Enhancing Cardiovascular Disease Management through Ubiquitous Computing and IoT in Malaysia

Cheong Jun Xian
Asia Pacific University of Technology and Innovation
Technology Park Malaysia, Bukit Jalil
Kuala Lumpur, Malaysia
tp060752@apu.edu.my

Kamalanathan Shanmugam
Asia Pacific University of Technology and Innovation
Technology Park Malaysia, Bukit Jalil
Kuala Lumpur, Malaysia
kamalanathan@apu.edu.my

Muhammad Ehsan Rana
Asia Pacific University of Technology and Innovation
Technology Park Malaysia, Bukit Jalil
Kuala Lumpur, Malaysia
muhd_ehsanrana@apu.edu.my

Sumathi Balakrishnan
Taylor University, School of Computer Science, Digital Health and Medical Advancement Impact Lab,
Subang Jaya, Malaysia
sumathi.balakrishnan@taylors.edu.my

Naresh Kumar Appadurai
Asia Pacific University of Technology and Innovation
Technology Park Malaysia, Bukit Jalil
Kuala Lumpur, Malaysia
naresh@apu.edu.my

Vazeerudeen Abdul Hameed
Asia Pacific University of Technology and Innovation
Technology Park Malaysia, Bukit Jalil
Kuala Lumpur, Malaysia
vazeer@apu.edu.my

***Abstract* – The prevalence of cardiovascular diseases, particularly Acute Myocardial Infarction (AMI), has become a significant public health challenge in Malaysia, with Ischemic Heart Disease (IHD) being the leading cause of death. This research explores the integration of ubiquitous computing and medical IoT devices in healthcare to enhance the monitoring, early detection, and management of cardiovascular diseases. By leveraging technologies such as AI, 5G, blockchain, and AR/VR, the study examines how continuous, real-time monitoring can be achieved, potentially transforming traditional healthcare systems that are limited to clinical settings. The research also discusses the limitations of these technologies, including privacy concerns, battery life, and accuracy, while proposing recommendations to overcome these challenges. The study aims to contribute to the development of a more efficient, patient-centred healthcare system that not only improves patient outcomes but also supports Malaysia's economic growth by fostering innovation in the healthcare sector.**

Keywords* – *Ubiquitous Computing, Acute Myocardial Infarction, Cardiovascular Diseases, Healthcare, Internet of Things (IoT)

I. INTRODUCTION

Cardiovascular diseases, including stroke, heart failure, etc., remain the top killer around the globe. In 2021, 20.5 million deaths are related to cardiovascular disease, which contributes to more than 30% of all kinds of deaths globally [1]. According to statistics on Causes of Death in Malaysia published in 2023 by the Department of Statistics Malaysia on Oct. 30 2023, indicates that Ischemic Heart Disease (IHD), which is one of the cardiovascular diseases, remains the top killer of Malaysian in 2023, with the percentage of 16.1% among all types of death. Cerebrovascular disease ranked third with a rate of 7.2%, followed by deaths due to COVID-19 infection and transport accidents [2]. Malaysia is one of the countries that Ischemic Heart Disease is the leading cause of premature death in 146 countries for men and 98 countries for women, according to statistics in 2015 for 176 countries [3].

The likelihood, expressed as a percentage, of dying in 2015 from NCD4 causes between the ages of 30 and 70 for each nation. Each country's text color designates a region (see appendix, p. 43, for a list of countries in each area). The quality of each nation's vital registration system is indicated by the number in parenthesis after its name: 1 denotes a high quality system, 2 medium, 3 low, and 4 very low.2,3 See appendix pp 29–30 for results on all non-communicable diseases including suicide between birth and 80 years of age—NCD4=four non-communicable diseases, including malignancies, cardiovascular diseases, chronic respiratory diseases, and diabetes.

Traditional healthcare systems, often confined to clinical settings, are increasingly proving inadequate in addressing these needs due to their limited capacity for continuous monitoring and timely intervention. This context sets the stage

for exploring the potential of ubiquitous computing, coupled with medical Internet of Things (IoT) devices, to revolutionise cardiovascular care. Ubiquitous computing refers to the seamless integration of computing capabilities into everyday environments, enabling continuous access to digital services anytime and anywhere.

This research seeks to address how can ubiquitous computing, assisted by medical IoT devices, be effectively implemented in the Malaysian healthcare system to monitor and reduce the risk of Acute Myocardial Infarction (AMI) and other cardiovascular diseases. The study aims to bridge the gap between the theoretical potential of these technologies and their practical application, focusing on the unique challenges and opportunities within the Malaysian context.

