Opportunities and Challenges Surrounding the Use of Wearable Sensor Bracelets for Infectious Disease Detection During Hajj: A Qualitative Interview Study

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Table of Contents

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Abstract

Background: Wearable sensor bracelets have gained interest for their ability to detect symptomatic and presymptomatic infections by detecting alterations in physiological indicators. Nevertheless, the utilisation of these devices for public health surveillance among attendees of large-scale events like Hajj is currently in a nascent phase.

Objective: To explore Hajj stakeholders' perspectives on the use of wearable sensor bracelets for disease detection.

Methods: We conducted a qualitative, theoretically informed, interview-based study involving a diverse sample of Hajj stakeholders, including technology experts, healthcare providers, and Hajj service providers. The study was guided by the Task-Technology Fit Model (TTF) and Unified Theory of Acceptance and Use of Technology (UTAUT) to provide a comprehensive understanding of the factors influencing the acceptance and utilisation of the technology. Semi-structured in-depth interviews were employed to capture perspectives on using wearable sensor bracelets for infectious disease detection in Hajj. Thematic analysis of interview transcripts was conducted.

Results: A total of 14 individuals were interviewed.Implementing wearable sensor bracelets for disease detection during Hajj faces obstacles from multiple perspectives, encompassing users, providers, and technological factors. Hajj stakeholders are concerned about the substantial financial and operational barriers. The motivation of providers and users is essential for the acceptance and uptake of devices during Hajj. Successful integration of wearables into the Hajj surveillance system depends on several factors, including infrastructure, device features, suitable use cases, training, and a smooth organisational integration process.

Conclusions: This study provides valuable insights into the potential opportunities and challenges of adopting wearable sensor bracelets for disease detection during Hajj. It offers essential factors to consider and important suggestions to enhance comprehension and ensure the effective implementation of this technology.

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KEYWORDS: wearable sensor ,

Introduction:

New Generation of Digital Tools for Public Health Surveillance

Understanding and reacting to health trends affecting communities is a core function of public health systems [1]. Public health surveillance is the tool utilised to respond to these health trends through "the ongoing, systematic collection, analysis, and interpretation of health-related data

essential to planning, implementation, and evaluation of public health practice" [1]. The COVID-19 pandemic has brought to light the urgent need for real-time public health surveillance to enhance the use of evidence in decision-making [1] .The 2020 Riyadh Declaration was formulated as a response to the global pandemic, aiming to propose a series of suggestions that would effectively tackle the shortcomings observed in global public health response systems. The Riyadh Declaration emphasised the significance of implementing digital health solutions that are both scalable and sustainable, as well as the adoption of health intelligence [1]

Traditional public health initiatives targeted at preventing the spread of infectious diseases, such as the recent COVID-19 viruses, have limitations that digital health technologies could address [2]. The WHO defined digital health technologies as "the field of knowledge and practice associated with the development and use of digital technologies to improve health"[3]. The utilisation of digital health tools during the global pandemic has exhibited their efficacy in fighting, mitigating, and controlling the transmission of emerging infectious diseases [2]. There is a significant potential for adopting digital surveillance as a valuable tool in monitoring and controlling infectious diseases [4]. IoT technological advancement has proven its ability to augment and optimise conventional preventative public health strategies and methodologies [2]. These Internet-based technologies possess certain characteristics that enable the expedited detection of infectious diseases [4]. The term "Internet of Things" (IoT) pertains to a network of interconnected objects, devices, and systems that engage in electronic communication and receive, process, and send digital data with minimal human involvement [5]. IoTs is expected to reach its "plateau of productivity" during the next 5-10 years [5].

Detection is the initial and important aspect in preventing infectious diseases [5]. In the context of these diseases, the computation speed plays a crucial role in reducing the time required for their diagnosis, facilitating prompt implementation of preventive measures. The performance of system automation has been found to enhance surveillance's efficacy in widespread disease transmission. Additionally, it has proven to be an effective means of reducing the workload of medical workers during pandemics [4].

Wearable Technologies and Body Sensors:

Wearable technologies are integral to widespread IoT technical advancements [6]. Wearable technologies apply to intelligent electronic devices worn on the body to measure, analyse, and transfer information. The data may encompass many bodily indicators associated with essential physiological parameters and levels of physical exertion. These wearables have the capability to provide information to the user by means of display technology or vibrotactile feedback [7].
Wearable sensors have garnered considerable attention in the past ten years, with a particular focus on their application within the healthcare sector. Their ability to establish connections with other devices and the Internet of Things, facilitating data exchange, has led to their designation as "smart" devices, setting them apart from traditional, non-connected step counters, wristwatches, or clothing [8]. Wearable sensors have the capability to monitor, collect, and send data [6]. They

offer precise, credible, and real-time data regarding an individual's behaviours and activities, hence aiding users in identifying potential issues. Wearables collect raw data from measurements using sensors to store them and use them for things like performance evaluation and ongoing health monitoring [9]. These sensors can find application in several areas such as illness monitoring, diagnosis and treatment, and health management [10].

Various terms are used to refer to wearable sensor devices that capture and analyse real-time physical data in a non-intrusive manner. These terms encompass smartwatches [11,12]smart sensors [13], wearable activity trackers [14], wearable sensors [15], wearable physiological sensors[16], integrated biosensors [17], and sensor bracelets [18]. In the context of this research, the phrase "sensor bracelet" will be employed.

Extensive research has been conducted on wearables to investigate their potential in health monitoring. However, there is a noticeable trend in current research towards applying wearables for the pre-symptomatic detection of infectious diseases. This transition signifies the growing importance of early detection of diseases, especially within the context of public health and large-scale occurrences. The utilisation of wearable technology has emerged as a significant factor in this pursuit, presenting the possibility of identifying infections before the manifestation of symptoms. This capability facilitates prompt interventions and preventive actions. The increasing emphasis on this matter highlights the significant contribution that wearables can make in augmenting healthcare and methods for disease control.

Wearable devices (sensor bracelets) have gained attention for their ability to anticipate both symptomatic and presymptomatic identification of viral respiratory infections by sensing changes in physiological markers, as highlighted in recent literature research [18,19]. Meraj et al [15] conducted a systematic review to assess the value of a verity of wearable bracelet devices in detecting SARC-COV-2. Building on this, Risch et al [18] assessed the use of a smart bracelet in the early detection of changes in physiological parameters related to COVID-19. Mishra et al [11]conducted a study whereby they demonstrated the use of data from smartwatches to detect respiratory infections, such as Covid-19, in real-time within a large-scale scenario, while Hirten et al [2] evaluated the longitudinal collection of HRV metrics from a wearable device for the prediction of COVID-19 diagnosis.

Hajj, The Largest Annual Religious Mass Gathering and Disease Transmission:

Safety and security have consistently been of utmost importance within the framework of Hajj, a significant religious event that attracts a substantial number of participants globally. This annual massive religious gathering in Makkah, Saudi Arabia, attracts almost three million pilgrims from 180 countries. These pilgrims spend several weeks in the cities of Makkah and Madinah. The problem of overcrowding and the lack of compliance with government-mandated preventative measures for diseases were highlighted in several prior studies. This lack of compliance has contributed to a long-standing high occurrence of respiratory infections before the COVID-19 outbreak. Low adherence

among pilgrims has been attributed to a number of factors, including insufficient coverage and limited access to information [20].

