real-time health data monitoring and analysis.

Our research indicates that the proposed system, while offering significant improvements in monitoring and user engagement, is one of many tools transforming patient care. Its effectiveness depends on how well it integrates with broader healthcare practices and adapts to user needs and advancements in technology. User feedback has been vital in refining our system, underscoring the need to align technology with practical usability and real-world applications.

We have also found a strong correlation between the perceived efficacy of these monitors and their usage frequency, with user perceptions playing a crucial role in technology adoption. Personal motivation and confidence in technology usage significantly influence acceptance, especially among the elderly who benefit from features like motion detection and heart rate monitoring. In emergency scenarios, these wearables prove invaluable to caregivers by enhancing the speed and efficiency of care. Additionally, our cross-demographic analysis suggests a wide appeal across various age and health groups, indicating a broad scope for application and recommendation.

Looking forward, our research and the proposed system represent steps towards more integrated, user-centric healthcare technologies. Continuous innovation and a deep understanding of patient needs are vital for ensuring these technologies genuinely improve patient care and quality of life. This research contributes to the broader discussion on the future of healthcare technology, emphasizing its potential and the need for thoughtful, patient-focused development.

Addressing the challenge of sourcing components, we adopted a strategic approach that balanced local procurement with global supply chain negotiations, highlighting the intricate nature of technological advancement that blends logistical expertise with scientific inquiry.

In summary, our research not only underscores the potential of advanced wearable technologies in healthcare but also envisions a future where such technologies are part of a holistic patient care approach, evolving continuously to meet diverse health needs.

Acknowledgment

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