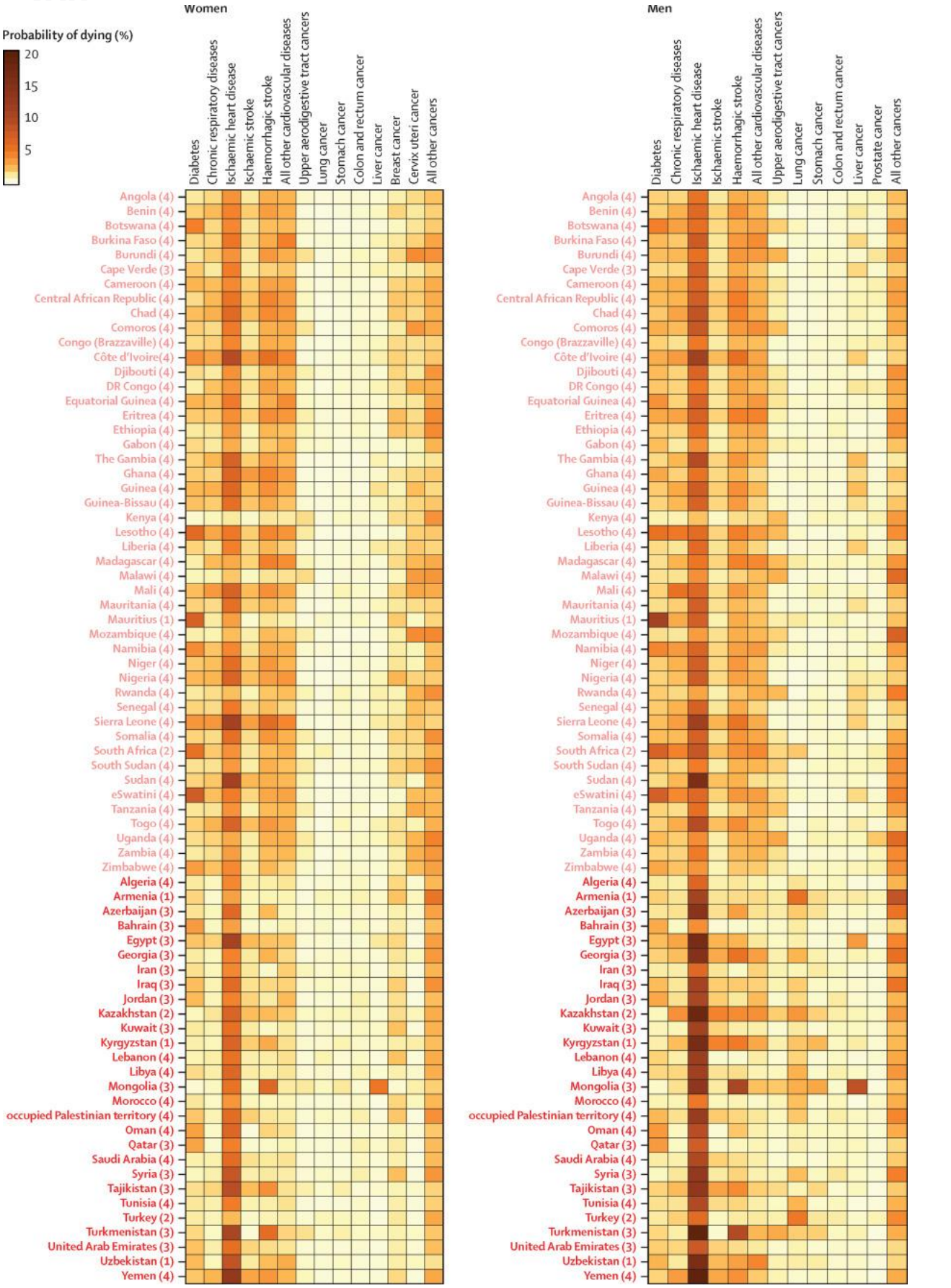


Fig 1: "NCD Countdown 2030: pathways to achieving Sustainable Development Goal target 3.4,

The Sustainable Development Goal 3 (SDG 3) of ensuring healthy lifestyles and promoting well-being for all at all ages is directly linked with the integration of ubiquitous computing into healthcare. One of the specific aims of SDG 3 is to lower the worldwide burden of non-communicable diseases, like cardiovascular disorders, by promoting early detection, risk reduction, and treatment. This research is situated within the broader framework of Industry Revolution 4.0, as Malaysia seeks to embrace Industry Revolution 4.0, which is characterised by the convergence of digital technologies, automation, and data analytics to transform industries, including healthcare. Industry Revolution 4.0 introduces advanced technologies such as Artificial Intelligence (AI), 5G, blockchain, and the Internet of Things (IoT), all of which play crucial roles in enabling ubiquitous healthcare.