Using intelligent and comprehensive monitoring tools for participants in this mass event is crucial to reducing the risk of future tragedies. Saudi Arabia utilises several technical methods, such as spatial computing, crowd simulation, mobile applications, and big data analytics, for Hajj activities [21].

In recent times, there has been an increasing focus on incorporating state-of-the-art technologies to tackle the distinctive difficulties linked to this occurrence. The Hajj pilgrimage, characterised by its large-scale congregation of millions of pilgrims, poses significant logistical, health, and safety complexities. Disease surveillance has emerged as a crucial component of Hajj management, progressively evolving over time by assimilating insights gained from prior operations.

The Kingdom of Saudi Arabia have been at the forefront of implementing digital solutions in order to improve the pilgrimage experience as part of the national strategy and the 2030 vision. One of the notable technological developments in this context involves the application of the smart bracelet initiative, which involved the collaboration of multiple governmental authorities. In 2021, the Pilgrims' Smart Bracelet initiative was introduced, offering 5000 pilgrims bracelets equipped with data storage and transmission capabilities, thus contributing to the Internet of Things. The main purpose of the bracelet was to provide extensive information on the pilgrim, including their health condition. The device enabled the tracking of important health indicators such as blood oxygen saturation and pulse rate, while also offering functionalities for requesting immediate medical or security support, guaranteeing swift reaction and help. In addition, pilgrims were given awareness messages via the bracelet they wore. The initiative's implementation entailed incorporating and enhancing business models and systems, spanning both operational and technological facets of the project [22].

The practice of post-mortem detection for infectious diseases underscores the criticality of real-time data and analytics in order to avert their transmission, which has severe social and economic repercussions for global citizens [5]. Within the framework of Hajj, it is imperative to not only identify diseases before symptoms appear but also to find and follow the individuals who have been in contact with infected individuals. This requires incorporating tracking elements into the device. The current state of affairs presents an opportune environment for scientific inquiry, specifically aimed at recognising and addressing nascent hazards and difficulties in order to predict and alleviate them. Hence, this study endeavours to investigate the opportunities and challenges surrounding using wearable sensor bracelets for presymptomatic detection of infectious disease during Hajj.

Methods:

Study Design & Data Collection

We conducted in-depth semi–structured, one-to-one qualitative interviews from (March 2022 - October 2023) with 14 selected Hajj stakeholders, Organizers, and professionals working in the field to capture their perspectives on using wearable sensor bracelets for infectious disease detection in

Hajj. Participants were identified through purposive sampling and snowballing sampling techniques. Purposive sampling was used to gain insights into a range of perspectives that need to be considered when considering implementing and adopting wearable sensor bracelets for disease detection in Hajj. Key stakeholders were identified through the organisational website and were reached purposefully via email. Purposive sampling was supplemented with a snowballing sampling technique to gather perceptions of participants in the field whose roles were lower in the organisational hierarchy of Hajj management. These participants were contacted directly via their contact numbers. This study adhered to the guidelines outlined in the Consolidated criteria for reporting qualitative research (COREQ) checklist [23] .

Interviews

We used a systematic approach to engage with our potential participants before the interviews started. We initially sent a Participant Information Sheet to each potential participant via email or WhatsApp using their direct contact number, informing them of the study's purpose and why they were selected.

The interview questions were then given to participants who replied favourably and indicated their desire to participate. This action guaranteed that participants had enough time to prepare for the following interview, promoting a deeper and more thoughtful discussion. We then scheduled the interviews after allowing participants to prepare and receive the interview questions.

Interview Topic Guide

Interviews were guided by a topic guide exploring professional background, experience, and involvement with the 2021 Pilgrims’ Smart Bracelet initiative. Questions were based on existing literature and organisations' online information to understand the current capabilities and existing tools used in Hajj. In addition to opportunities, gaps, and challenges associated with implementing wearable sensor bracelets for infectious disease detection in Hajj. Questions were tailored to the specific characteristics of participants and evolved in light of emerging findings. We explored the advancements of existing tools and technologies used in Hajj for public health surveillance, their limitations, and stakeholders' vision and perceptions toward using wearable sensor bracelets for disease detection in Hajj.

Digital audio recorders with encryption were used to capture the interviews. Transcripts were read numerous times and annotated with notes to fully immerse us in the facts.

Data Analysis

Thematic analysis of interview transcripts was conducted .The primary author, NM led the data analysis by integrating The Theory of Acceptance and Use of Technology (UTAUT) [24], and The Task-Technology Fit (TTF) [25] ,to create a comprehensive framework. This framework posits that the user's intention to use technology and their acceptance of it is influenced by many criteria derived from the Unified Theory of Acceptance and Use of Technology (UTAUT), as well as the degree of compatibility between the task at hand and the technology being used [26].

In this analysis, we explored the utilisation of wearable sensor bracelets for disease detection during

Hajj. We thoroughly evaluated several aspects, such as the integration of technology, development of systems, augmentation of infrastructure, and acceptance among users and suppliers. This comprehensive exploration allowed us to understand the intricate interplay of factors influencing the successful deployment of wearable sensor technology within the unique context of Hajj.

Data analysis commenced immediately after the completion of data collection, and data collection was halted after no novel themes were identified during the analysis stage. To improve the dependability and verification, synopses of discoveries were regularly communicated to other researchers engaged in the study subsequent to each interview with a participant. The completed transcripts and field notes were systematically arranged and categorised using NVivo 12, utilising a research-oriented theme approach (Arent code) derived from the interview guide. We followed the characteristics of an inductive coding strategy to guarantee thoroughness and complexity in our investigation [27].

Ethics

According to the ethical guidelines set forth by the University of Manchester, this research study falls under the exempt category, indicating that formal ethical approval was not required to involve human participants.

Theoretical Framework

Technology acceptance models have been criticised for their limited ability to evaluate the extent to which wearable technology offers the requisite functionalities to attain desired outcomes. This concern can be effectively resolved by integrating the TTF and Technology acceptance models [28].

The UTAUT model is considered beneficial for the complex nature of this research, which involves evaluating several interrelated factors in disciplines such as health informatics and public health during large-scale events. In order to provide a more thorough explanation, the Task-Technology Fit (TTF) model has been incorporated with the Unified Theory of Acceptance and Use of Technology (UTAUT). This integration improves understanding and focuses on particular elements inside the UTAUT framework.

For the purpose of this research, the UTAUT model can provide insights into the determinants that affect the adoption and utilisation of wearable sensor bracelets among various stakeholders participating in the Hajj pilgrimage. The Technology Task Fit (TTF) framework can be utilised to evaluate the degree to which the features of the technology align with the requirements and demands of its users, including both pilgrims and authorities.

To aid in effectively applying wearable sensor bracelets during the Hajj pilgrimage, this integrated approach can offer a comprehensive understanding of stakeholders'' viewpoints.

Results:

Participants Characteristics:

A total of 14 semi-structured, in-depth interviews were carried out, with each session having a duration ranging from 20 to 70 minutes. The interview participants in our study encompassed a wide

array of backgrounds, which included individuals involved in Hajj, specialists in public health, and professionals from several disciplines (see Table 1 for further information). A subset of the individuals involved in the study held prominent positions inside governmental entities, whereas others assumed positions with varied levels of decision-making power.

Two distinct groups were formed based on the results of the conducted interview. The initial cohort consisted of four participants who were directly engaged in the 2021 initiative and made significant contributions to the study. The second cohort consisted of ten persons who were not directly engaged in the 2021 initiative and had no further information to contribute regarding the utilisation of wearable devives in Hajj. Nevertheless. These individuals were engaged in the provision and coordination of Hajj services, as well as direct engagement with pilgrims.

Table 1: Study Participant's Expertise and Industries.

Participant No.	Expertise	Sector
1	System Engineering, Business and Project Management	Hajj and Umrah Services
2	Healthcare Provider & Public Health Specialist	Healthcare and Public Health
3	Healthcare Provider & Public Health Specialist	Healthcare and Public Health
4	Communication Engineering and Artificial Intelligence	Technology/ Consulting (Business)
5	Service Provider	Hajj Services
6	Service Provider	Hajj Services
7	Service Provider	Hajj Services
8	Service Provider	Hajj Services
9	Service Provider	Hajj Services
10	Service Provider	Hajj Services
11	Service Provider	Hajj Services
12	Service Provider	Hajj Services
13	Service Provider	Hajj Services
14	Service Provider	Hajj Services

Each participant had a minimum of ten years of professional experience in their respective fields. The individuals who made these contributions were located in Saudi Arabia. 10 interviews were performed via telephone, and the remaining four were administered using the Zoom platform. Audio recordings were conducted for all interviews.

Overview:

The analysis generated insights about four main themes and thirteen subthemes (Figure 1), highlighting crucial challenges, considerations, recommendations, and opportunities in the utilization of wearable sensor bracelets for the pre-symptomatic detection of infectious diseases during Hajj. A narrative synthesis was used to report the findings yielded from data collected of the first group of the 4 participants who played a role in the 2021 smart bracelet initiative. Table 2 highlights inputs

from each individual of the 4 participants related to the discovered theme.

The findings of the second group of participants who had less contribution to the study due to their lack of involvement in the 2021 initiative are summerized below.

This second group of participants cited their duty to serve the Guest of God during their Hajj journey to Makkah. They discussed the many types of Tawafa organizations they belong to (a service provider for external pilgrims) and the role of each one. The classification of Tawafa Organizations lies in 4 distinct groups; The first group consists of 6 organizations responsible for assisting pilgrims in Makkah and holy sites and are segregated into subgroups according to the countries and continents from which they originate. These 6 organizations are for pilgrims coming from (1) Iran, (2) South Asia, (3) Turkey, Europe, Australia and America, (4) Arabic countries, (5) African non- Arabic Countries, and (6) South East of Asia.The second group consist of 1 organization responsible for providing water to pilgrims at the Sacred House, quenching their thirst. The third group consist of an organization which is licensed to receive and dispatch pilgrims arriving via air, sea, and land ports, facilitating and arranging their deprtaure protocols. The final group is an organization that is licensed to provide services to pilgrims visiting the sacred mosque located in Madinah city.

Several prevalent health concerns among the pilgrims they assist were brought up by the participants. The most common health problems associated with the Hajj event include heat-related illnesses such as heat stroke, heart diseases, and infectious diseases. The importance of medical missions associated with each group of pilgrims was also underscored.

Participants commented on a common issue related to pilgrims lack of adherence to specific preventive measures designed by hajj authorities to safeguard their well-being, such as hygiene, and stampedes in Al Jamarat Bridge. In addition, they highlighted that the most holy site between (Mina, Muzdalifa, Arafat, And the Holy Mosque) where the crowd density becomes high is Mina.

Table 2: Themes Generated During Data Collection

Themes & Subthemes	***Participants***			
	1	***2***	***3***	***4***
Challenges				
General Challenges				
1. Resistance to Technology		•		
Provider Challenges		•		
1. Limited Data			•	•
2. Financial Burden				
3. User Consent for Data Collection	•			
4. Operational Burden	•			
User Challenges				

1. Pilgrim's Acceptance & Adherence		●		
2. Cost				
Technology/ Device Challenges				●
1. Data Privacy				
2. Trust in Technology	●	●		●
3. Existing Infrastructure Capabilities			●	
			●	
Considerations				
Stakeholder Motivations				
1. Meeting the Needs				
2. Trust in Device Features and Capabilities		●		●
3. Cost Reduction Through Private Sponsorship	●	●		
4. Interest of Entities Involved			●	●
User Motivations	●			●
1. Promoting Device for Pilgrim's Safety	●	●		
Recommendations				
Comprehensive Infrastructure			●	●
Device Characteristics and Features				●
Business Model	●	●		●
Effective Staff Training for wearable Implementation and Distribution			●	
The Need for Organic System Harmony			●	
Opportunities				
Multidisciplinary Features and Distinctiveness Among Other Digital Tools with AI Integration		●		●
Gradual Integration of Wearables in Hajj		●		