II. Problem Statement

Acute Myocardial Infarction (MI), known as heart attack, is a more severe event that progresses from ischemic heart disease, occurs when there is a sudden blockage in one or more coronary arteries, can lead to a significant reduction or complete cessation of blood flow to the myocardium, which known as heart muscle. The blockage causes serious ischemia, which describes the deprivation of blood in the heart muscle, ultimately causing the affected muscle tissue to become damaged or die due to lack of continuous supply of oxygen through blood flow. Symptoms include chest pain, shortness of breath, fatigue, nausea, sweating, and dizziness are the common signs of possible happening of Acute Myocardial Infarction [4]. Several measures can diagnose Acute Myocardial Infarction, which includes an Electrocardiogram (ECG) that records the electrical activity of the heart and can reveal abnormal patterns which indicate the potential for heart attacks, such as ST-segment elevation or depression. Cardiac Stress Test, which involves monitoring heart functions while the person is exercising can detect the sign of heart attack. An echocardiogram is an ultrasonic imaging method of the heart to assess heart structure and function. Blood Test is the most basic diagnosis of cardiovascular disease, measuring levels of specific markers such as cholesterol, lipids, and glucose. Treatment such as medication and surgeries can be provided if the symptoms are noticed and early diagnosed before they become severe. If the treatment is delayed, Acute Myocardial Infarction can lead to severe complications, including total heart failure, where the blood cannot be pumped, and ultimately a sudden cardiac arrest, where the heart stops beating.

In Traditional healthcare systems, patients have to visit hospitals, clinics, or healthcare facilities to receive tests, check-ups and treatment that require scheduled appointments. We are facing a challenge in that a lot of patients miss the early signs of normal cardiovascular events, which leads to the unnoticed potential of Acute Myocardial Infarction. Monitoring of patients' health is usually done in controlled clinical environments. Continuous monitoring of patient's health metrics outside of these settings is limited, and acute myocardial infarction may occur at any time. When it happens, rapid response has been given to the patient to minimise the damage to the heart and body. The traditional healthcare system is reactive, which responds to health issues only after they happen and are noticed by someone; these often delay the response to be given instead of proactively detecting the happening of emergencies before it escalate.

Innovative solutions are trying to go beyond hospital walls. Ubiquitous computing, also known as pervasive computing, offers a new approach by seamlessly integrating technology into everyday life, allowing real-time health data collection and monitoring anywhere, anytime. This decentralises the healthcare system and distributes the healthcare resources closer to the public. For instance, smartwatches equipped with ECG monitors can monitor the heart rhythm from time to time and detect anomalies instead of traditionally sticking multiple electrodes to the skin and connecting them to the electrocardiograph. The professionals manually observe the wave-like pattern of heart activity. With continuous monitoring, healthcare systems can shift from being reactive to proactive. Instead of waiting for patients to experience symptoms and visit a clinic, healthcare providers can intervene early, potentially preventing serious events or managing them more effectively when they occur. With the trends of new medical IoT devices being introduced in the market, technology companies like Apple and Samsung are putting more effort and investment into the development of healthcare IoT devices, further accelerating the ubiquitous computing advancing in the medical domain.

The primary problem statement of this research revolves around the limitations of traditional healthcare systems in providing continuous, real-time monitoring and rapid response to cardiovascular events. Despite advancements in medical technology, many patients still suffer from delayed diagnosis and treatment, leading to higher mortality rates. Ubiquitous computing, with the aid of IoT devices, offers a promising solution by enabling continuous health monitoring outside of clinical settings. However, the successful implementation of this approach is not without challenges. Key issues such as data privacy, the accuracy of health monitoring devices, and the sustainability of such systems in terms of battery life and cost must be addressed to ensure their effectiveness.

III. Similar Systems

A. *Wearable Fitness Tracker (WFT)*

The concept of a fitness tracker can be traced back to the Roman Era when Roman soldiers used pedometers to measure the distances of marching as the approach to tracking the physical activity of humans. Dr Yoshiro Hatano invented a recent wearable fitness tracker is a step counter to access physical activity, which is aimed to overcome obesity by encouraging people to walk more [5]. In the digital revolution in the early 1990s, the advancement of electronic pedometers offered more accurate step counting and fused with basic calorie estimation. In 1996, with the integration of GPS, outdoor sports that use wearable fitness trackers to track their covered distances became possible and popular as more accurate metrics such as location, speed, altitude and other data pointers could be recorded during the exercise. In 2007, an American startup company, Fitbit released its first fitness tracker known as Fitbit Classic. This tracker can be clipped on clothes or worn as a wristband. Fitbit can monitor a user's distance travelled, steps taken, and even an estimate of the calories burned during each session. In the same year, Apple introduced the first iPhone and allowed Fitbit Classic to sync its data over the phone via Bluetooth and an internet connection. Due to the limited screen size of fitness trackers, many brands have entered the smartwatches market.