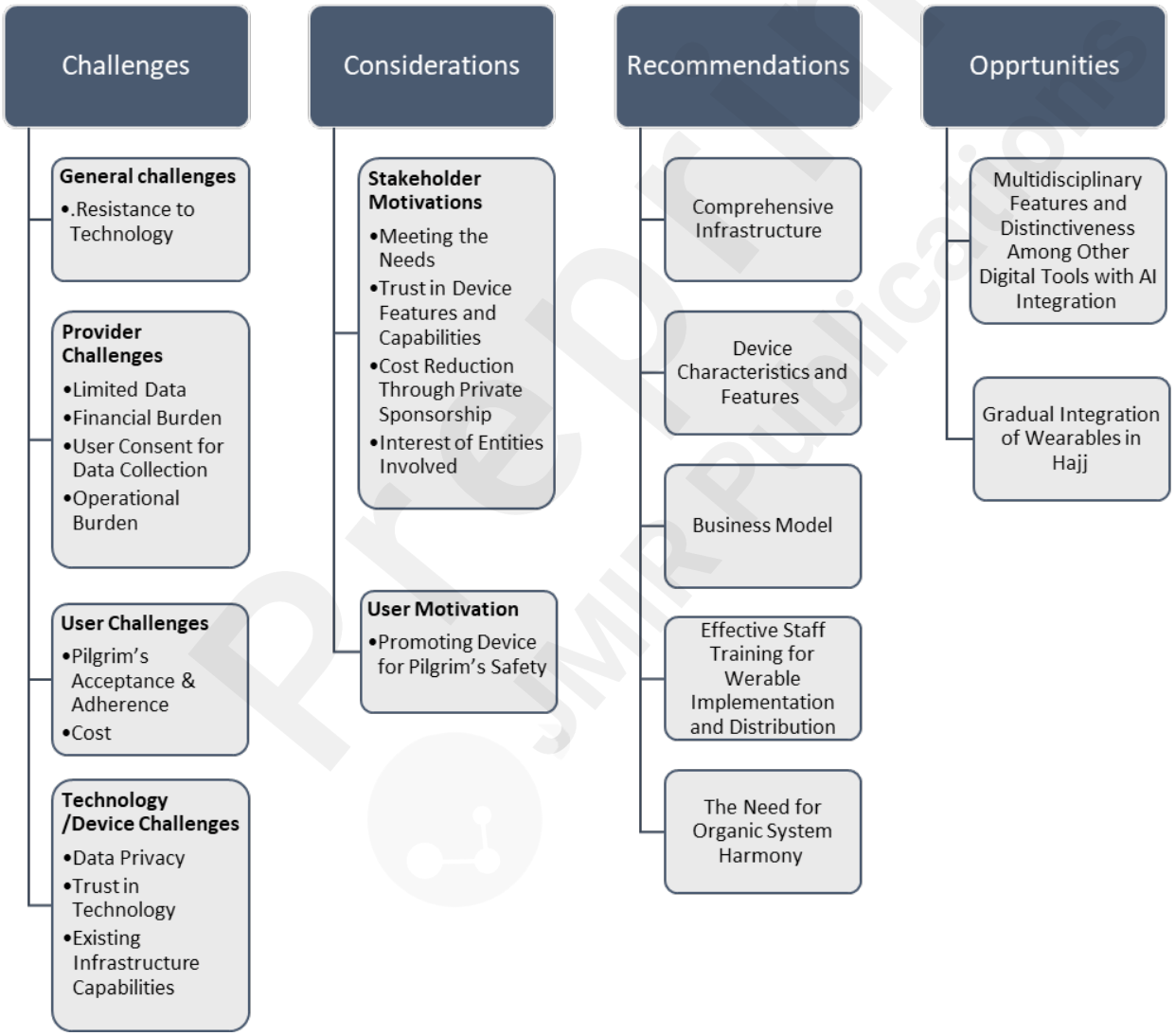

Figure 1: Thematic Analysis of the Conceptual Theme Framework of the Interviewers

Perceptions of using wearable sensor bracelets

The idea of 'Smart Hajj' was a recurring topic in the interviews, as respondents emphasised their goals for the future and their current capabilities and constraints. The concept of 'Smart Hajj'

signifies the continuous endeavours of the Hajj organisation to adapt to technological advancements and improve the overall pilgrimage journey. The concept comprises various technical solutions designed to tackle difficulties and enhance the welfare and security of pilgrims.

However, the deployment of 'Smart Hajj' and incorporating wearable devices into the technology utilised by Hajj authorities present challenges and potential. Several important points were raised, and suggestions were made by the participants.

Implementation Challenges of Wearable Sensor Bracelets for Infectious Disease Detection at Hajj

In the context of using digital health technologies for public health surveillance, participants in our study highlighted a range of challenges in deploying wearable sensor bracelets for disease detection during Hajj. The issues encompass a range of areas, including general challenges, challenges connected to providers, challenges linked to users, and challenges related to devices and technology.

General Challenges

Resistance to Technology

Participants voiced apprehensions over the wider difficulties linked to integrating technology, such as wearables, within the public health domain. They emphasised a vital concern related to resistance from both users and providers due to factors such as data privacy, information security, and human rights. Despite encountering initial opposition, there is a shared conviction that artificial intelligence (AI) will assume a crucial function in propelling the future advancement and acceptance of wearable technologies, emphasising its potential advantages for public health during the Hajj pilgrimage.

We will face a challenge in using technology for public health due to data, information, and human rights. This challenge is present, and we will face resistance. [Participant #2 , Healthcare Provider & Public Health Specialist]

I think there will be resistance at the beginning with concern of losing the data, and from specialists. [Participants #2, Healthcare Provider & Public Health Specialist]

Provider Challenges

Participants cited concerns regarding various factors from the provider’s perspectives, including limited data availability, resistance to adoption, and the operational and financial burdens associated with wearable implementation. In addition, the conversation explored several aspects pertaining to the previous Smart Bracelet initiative effort, elucidating significant barriers that hindered the advancement of the initiative.

Limited data

The lack of readily accessible health data remains a significant barrier, as it causes delays in patient diagnosis and prevents healthcare providers from assessing the unique healthcare requirements of the patient population. This scenario may also strain healthcare facilities, as they are required to cater to individuals with undisclosed medical issues and incomplete health records, hence requiring increased time and resources for precise diagnosis and treatment strategizing.

The limited availability of health data can be attributed to the apprehensions of pilgrims regarding

disclosing their medical records to Hajj authorities. There exists a concern among individuals that the act of revealing specific information pertaining to their health status and underlying medical disorders will potentially impede their ability to be granted permission to partake in the Hajj pilgrimage or, alternatively, affect their eligibility to get Hajj visas.

there is always the fear of pilgrims giving us full information. I am sure I will not get 100% of the data, but at least 60 %. I am worried that even the 60% I want that I may not get. [Participants #2, Healthcare Provider & Public Health Specialist]

Pilgrims worry that if they mention any medical condition, that the Ministry of Hajj will not issue them the visa. For example, they do not mention that they have Cancer fearing that they will not get issued the visa. I do not mind if the pilgrim has Cancer, I will treat you, but I need to know in advance to prepare and provide you with the service. [Participants #2, Healthcare Provider & Public Health Specialist]

Financial Burden

One major issue brought up by participants, especially the Hajj service providers, was the expense of integrating wearables throughout the pilgrimage. Considering the wide range of services they already offer, they voiced concerns regarding the cost load related to the adoption of wearables. Participants attributed the previous Smart Bracelet initiative (NUSUK)'s failure and incomplete implementation to the high cost of wearables and the significant budget needed for their deployment. Service providers questioned whether they could cover the expense of integrating wearables for all pilgrims.

Let's return to the smart bracelet project and why it was not completed. So, the first year the project was initiated, the number of pilgrims was 5000. For the second year, there was supposed to be a new hardware version with better features. However, finance was an issue at that stage, and the projects couldn't proceed. The cost of these devices is considered high. [Participants #4, Communication Engineering and Artificial Intelligence]

Can we afford to provide the wearable to all pilgrims? [Participants #3, Healthcare Provider & Public Health Specialist]

Yet, there was no budget for the project. [Participants #4, Communication Engineering and Artificial Intelligence]

User Consent for Data Collection

The interviewee emphasised the difficulties faced while implementing the Hajj smart bracelet initiative (NUSUK), specifically focusing on data protection concerns. They underscored the significance of acquiring informed consent for data collection by technological means, such as health data and location information.

This initiative was experimental on 5000 people but was not successful as we expected. Most mobile phones offer a lot, and smart watches offer this service without connecting it to a central centre to track it, especially since it involves data privacy where we need a clearance form that needs to be signed personally by each beneficiary. [Participants # 1, System Engineering, Business and Project Management]

Operational Burden

Participants highlighted the operational challenges associated with implementing ubiquitous sensor bracelets, including the need for staff training and the availability of expert teams for data analysis and decision-making. Concerns were also expressed over the substantial data flow generated by wearables. Despite their complete readiness, there were concerns that these efforts might not produce

valuable outcomes owing to a lack of user engagement.

It will be a huge operational load. [Participants # 1, System Engineering, Business and Project Management]

I will need a comprehensive team available which will cost a lot. And after all of this, only 50 or 100 people may purchase the watch. [Participants # 1, System Engineering, Business and Project Management]

We will have a stream flow from these types of data. [Participants # 1, System Engineering, Business and Project Management]

There is an operational effort without value. [Participants # 1, System Engineering, Business and Project Management]

It needs a specialised team that deals with the data collected by the watch and decides whether the person needs a team to be dispatched. So, there was a big operational load with a minimal value, especially during Hajj. [Participants # 1, System Engineering, Business and Project Management]

The desired benefits were not worth the operational burden of working on this initiative. [Participants # 1, System Engineering, Business and Project Management]

User Challenges

Pilgrim's Acceptance and Adherence

Participants underlined the difficulty of obtaining user acceptance, particularly in light of the wide range of backgrounds, beliefs, and degrees of faith in technology exhibited by pilgrims hailing from more than 180 nations across the globe. Stakeholders observed that the implementation of the tracking and tracing feature may potentially discourage certain pilgrims from adopting or adhering to the technology.