B. *Smartwatches*

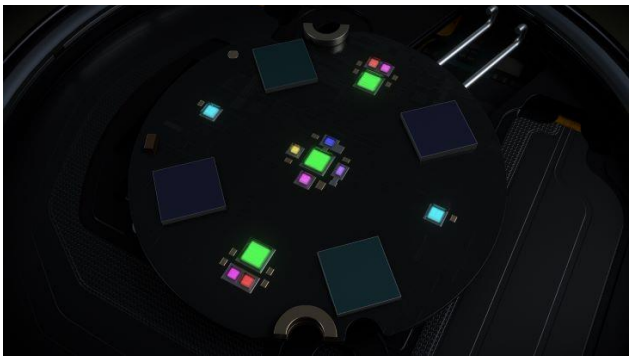
i. Apple

Apple watch can monitor and detect unusually high or low heartbeat rates and notify the user. If the user's heartbeat rate is above 120 bpm or lower than 40 bpm while inactive for 10 minutes, the user will receive a notification. Apple watch continuously monitors the user's physical activity; if the watch detects the user has been sitting for a long period, a standing reminder will be sent to the user, as recording to study, prolonged sitting will increase the risk of cardiovascular disease [6]. The watch has a built-in optical heart sensor to detect irregular rhythms that have the potential to trigger atrial fibrillation (AFib). Atrial fibrillation is an irregular, chaotic and very rapid heart rhythm. It is considered a symptom of a heart attack caused by hypertension, obesity or other heart problems. The watch will notify the user if the irregular rhythm is detected, allowing the user can seek medical help early. According to the Apple Heart Study, which took place in 2017 and 2018, researchers from Stanford University School of Medicine collaborated with Apple to identify atrial fibrillation, a heartbeat irregularity that is a major cause of stroke and hospitalisation. Participating in this study, more than 400,000 Apple Watch owners confirmed that wearable technology can assist in the early detection of this condition. The irregular rhythm notification was first made available as a result of the study. Early in 2022, the feature was updated to enhance the AFib identification algorithm through the use of cutting-edge machine-learning techniques [7]. Since 2018, The ECG app has been available on Apple Watch Series 4 or later models. Traditionally, standard 12-lead ECG electrodes are used to record electrical signals from different angles in the heart to produce 12 other waveforms. The ECG app on Apple Watch can measure a waveform similar to those waveform. Studies that compared the 12-lead standard ECG to the ECG app on the Apple Watch showed that the ECG app's classification of the rhythm as sinus or AFib agreed with the standard 12-lead ECG's classification. In a clinical trial comprising roughly 600 participants, the ECG app's ability to classify an ECG recording into sinus rhythm correctly and AFib was evaluated. The classifiable results showed 98.3% sensitivity for AFib classification and 99.6% specificity for sinus rhythm classification.

[3] Apple ECG app

ii. Samsung

Samsung Galaxy Watch series are the smartwatch developed by Samsung Electronics and are the successor to Samsung Gear, which are the wearable fitness tracker. The Samsung Galaxy Watch series have multiple sensors featuring health and fitness monitoring. With the Samsung Health and Samsung Health Monitor which are the applications in Samsung Galaxy Smartphones, the health data can sync across devices. Since the first smartwatch under this series, the Galaxy Watch is capable of measuring heartbeat rate and oxygen saturation (SpO2) in blood using electro-optical sensor that shots different wavelength of light to the skin and the sensor looking for the penetration of lights to measure the different health metrics. The same technology can be found in Samsung Galaxy S9 and S10 series smartphones. During Covid-19 pandemic, where the pulse oximeter which measures blood oxygen saturation is hard to find due to tremendously increasing of demands all over the globe, Samsung's biosensors and their proprietary algorithm become an alternative to monitor people's health. A Covid-19 infector will have decrease in blood oxygen saturation, Samsung wearable devices are proven that they can accurately monitor the vital health metrics including heartbeat rate, blood preassure and blood oxygen saturation [8]. The latest Galaxy Watch 7 was released in July 2024, equipped with new BioActive Sensor that integrates blue, yellow, violet, ultraviolet, green, red, and infrared LEDs to improve the accuracy of measurement. The new sensor is featuring the watch to be the first smartwatch to measure Advanced Glycation End Products (AGEs) index, which is the health metrics of metabolism and biological aging. Proteins, lipids, and nucleic acids undergo non-enzymatic glycation and oxidation, which results in the production of advanced glycation end products (AGEs). Increased AGE formation is more common in diseases like diabetes mellitus (DM) that are linked to hyperglycemia which can progress to cardiovascular diseases [9]. The watch is able to have ECG, blood pressure monitoring, skin temperature measurement, and bioelectrical impedance analysis (BIA) that can estimate body composition including body cell mass, fat mass, total body water etc.



[24] Samsung new BioActive sensors

C. Smart Rings

While smartwatches is versatile to provide healthcare monitoring and assist users in daily routines, there are some limitations including discomfort for prolonged used as its bulky size, and have limited battery life which require charging after 1-3 days as it consumes much powers for other features, an alternative that promising to have 1 week battery life is introduced which is smart rings. Oura Ring is the pioneer in this market. Insomnia is linked to an increased risk of heart disease, including high blood pressure, coronary heart disease, and heart failure [10]. Smart rings excel in monitoring sleep patterns and recovery data, which is crucial for patients with conditions like insomnia, sleep apnea, or chronic stress.

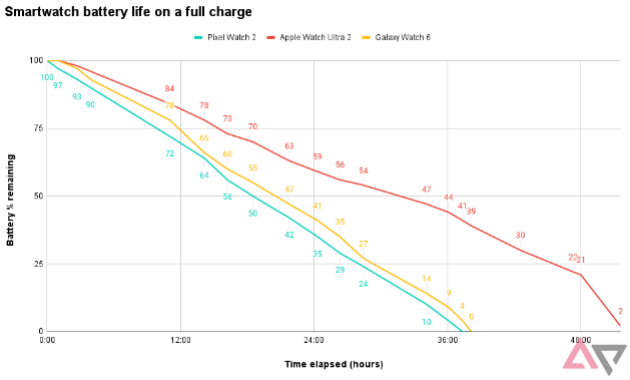


Fig 4: Smartwatch battery showdown: Which wearable lasts longest?