Once you mention to the user that they can't take the bracelet off their wrist, or you can't give it to someone else, cut it, or I will notice what happens to the bracelet once you have done any of these. It will be like you are tracking me as a prisoner, and there will be high resistance. [Participants #2, Healthcare Provider & Public Health Specialist]

Cost

In addition to being a financial burden for the providers, wearable device costs may be seen as an obstacle by users if they are part of their Hajj package. Participants voiced apprehension regarding the potential financial burden of including the cost of the bracelet in the pilgrims' bundles, deeming it to be costly.

if we estimate that the cost of the bracelet will be 100 Saudi Riyal, it will be considered expensive for pilgrims to add that amount to their package. [Participants #4, Communication Engineering and Artificial Intelligence]

Technology / Device Challenges

Data Privacy

The issue of data privacy is intricate and delicate, particularly in relation to the acquisition of user data through diverse technological means. Privacy considerations are important in utilising wearable

sensor bracelets for public health surveillance during events like Hajj. This is primarily due to the acquired data's sensitive nature and the wide range of users participating in these activities. When individuals collect data pertaining to their health and movements, it is natural for them to express concerns regarding the entities that possess access to this data and the potential applications it may be subjected to.

The utilisation of wearable devices in large-scale gatherings such as the Hajj pilgrimage encompasses individuals hailing from diverse nations and cultural contexts. The issue at hand is further complicated by the existence of a wide range of attitudes, conventions, and expectations pertaining to data privacy. The acceptability of data usage may vary across various cultures. This necessitates a meticulous examination of cultural sensitivity and the necessity for tailored data protection strategies.

Well, the issue of wearables usually and all digital solutions are human rights. [Participants #2, Healthcare Provider & Public Health Specialist]

Especially with, you know, the point of data privacy, collecting beneficiaries' personal data and using it illegally. It is a highly sensitive topic, especially internationally.

In addition, one of the reasons that prevented us from activating the tracking for all beneficiaries despite its great benefits in the services we provide them with, which is more than these primary health data, is that we cannot penetrate the privacy agreement. Then we get into how we collect data for goals other than providing services to beneficiaries. [Participants # 1, System Engineering, Business and Project Management]

Regarding data privacy, no data can be collected without an individual consent. Tracking location and gathering medical or health data as you know are considered private data which fall under the General Data Protection Regulation (GDPR). [Participants #4, Communication Engineering and Artificial Intelligence]

Trust in Technology

Participants have expressed certain reservations about the usefulness of wearable technology. One of the difficulties that participants expressed concerns about is the efficacy of wearable devices. The aforementioned element substantially enhances individuals' confidence in effectively deploying wearable sensor bracelets for disease detection during the Hajj pilgrimage. In alternative terms, Participants emphasised the necessity for these technologies to possess a high level of efficacy to foster a sense of assurance in their utilisation. The efficacy of wearable technology for health monitoring during the trip is crucial for its successful implementation.

There are lots of challenges. First, the technology part. How effective is it, how does it capture data, and is it durable? Is it accurate? [Participants #3, Healthcare Provider & Public Health Specialist]

I think we still can't say that the wearables are ready from the technological side. [Participants #3, Healthcare Provider & Public Health Specialist]

Current /Existing Infrastructure Capabilities

Despite the notable advancements in the network infrastructure built in the kingdom, participants have expressed concerns regarding the adequacy of connectivity strength necessary to effectively manage the vast number of devices used during Hajj and the amount of data transmitted.

What if we have 2 million devices in an area with weak connections? Do you think we can

manage it? Still early. [Participant #3, Healthcare Provider & Public Health Specialist]

Key Considerations in the Adoption of Wearable Sensor Bracelets for Disease Detection in Hajj

The motives of both consumers and providers significantly impact the successful integration of technology in any domain. In implementing wearable sensor bracelets during the Hajj pilgrimage, it is imperative to thoroughly examine and comprehend the motives of all stakeholders and users concerning their acceptance and adoption of this technology. Participants identified several factors that should be considered to encourage stakeholders.

Stakeholder Motivation

Meeting the Needs: Integrating Pilgrims' Health Record for Improved Data Accessibility and Enhanced Data Availability

Stakeholders are primarily driven to integrate technology into their strategic plan when it caters to their distinct requirements and eliminates the obstacles they have experienced. Furthermore, stakeholders tend to adopt a technology when it effectively mitigates current challenges and when the characteristics and capabilities of the device correspond to their specific needs. The motivation behind this behaviour arises from a comprehensive comprehension of how the technology may optimise their activities and contribute to their overarching goals.

The availability of health data, especially with the heterogeneity of languages of pilgrims attending Hajj, is of tremendous value to healthcare professionals, as it helps them to determine the individual requirements of participants (Hajj attendees) and make required preparations. Implementing a consolidated health data system would significantly streamline the identification and understanding of the medical background and requirements of individuals, regardless of the healthcare facilities they visit within the holy sites and Makkah hospitals. Integrating systems would facilitate uninterrupted access to participants' records and optimise the delivery of critical healthcare services.

MoH needs to have a complete EHR for the pilgrim, they would prefer to have reliable and accurate health data, so data availability. [Participants # 4, Communication Engineering and Artificial Intelligence]

Today, I need basic information. Wearables for public health is different from normal bracelet. For the normal bracelet, I need major clinical data. For example, I need to know in advance the conditions that the patient (pilgrim) has, such as if he has kidney failure, if she is pregnant and so on, so I get ready to serve them. I do not want to be surprised; I want to be ready.

The worst thing in healthcare is that you get surprised by cases and different conditions. I do not want to be surprised by the conditions within this crowd during Hajj. I want to know the patient's condition in advance; if it is kidney failure or cardiac failure, I want to know his/her story without being surprised. We have a huge challenge during Hajj, which is the language barrier. We have pilgrims from different countries with more than 200 languages. We do not speak their language, and vice versa. To us, the barcode in the bracelet is a crucial step. [participants #2, Healthcare Provider & Public Health Specialist]

Today, we register data as we receive it. [participants # 2, Healthcare Provider & Public

Health Specialist]

Trust in Device Capabilities and Features

From the perspective of healthcare services providers, participants emphasised the key features that must be incorporated into wearable sensor bracelets in order to instil faith and reliance in these devices, hence minimising the necessity for additional evaluation. The accuracy of the data collected by these devices is a crucial factor. Although healthcare providers may choose to perform supplementary evaluations such as laboratory tests, it is imperative that the wearable device delivers data of utmost precision. The significance of accuracy cannot be overstated, as it guarantees the reliability of the acquired information and establishes a robust basis for further evaluations. Data accuracy plays a crucial role in enhancing the overall value and credibility of the device for healthcare practitioners.

If you look at Apple Fit watch or any other Fitbit watch, the heart rate increases if a person makes any physical effort. Sometimes even if you are sitting, your heart rate could be irregular. [Participants # 1, System Engineering, Business and Project Management]

In addition to recognising the significance of trust and the attributes of the wearable sensor bracelet, participants underscored their preference for specific aspects in wearable technologies. A further motive emphasised by the study participants pertained to a particular attribute of the device, namely its capacity to both transmit and receive data. Participants emphasised the significance of bidirectional data connection, as it enables service providers to gather data from the wearables and monitor the bracelets themselves. This attribute was perceived as highly advantageous in terms of facilitating efficient surveillance and guaranteeing the integrity of the sensor bracelets, hence preventing any unauthorised tampering or substitution.