D. *Smart Clothing*

Hexoskin smart clothes are particularly valuable in the healthcare sector for cardiovascular monitoring and management, especially for conditions like heart disease, including cardiovascular events such as Acute Myocardial Infarction (MI). After cardiac surgery or a heart attack, patients need continuous monitoring to ensure proper recovery and detect any early signs of complications. Hexoskin garments allow patients to be monitored from home, reducing the need for extended hospital stays. Real-time data can be transmitted to healthcare providers, enabling them to monitor recovery remotely. For patients with chronic conditions such as hypertension or heart failure, continuous monitoring helps in managing the disease by providing consistent data on heart function, activity levels, and overall health. Doctors can adjust treatments or lifestyle recommendations based on real-time data, making disease management more personalised. Hexoskin supports remote patient monitoring, enabling healthcare providers to track patients' cardiovascular health without requiring them to come to the clinic. The data collected by the smart clothes can be integrated with telemedicine platforms, allowing for remote consultations and continuous care management, especially for patients living in remote or underserved areas.

E. *Continuous Glucose Monitors (CGMs)*

A study found that an increase in casual blood glucose levels, even within the normal and borderline ranges, was associated with an increased risk of CVD and mortality in adults without a known diabetes diagnosis [11]. Continuous Glucose Monitors (CGMs) are wearable medical devices that provide real-time, continuous monitoring of glucose levels in the body. Traditionally, testing blood glucose levels involves using a blood glucose meter with test strips and a lancing device. This method requires a fingerstick to obtain a small drop of blood. CGMs use a small sensor inserted just beneath the skin, typically on the abdomen or the upper arm. This sensor measures the glucose levels in the interstitial fluid (the fluid between the cells) rather than directly in the blood. The sensor is usually replaced every 7 to 14 days. Dexcom G6 is a CGM system provides real-time glucose monitoring and continuously transmitting glucose data to a smartphone app or receiver. Dexcom G6 allows users to share their glucose data with up to 10 followers. However, it has the limitation of needing physical insertion of sensors into the human skin tissues. Non-invasive glucose monitoring (NIGM) is an technology breakthrough that use mid-infrared optoacoustic signals to detect the level of blood glucose [12]. Some experimental studies reviewed the feasibility of using electrochemical technology, optical technology as well as electromagnetic and microwave technology to achieve non-invasive blood glucose monitoring [13]. Once a solution for non-invasive glucose monitoring is introduced, the glucose monitoring can be undergone anywhere, anytime just like using smartwatches to monitor blood pressure and oxygen saturation.

IV. TECHNICAL RESEARCH AND PROPOSED DESIGN

A. *Smart implants*

Smart implants use ubiquitous computing and IoT in the healthcare industry, which seeks to improve medical care through advanced technology placed directly into the body. It means that they can collect health information all the time, provide personal care and even administer medication themselves. A smart pacemaker is a type of device implantable cardioverter-defibrillators (ICDs) which help in monitoring and controlling heart functions [23]. This is because it monitors and regulates one's heartbeat rate but also transmits this information in real time to the doctors. Through this, doctors are able to monitor a patient's heart rhythm remotely, make non-invasive changes to settings as well as detect arrhythmias early enough. Some pacemakers can even predict chances of having heart attacks hence notifying patients and health experts accordingly.

B. *Seamless without any gadget*

Implementing seamless healthcare monitoring without the need for wearable gadgets involves leveraging non-invasive technologies and smart infrastructure that can continuously collect and analyse health information. In smart home with ambient sensors, various measurements including air quality, temperature, humidity, light intensity, sound intensity, and residents' physical activity can be tracked to determine the health of residents. Use smart home devices like smart thermostats, lights, and appliances to gather data on activity patterns and detect anomalies that might indicate health issues. For example, changes in daily routines or sleep patterns can provide insights into a person's health. In smart house or other premises, radar or radio technology are used to monitor vital signs such as body temperature, heart rate and respiration rate without physical contact. These technologies can be embedded in the walls of homes or medical facilities [20].