I am not a technology person, but I imagine that if we are using such bracelet, I would prefer that it send me data, and I could pull data from it as well. So, push and pull material for data. In addition, the activation and deactivation are central. The user shouldn't be able to activate or deactivate something. I need to know that someone has cut it, removed it, given to someone else or exchanged, so I can track people. [Participants # 2, Healthcare Provider & Public Health Specialist]

Cost Reduction Through Private Sponsorship

Considering the cost of the bracelet is of utmost importance, as participants have emphasised the need to minimise the financial load on Hajj authorities. The consensus among participants was that developing or deploying such a device within the context of the Hajj must strike a delicate equilibrium between cost-effectiveness and the essential functionalities it provides.

We need to think about another point is that when we guide people working on inventing the new devices they should think about the cost and invent a cheap device. [Participants # 3 , Healthcare Provider & Public Health Specialist]

The significance of private sector engagement in overseeing the management of devices and data flow was underscored by the participants, who recognised that this would entail expenses. However, they also acknowledged that such involvement would be advantageous for the device vendor and contribute to the project's long-term viability.

We need a private sector to manage it and manage the data flow, and all of this has its price, which will go to the vendor. You need to manage the whole circle to add cash flow for the people working on the device, and for them to proceed not recede. [Participants # 2, Healthcare Provider & Public Health Specialist]

Honestly, the operation model for this whole business should be provided by the private sector, not the government. [Participants # 1, System Engineering, Business and Project Management]

Interest of Entities Involved

A significant aspect highlighted by participants was the identification of the interests of the entities involved in the project and assessing the value derived from integrating the technology into their roadmap development. Among the many organisations participating in the Hajj season, such as the Ministry of Health (MoH), Ministry of Hajj and Umrah (MoH&U), Ministry of Interior (MoI), and others, a number of duties and responsibilities were highlighted.

In the Ministry of Hajj, we talk about services and the system of services that we work in. For example, the Ministry of Interior has an eye on the data because they share the organising part with us and allow entry and exit. Primarily, most data that deals with the technologies are placed in the information centre of Hajj and Umrah as part of the Ministry of Hajj. [Participants # 1 , System Engineering, Business and Project Management]

The Ministry of Hajj, which provides services, does not need to focus on the health side in the first place. If you talk to the Ministry of Health, their answer will be completely different. Health is important to them in terms of disease transmission and other similar things. [Participants # 1 , System Engineering, Business and Project Management]

The obligation to facilitate and ensure a seamless pilgrimage is vested in the Ministry of Hajj and Umrah (MoH&U), whereas the Ministry of Health (MoH) is tasked with providing healthcare services. It is crucial to ensure that while utilising a device, it adequately caters to the distinct needs of each collaborating entity. By adopting this methodology, a thorough evaluation can be obtained regarding the precise advantages that each institution will obtain, as well as how the device will impact the internal operations of each organisation.

The Ministry of Hajj & Umrah focuses on the quality of services, which is why we focus on measuring satisfaction with crowd management, movements, and safety. We do not focus on diseases and infectious diseases because it is different from the scope of work we are looking for. We are not wasting our effort and time on technologies of that interest. It is not our specialist as a ministry, but the Ministry of Health are working on this file. [Participants # 1 , System Engineering, Business and Project Management]

The interest of the MoH&U is not health issues. Thay are more concerned with lost pilgrims, crowed management, scheduling movements, bookings to enter the holy mosque or a holy site, being notified of which group accessed this location or the other, access control to campaigns (tents) to limit unauthorized access. [Participants # 4 , Communication Engineering and Artificial Intelligence *]*

User Motivation

Promoting the Device for Pilgrim Safety

The significance of encouraging pilgrims to adopt wearable sensor bracelets actively is emphasised by the participants. They stress the importance of communicating a message that revolves around the person's interest in and reasons for utilising the technology, especially in light of their safety. It is widely agreed upon that presenting the utilisation of wearables during Hajj as a matter of personal preference, closely linked to the individual's welfare, enhances the probability of acceptance among pilgrims. The participants express reservations about adopting methods that could be interpreted as invasive or limiting, emphasising the importance of presenting wearables as instruments for individual safety and autonomy.

I think you can work it out with the Ministry of Hajj and the Hajj missions by agreeing that the wearable's objective is user health and user safety. They should propose it from the health and safety aspect, so people accept wearing it. [Participants # 2, Healthcare Provider & Public Health Specialist]

Nowadays, Smartwatches are available everywhere, with about 500 types. A person can download any health-tracking apps that give an alert; when the alert is given, the person will have the option to call the hospital or the group leader. So, if the person is interested, he/she can activate the service itself without us doing this tracking. [Participant # 1, System Engineering, Business and Project Management]

Recommendations for Wearable Sensor Bracelets for Disease Detection in Hajj

Interviewees underlined and provided valuable insights into many prerequisites that must be considered to successfully and efficiently implement wearable sensor bracelets for disease detection in Hajj.

Comprehensive Infrastructure

The importance of establishing a resilient and all-encompassing infrastructure to effectively handle the large number of devices deployed in the vicinity of the holy sites of Makkah and to enable seamless data transmission was emphasised as a crucial component. Moreover, the emphasis was placed on the many components and characteristics of the devices that could efficiently carry out the functions of disease detection and tracking throughout the hard period of the Hajj, taking into account the large number of participants.

An important variable in the success of smart cities is first the infrastructure. [Participants # 4 , Communication Engineering and Artificial Intelligence *]*

If you collected that huge amount of data, you would also need a strong infrastructure and security. Can you innovate something and, at the same time, have strong cybersecurity? I do not know; I will leave this to technical people. [Participants # 3 , Healthcare Provider & Public Health Specialist]

Device Characteristics and Features

Strength, Type of Connectivity, and Availability of Free Network Coverage

The current state of connection in holy places was underscored as being in its nascent phase,

notwithstanding the progress made in 4G and 5G technologies and the deployment of Internet of Things (IoT) infrastructure. The current connectivity infrastructure faces challenges in effectively supporting the substantial volume of users, namely the pilgrims in the region. The significance of connectivity was underscored as a pivotal element for effectively integrating wearable devices. This particular component contributes to the comprehensive cost considerations, encompassing both the individual cost of wearables and the essential infrastructure required for uninterrupted connectivity.

In previous years, the infrastructure of internet connectivity for 4G and 5G improved remarkably, I do not think any place in the world has this strong network infrastructure. [Participant # 4 , Communication Engineering and Artificial Intelligence]

However, the internet is not free. Also, the connectivity would be very low in holy sites such as Arafat and Mina due to the huge number of pilgrims presents simultaneously in that area. No network can accommodate this huge number of people in one place unless it is a Wi-Fi that is linked in a way either through Fibre that can cover certain places and serve a certain number of users. [Participants # 4 , Communication Engineering and Artificial Intelligence]

Connectivity needs to be strong around all holy sites and areas. Not all areas were 100% covered, some were covered under a certain company, and others were served under another coverage company. In addition, the large number of people in a certain area using that network could weaken the connectivity. [Participants # 4 , Communication Engineering and Artificial Intelligence]

A cost-effective communication infrastructure was suggested as a means to facilitate data transmission for devices and guarantee equitable service for the substantial number of pilgrims. The proposal entails offering complimentary access to this form of connectivity while considering the economic strain on both the organisers and the users. This strategy aims to facilitate the smooth functioning of wearable devices, improve the efficiency of data transmission, and contribute to the overall achievement of the initiative, specifically in the setting of a significant event such as Hajj.

There is the cost of the device itself and the cost of communication. What I mean by communication is your network package or availability of Wi-Fi services. [Participants # 4 , Communication Engineering and Artificial Intelligence]

Free Wi-Fi services need to be available for the technology to be implemented. [Participants # 4 , Communication Engineering and Artificial Intelligence]

Flexibility and Independency of Device Connectivity

Emphasising the necessity for data transmission autonomy, it was critical that wearable sensor bracelets possess the capability to transmit data autonomously without dependence on an intermediary device like a mobile phone. Autonomy is attained by the use of different forms of connectivity, such as Ultra-Wide Band (UWB).

We usually recommend that when using a smart watch not to connect it to a mobile phone, rather to a sim card or to any type of connectivity such as the UWB where data can be sent whenever it gets signal form a sensor, a device, or any connectivity. [Participants # 4 , Communication Engineering and Artificial Intelligence]

Accuracy and Length of Communication Range

The conversation covered a range of Internet of Things (IoT) connections and technologies, providing insights into their unique benefits. Emerging technologies such as LoRa Network and Ultra-wide Band (UWB) have been introduced, each offering distinct advantages. The affordability of Ultra-Wideband (UWB), available at a price below 10 Saudi riyals, renders it a noteworthy factor to be taken into account in the context of network connectivity. Furthermore, the strong reliability of

Bluetooth was highlighted, specifically in the context of short-range communication. Nevertheless, it has been recognised that Bluetooth possesses certain restrictions, necessitating specific intervals for optimal functionality when operating over particular distances. On the other hand, Ultra-Wideband (UWB) technology was emphasised due to its considerable range of up to 1000 metres, which can potentially decrease the requirement for a large number of sensors. The presented overview offers valuable insights into the varied landscape of Internet of Things (IoT) connections and their corresponding strengths.

There are new technologies called LoRa Network. In IoT's we use Ultra-wide Band (UWB) which is similar to what Apple tag is where it can connect to any sensor, and it cost less about few Saudi riyals, less than 10 riyals. That is if we needed to connect it to a network. [Participants # 4 , Communication Engineering and Artificial Intelligence*]*

The advantage of Bluetooth is the strong accuracy. However, one of the limitations is that every 50-100 m you need an interval. [Participants # 4 , Communication Engineering and Artificial Intelligence]

The UWB you can reach up to 1000 m, so less sensors. [Participants # 4 , Communication Engineering and Artificial Intelligence]

Device Features:

Apart from the various characteristics of the wearable sensor bracelet that were previously discussed, with a focus on accuracy and efficiency in wearable devices for disease detection during the Hajj, technologists emphasised the importance of battery life as a critical factor to be taken into account. The importance of selecting an appropriate connectivity option
that aligns with the specific circumstances was underscored, as it helps to reduce excessive battery usage and enables consistent and efficient utilisation of these devices within the challenging pilgrimage setting. This proposal aims to promote the efficient and long-term utilisation of these devices within the challenging setting of disease diagnosis during the pilgrimage.

Battery life as I mentioned is a factor you need to consider. How many days would you like the bracelet to last for. Nowadays companies manufacture devices based on your need, do you want it to last a day more, a week or what. [Participants # 4 , Technologist]

The most thing that influence the battery life is the network, the Wi-fi, 4G, 5G, they all consume. It is important that the technology that is used for such purpose doesn't consume a lot of battery. [Participants # 4 , Communication Engineering and Artificial Intelligence]

Business Model

Use Case

Identifying the right and appropriate use case for the technology was highlighted based on user interest, needs, and cost to facilitate the successful integration of new technology into the Hajj system.

We need to know the appropriate and right use cases for technology usage and implementation. It needs to be clear. [Participants # 4 , Communication Engineering and Artificial Intelligence]

People do not refuse to use or wear plastic wearables like Disney Land's one. But any wearable with a sim or ship people will refuse it. I think you need to make sure if you want to innovate something that, it does not contain a sim or ship because this is the type of zone were people refuse it. [Participants # 2 , Healthcare Provider & Public Health Specialist*]*

Participants emphasised the significance of rendering the use of wearables a personal decision, striking a balance between the device's advantages and the costs involved. The rental model, individual activation, and targeted distribution were identified as crucial elements in attaining a more customised and economically efficient strategy for deploying wearables during the Hajj pilgrimage.

A person could personally benefit from this wearable if he/she feels they have a critical condition and needs this service; it can be requested as a special request. Anyone can activate it by connecting the watch with contact numbers in an emergency. The government does not need to provide this service, especially since the watch cost is very high. We are talking about (1000 Saudi Riyal) (£225) for one watch. Honestly, the value for the cost was not achieved in the project. [Participants # 1, System Engineering, Business and Project Management*]*

Personal Choice and Rental Model

Participants highlighted the importance of offering pilgrims the option to utilise wearable sensor bracelets for additional services or in accordance with their individual health conditions, as opposed to imposing a mandatory requirement. This is consistent with the notion of a rental model, which participants regarded as a favourable solution. The concept entails pilgrims engaging in the temporary acquisition of the device, followed by its subsequent return, with the potential for reutilising the device itself by altering the strap.

Let's think about it, if you go to any mass gathering such as a sport gathering around the world like Olympics, you only want to pay for the plan tickets and accommodation. You do not want to add extra charges and do not want to be forced to pay for the extra charge for any tool or device that is going to be used unless you need it if you have a health issue for example. So, it needs to be a personal choice. [Participants # 4 , Communication Engineering and Artificial Intelligence]

We talked previously that for a best solution for these devices is to apply a rental model. [Participants # 4 , Communication Engineering and Artificial Intelligence]

One of the solutions is to be rented by pilgrims and then returned. You can make use of the device itself again but change the strap. [Participants # 4 , Communication Engineering and Artificial Intelligence*]*

Individual Activation

In addition to the proposed rental model, participants suggested that pilgrims should be allowed to directly activate and establish connectivity between the wearable device and the accompanying/ existing application (NUSUK). This would afford consumers increased agency in managing the device's functionality, rendering it an optional selection for individuals who perceive utility in its offerings.

In my opinion, if this idea is going to be run again, it should be a personal choice for individuals who wants to buy the watch, activate it, and connect it to the app. [Participants # 1, System Engineering, Business and Project Management*]*

Privatisation and Vendor Involvement

Given the prevailing inclination towards privatisation in the kingdom, the participants underscored the significance of a private vendor's involvement in providing wearable gadgets. This technique involves an individual with innovative capabilities who develops the device, an information technology (IT) company responsible for marketing and selling the device to the Ministry of Hajj, and a vendor who receives a portion of the generated profit. This paradigm aims to facilitate the

effective development, acquisition, and provision of device.

The approach of the kingdom right now is to be privatised. [Participants # 2, Healthcare Provider & Public Health Specialist]

There should be a private vendor that provides these devices, having a portion of the benefit share from the cost. So, an innovator will innovate the device, an IT company will sell it to the Ministry of Hajj, and when they buy it there will be profit for the vendor. [Participants # 2, Healthcare Provider & Public Health Specialist]

A participant conveyed the company's inclination to support the project in the capacity of a community service initiative. The concept entails engaging in collaborative efforts with other entities and commencing the distribution of a specific quantity of bracelets as a preliminary initiative in the initial phases of the project.