C. *Smart furniture*

Smart beds or smart mattress with embedded sensors can monitor heart rate, respiratory rate, and sleep quality without requiring wearable devices. Smart beds with more features can be implemented in hospital settings, while smart mattress will be a budget solution for home usage. A smart desk in a healthcare setting can adjust its height to encourage standing and reduce prolonged sitting, which is beneficial for cardiovascular health. The desk can also monitor posture and provide reminders to take breaks, reducing the risk of strain injuries. In telemedicine, a smart desk with integrated screens and sensors could facilitate virtual consultations by ensuring the patient and doctor can interact effectively. Smart chairs and smart sofas equipped with sensors and IoT devices can monitor sitting posture and pressure distribution to prevent discomfort and sores. The smart chairs can also remind the user to stand up and stretch the body when prolonged sitting without movement is detected. In addition to being able to

gather biological samples like urine and stool samples that provide information on hydration levels, glucose levels, and other health markers, modern smart homes feature luxurious toilets that are outfitted with sensors to monitor temperature, heart rate, and oxygenation [18]. In addition to blood pressure and blood oxygenation, toilet seats can incorporate sensors that detect cardiovascular data, including cardiac health, optical measurements of blood volume changes, and measurements of the ballistic forces exerted by the heart [19]. Smart wardrobes can assist patients in selecting clothing based on their health conditions, activity level, and the external environment such as weather. Smart scale and smart mirror can be used for health monitoring, providing real-time feedback on a patient's appearance, such as analyse a user's skin for signs of dehydration or other health issues and offering health tips as well as motivate patient to help them stay on track with their health goals.

Other household appliances such as air conditioning and air purifier are embedded with smart home connectivity features to achieve ubiquitous computing. Air pollution and particulate matters has high corelation to the causes of cardiovascular diseases [21]. For a patient with asthma or chronic obstructive pulmonary disease (COPD), a smart air purifier can detect high levels of allergens or pollutants in the air and automatically increase filtration to reduce symptoms. The purifier can also send alerts if air quality drops below safe levels and provide recommendations for improving indoor air, such as open the windows and fans for better ventilation. Nocturnal light exposure can affect the cardiometabolic diseases [22]. A smart lighting system can simulate natural daylight to help regulate the circadian rhythm of patients, promoting better sleep and overall health. For elderly individuals or those with vision impairments, the lights can automatically brighten when movement is detected, reducing the risk of falls. Refrigerators with internal cameras can implement AI technology by using computer vision to analyse the condition of food, generate dietary reports of users and suggest healthy meals. Smart kitchens with intelligent ovens, microwaves, breadmakers, multi-cookers, water filters etc. help users cook meals that are low in salt or fat, essential for individuals with cardiovascular diseases. A smart medication dispenser in a smart home can track the patient's medication schedule and alert them when it's time to take their pills. It can also send notifications to caregivers or family members if a dose is missed.

D. Integration with other emerging technologies in ubiquitous computing

i. Artificial Intelligence (AI)

In order to forecast the risk of cardiovascular events, artificial intelligence can analyze enormous volumes of health data, including genetic information, lifestyle factors, and electronic health records (EHRs). Medical IoT devices can become more accurate thanks to machine learning algorithms, which can also detect risk factors that human clinicians might miss. Small alterations in vital indicators, like trends in blood pressure or heart rate variability, can be used to identify early warning signals of cardiovascular disease and begin treatment sooner. AI-powered virtual assistants can offer patients real-time health advice, prescription reminders, and responses to inquiries about their health. Between professional visits, these aides can assist patients in better managing their conditions.

ii. Fifth-generation technology standard for cellular networks (5G)

The ultra-low latency of 5G ensures that data from remote monitoring devices, such as ECG monitors or smart implants, is transmitted with minimal delay. This supports real-time decision-making and rapid response to emerging health issues. 5G supports the connectivity of numerous IoT devices simultaneously, enabling a comprehensive network of sensors and smart devices to monitor cardiovascular health. This scalability ensures that patients can benefit from a wide array of monitoring tools without connectivity issues.

iii. Augmented reality (AR) and Virtual Reality (VR)

5G supports the connectivity of numerous IoT devices simultaneously, enabling a comprehensive network of sensors and smart devices to monitor cardiovascular health. This scalability ensures that patients can benefit from a wide array of monitoring tools without connectivity issues. AR can be used to help patients understand their cardiovascular conditions and the impact of their lifestyle choices. For instance, an AR app could visualise the effects of clogged arteries on blood flow or demonstrate how different interventions, such as stents or lifestyle changes, can improve heart health. Additionally, AR can be used in the operating room to overlay critical information onto the patient's anatomy, guiding surgeons with real-time data during procedures. VR is being explored as a tool for cardiac rehabilitation, providing virtual environments where patients can perform exercises tailored to their recovery needs. These programs can monitor a patient's progress, adjust the difficulty level in real-time, and provide motivational feedback, all within the comfort of the patient's home.

iv. Blockchain

Privacy in healthcare is always a hot topic as people are worried about their personal sensitive information being used or attacked when their health data are saved in a cloud server or even their local devices. Blockchain is a decentralised and secure digital ledger technology that ensures the integrity and transparency of data across multiple points in a network. In healthcare, it can be used to securely store and share patient data, providing privacy and accuracy. Blockchain can secure sensitive health data collected by IoT devices in ubiquitous healthcare systems, such as patient heart rates, blood pressure, and other vital signs.

V. LIMITATIONS

A. Privacy concern

When discussing the integration of IoT devices in healthcare ubiquitous computing, people are always concerned about their data privacy when using the services and products of medical IoT devices. As the data is always sent and backed up in the cloud, it is exposed to malicious attacks such as unauthorised access, data privacy violations, and altered health data by cybercriminals. Obtaining and managing informed consent for data collection and usage can be difficult, especially when data is shared among multiple parties or used for research purposes. Patients need clear control over their data and how it is used. Mismanagement or lack of transparency regarding data usage can lead to distrust and reluctance to use IoT devices. Hence, patients may resist adopting new technologies due to comfort, usability, or perceived invasiveness. Several approaches have in studied and proposed recently to protect data privacy, including

Homomorphic encryption [14], time-based elliptic curve algorithm by Sharmila al. [15], and Multi-Modal Secure Data Dissemination Framework (MMSDDF) by Rajakumar Arul et al. [16]. Due to privacy concerns, many features may only be available to a few countries, as those medical IoT devices must undergo rigorous testing and certification to meet the regulatory standards of each country.

B. Battery life

Medical IoT devices often require continuous monitoring and data transmission, which can be power-intensive. Ensuring that devices have long-lasting battery life without frequent recharging or replacement is a significant challenge. Larger batteries can improve battery life but may impact the comfort and portability of wearable devices. Striking a balance between battery life and user comfort is essential. Regular maintenance and battery replacement can be a burden for users, especially for devices that are worn or used daily. Innovative solutions are needed to extend battery life and minimise maintenance requirements. Some advancements in energy harvesting technologies, using body heat or movement to generate power, are being explored to address battery life issues [17]. However, these technologies are still evolving and may not yet be practical for all medical IoT devices.

C. Accuracy

Medical IoT devices rely on sensors to monitor vital signs and other health metrics. Ensuring these sensors are accurately calibrated and provide reliable readings is crucial. Calibration can be affected by factors such as device placement, user movement, and environmental conditions. Variability in the performance and accuracy of different IoT devices can impact the overall reliability of health monitoring. Standardisation and quality assurance are necessary to ensure consistent performance across devices. There is a risk of false positives, which is incorrectly indicating a problem or false negatives, which is failing to detect an issue, which can lead to unnecessary anxiety or missed diagnoses.

D. Cost and Accessibility

The cost of acquiring and implementing medical IoT devices, including sensors, monitoring systems, and associated infrastructure, cannot be affordable to most people in need if subsidies and government policy are not given. Variations in access to advanced healthcare technology based on socioeconomic status can create disparities in healthcare delivery. Ensuring equitable access to IoT devices and technology is essential. For instance, during the COVID-19 pandemic, although wearable medical IoT devices can be an alternative to clinical devices for rural areas, however, medical IoT devices might be more rare than clinical devices.

VI. CONCLUSION

This research underscores the transformative potential of ubiquitous computing, supported by medical IoT devices, in addressing the growing challenge of cardiovascular diseases, particularly Acute Myocardial Infarction (AMI), in Malaysia. By extending healthcare monitoring beyond traditional clinical settings, ubiquitous computing enables continuous, real-time data collection, leading to earlier detection and more effective management of cardiovascular conditions. The integration of emerging technologies such as AI, 5G, blockchain, and AR/VR further enhances the capabilities of this approach, offering personalised, secure, and immersive healthcare experiences. However, challenges such as privacy concerns, battery life, and accuracy must be addressed to fully realise these benefits. The research highlights the need for ongoing innovation and regulatory frameworks to ensure that these technologies are effectively integrated into the healthcare system, ultimately improving patient outcomes and contributing to the economic development of Malaysia.

VII. REFERENCES

[1] "Summary of Global Burden of Disease Study Methods," Journal of the American College of Cardiology, vol. 80, no. 25, pp. 2372–2425, Dec. 2022, doi: https://doi.org/10.1016/j.jacc.2022.11.001.

[2] Department of Statistics Malaysia, "Statistics on Causes of Death Malaysia 2023," Oct. 2023. Available: https://www.dosm.gov.my/portal-main/release-content/statistics-on-causes-of-death-malaysia-2023

[3] "NCD Countdown 2030: pathways to achieving Sustainable Development Goal target 3.4," The Lancet, Sep. 2020, doi: https://doi.org/10.1016/s0140-6736(20)31761-x.

[4] B. Birnbach, J. Höpner, and R. Mikolajczyk, "Cardiac symptom attribution and knowledge of the symptoms of acute myocardial infarction: A systematic review," BMC Cardiovascular Disorders, vol. 20, no. 1, Oct. 2020, doi: https://doi.org/10.1186/s12872-020-01714-8.

[5] S. Stunkard, "A method of studying physical activity in man," American Journal of Clinical Nutrition, vol. 8, no. 5, pp. 595–601, Sep. 1960, doi: 10.1093/ajcn/8.5.595.

[6] S. Mayor, "Prolonged sitting increases risk of serious illness and death regardless of exercise, study finds," BMJ, vol. 350, no. jan19 7, pp. h306–h306, Jan. 2015, doi: https://doi.org/10.1136/bmj.h306.

[7] M. V. Perez et al., "Large-Scale Assessment of a Smartwatch to Identify Atrial Fibrillation," New England Journal of Medicine, vol. 381, no. 20, pp. 1909–1917, Nov. 2019, doi: https://doi.org/10.1056/nejmoa1901183.

[8] S. H. Browne, M. Bernstein, and P. E. Bickler, "Accuracy of Samsung Smartphone Integrated Pulse Oximetry Meets Full FDA Clearance Standards for Clinical Use.," medRxiv, p. 2021.02.17.21249755, Feb. 2021, doi: https://doi.org/10.1101/2021.02.17.21249755.

[9] Z. Hegab, S. Gibbons, L. Neyses, and M. A. Mamas, "Role of advanced glycation end products in cardiovascular disease," World Journal of Cardiology, vol. 4, no. 4, pp. 90–102, Apr. 2012, doi: https://doi.org/10.4330/wjc.v4.i4.90.

[10] S. Javaheri and S. Redline, "Insomnia and Risk of Cardiovascular Disease," Chest, vol. 152, no. 2, pp. 435–444, Aug. 2017, doi: https://doi.org/10.1016/j.chest.2017.01.026.

[11] A. V. Poznyak, L. Litvinova, P. Poggio, V. N. Sukhorukov, and A. N. Orekhov, "Effect of Glucose Levels on Cardiovascular Risk," Effect of Glucose Levels on Cardiovascular Risk, vol. 11, no. 19, pp. 3034–3034, Sep. 2022, doi: https://doi.org/10.3390/cells11193034.

[12] N. Uluç et al., "Non-invasive measurements of blood glucose levels by time-gating mid-infrared optoacoustic signals," Nature Metabolism, vol. 6, no. 4, pp. 678–686, Apr. 2024, doi: https://doi.org/10.1038/s42255-024-01016-9.

[13] J. Wu, Y. Liu, H. Yin, and M. Guo, "A new generation of sensors for non-invasive blood glucose monitoring," American journal of translational research, vol. 15, no. 6, pp. 3825–3837, 2023, Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10331674/

[14] Ben Othman Soufiene, Abdullah Ali Bahattab, A. Trad, and H. Youssef, "LSDA," Jun. 2020, doi: https://doi.org/10.1145/3447568.3448530.

[15] A. H. Sharmila and N. Jaisankar, "E-MHMS: enhanced MAC-based secure delay-aware healthcare monitoring system in WBAN," Cluster Computing, May 2020, doi: https://doi.org/10.1007/s10586-020-03121-2.

[16] R. Arul, Y. D. Al-Otaibi, W. S. Alnumay, U. Tariq, U. Shoaib, and M. D. J. Piran, "Multi-modal secure healthcare data dissemination framework using blockchain in IoMT," Personal and Ubiquitous Computing, Feb. 2021, doi: https://doi.org/10.1007/s00779-021-01527-2.

[17] Z. Tabaie and A. Omidvar, "Human body heat-driven thermoelectric generators as a sustainable power supply for wearable electronic devices: Recent advances, challenges, and future perspectives," Heliyon, p. e14707, Mar. 2023, doi: https://doi.org/10.1016/j.heliyon.2023.e14707.

[18] T. J. Ge et al., "Passive monitoring by smart toilets for precision health," Science Translational Medicine, vol. 15, no. 681, Feb. 2023, doi: https://doi.org/10.1126/scitranslmed.abk3489.

[19] N. J. Conn, K. Q. Schwarz, and D. A. Borkholder, "In-Home Cardiovascular Monitoring System for Heart Failure: Comparative Study," JMIR mHealth and uHealth, vol. 7, no. 1, p. e12419, 2019, doi: https://doi.org/10.2196/12419.

[20] F. Fioranelli and J. Le Kernec, "Radar sensing for human healthcare: challenges and results," IEEE Xplore, Oct. 01, 2021. https://ieeexplore.ieee.org/document/9639702

[21] B.-J. Lee, B. Kim, and K. Lee, "Air Pollution Exposure and Cardiovascular Disease," Toxicological Research, vol. 30, no. 2, pp. 71–75, Jun. 2014, doi: https://doi.org/10.5487/TR.2014.30.2.071

[22] P. Jemielita et al., "Noise and light Exposure and Cardiovascular Outcomes: A review of evidence, potential Mechanisms and implications.," Trends in Cardiovascular Medicine, Jul. 2024, doi: 10.1016/j.tcm.2024.07.001.

[23] G. Gaobotse, E. Mbunge, J. Batani, and B. Muchemwa, "Non-invasive smart implants in healthcare: Redefining healthcare services delivery through sensors and emerging digital health technologies," Sensors International, vol. 3, p. 100156, 2022, doi: https://doi.org/10.1016/j.sintl.2022.100156.\

[24] "Unlocking new possibilities for preventative wellness with new Galaxy Watch and BioActive Sensor." https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

[25] N. Gondhia, "Smartwatch battery showdown: Which wearable lasts longest?," Android Police, Feb. 14, 2024. [Online]. Available: https://www.androidpolice.com/samsung-google-apple-smartwatch-battery-comparison/