Our company could sponsor the project and contribute as a community service by collaborating with other entities and start providing a number of bracelets as a pilot project. [Participants #4, Communication Engineering and Artificial Intelligence]

Targeted Distribution and Special Request

According to accessible health data or statistical morbidity information, participants suggested a targeted distribution plan that would provide wearables to people who are at risk. This proposed system adopts a rental model wherein users have the ability to submit specific requests for device activation. This mechanism ensures that the device is distributed to individuals who genuinely require it.

Thinking about the bracelet, I believe it should be given to pilgrims, either 100 or 1000, not everyone, but people at risk based on data you have or statistics on morbidity, and it should follow a rental model. [Participant #4, Communication Engineering and Artificial Intelligence]

The interested authority provides the services and you as a pilgrim subscribe to that service based on your need. For example, subscribe to this service and we will provide you with health insurance or, x, or y. [Participant #4, Communication Engineering and Artificial Intelligence]

Effective Staff Training for wearable Implementation and Distribution

Staff training has been identified as a crucial component for successfully implementing wearables. The tasks encompassed managing a substantial volume of data and guaranteeing precise allocation of the wearable devices. The Hajj event yields a substantial amount of data, necessitating the provision of sufficient training to staff personnel in order to handle, analyse, and understand this information effectively.

Another thing we need to think about. When I receive a large amount of data, and I am not ready for it, how can I deal with it? Last Hajj, we suddenly received a large amount of data from other departments it was very detailed /360, and we had no idea how to deal with them. We didn't expect it. [Participants #3 , Healthcare Provider & Public Health Specialist]

Another issue we need to consider is how we will guarantee the distribution of the device. You know the food itself; we have an issue with it with the campaigns.

Think about this scenario. I am receiving pilgrims from various countries, and I have the bracelet to give to the campaign manager or staff that were not trained enough to match the bracelet with the right person. I can't guarantee this; most likely, there will be a mix-up. [Participants

#3 , Healthcare Provider & Public Health Specialist]

The Need for Organic System Harmony

Participants highlighted the significance of achieving a smooth and natural incorporation of wearable devices into the system in order to facilitate prospective expansion. This sentiment agrees with the perspective expressed by a participant who emphasised the importance of adopting an organic approach and considering integration as a complete system. The importance of careful deliberation was emphasised by the participant, emphasising the need for alignment between decision-makers and persons who wear the bracelets. The primary focus lies in establishing a cohesive, interrelated framework that promotes user-friendly functionality, comprehension, and expansion.

These things need to be organic; it is a system. We need to think about the person taking the decision, the person wearing the bracelet. Everything need to be harmonised and work together. We *all need to know how to deal with it and there need to be built on organic growth. [Participants #3 , Healthcare Provider & Public Health Specialist]*

Opportunities and Advantages of Wearable Sensor Bracelets in Hajj.

Multidisciplinary Features and Distinctiveness Among Other Digital Tools with AI Integration

Participants provided insights into the possible benefits of incorporating wearables, highlighting the numerous opportunities that arise from the varied range of features offered by these devices. They emphasised the potential for transformation that is enabled by improvements in artificial intelligence (AI) capabilities, which play a vital role in developing and improving these devices. The perspectives shared by the participants shed light on a favourable perspective about the distinctive attributes of wearable devices and the potential synergies they offer with modern artificial intelligence technologies. These observations indicate a wide range of opportunities for further advancements in this field.

Yes, a Wearable sensor bracelet is a good device. Can we use it? The answer is yes. AI will take a very huge platform in public health. [Participants # 2 , Healthcare Provider & Public Health Specialist]

I believe AI will drive PH to the future. [Participants # 2 , Healthcare Provider & Public Health Specialist*]*

Participants underscored the unique features of wearable sensing devices compared to other gadgets, such as mobile phones. The authors emphasised that wearable devices can assess a wider array of physiological indicators in contrast to mobile devices. The distinctive capacity of wearable sensors makes them valuable instruments for gathering a complete array of health-related data, surpassing typical mobile devices' capabilities.

So, both devices; smart watches and mobile phone can use Bluetooth to track and trace infected individuals and people who have been in contact with. However, Smart watches have an advance of measuring vital signs. [Participants # 4 , Communication Engineering and Artificial Intelligence]

Gradual Integration of Wearables in Hajj

Participants emphasised the importance of gradually integrating wearable devices as public health tools for effective implementation into the Hajj system.

of course. Wearables started to get large space in healthcare. Yes, we can use wearables, but I wouldn't use them for public health at first. It could start with healthcare tackers, so I use the wearable, which can give signals to the healthcare tacker first. Each group of pilgrims have their own identifier (healthcare tacker) or medical mission, so it gives a warning to the medical mission, which gives him a summary of number of cases for example 4 cases have X without a diagnosis just based on the wearable. Then, as a PH department, I get notified and decide what actions need to be taken, such as checking A, B, & C to ensure it is X or Y. [Participants # 2, Healthcare Provider & Public Health Specialist]

Discussion

Principal Findings

In this study, we explored participant perceptions and experiences of using wearable sensor bracelets during the Hajj pilgrimage. The primary objective was to investigate the potential advantages and obstacles associated with wearables monitoring pilgrims' well-being and detecting diseases. The main findings and themes that emerged from the interviews will be analysed and summarised to provide insights into opportunities and challenges involved in incorporating wearable technology (sensor bracelets) into Mass Gatherings, including the Hajj pilgrimage.

Wearable sensor bracelets have the capability to monitor the health of pilgrims and detect emerging infectious diseases during the Hajj pilgrimage. However, achieving these capacities depends on properly tackling existing problems and meticulously evaluating multiple elements.

The diverse range of valuable information obtained from interviews with participants reveals a variety of obstacles that hinder the seamless use of wearable sensor bracelets for detecting infectious diseases during the Hajj pilgrimage. However, in the midst of these difficulties, a variety of factors for achieving successful implementation become apparent, uncovering hidden possibilities that these devices possess. Charting a path for future deployments in the dynamic landscape of mass gatherings like Hajj, we will unravel the multifaceted nature of these challenges, explore the promising vistas these wearables offer, and present recommendations highlighted by our interviewees' insightful perspectives as we navigate the discussion.

Challenges:

Numerous challenges associated with implementing wearable sensor bracelets during Hajj were highlighted. The primary obstacle underlined was the anticipated opposition to technology, which may potentially emerge from providers and users of wearable devices. Participants observed that trust in technology, data privacy, information security, and human rights concerns could influence this reluctance.

The opposition of providers is affected by both the operational and financial challenges associated with implementing wearable technology into the Hajj system. Although data is an essential element in detecting diseases, staff training in data collection and analysis is required to handle the

anticipated volume of data produced by the device. Participants voiced reservations about the limited and inaccurate pre-Hajj data on pilgrims' health. Furthermore, there is concern that despite the dedicated efforts put into the implementation, the results may not correspond with the anticipated or intended value.

The issue of financial burden is not limited to providers alone; it affects pilgrims as well. Due to the financial obligations pilgrims encounter during their Hajj journey [29], the cost could provide a barrier if the services were to be included in their Hajj packages. The cost-related reluctance may affect users' willingness to utilise the device during their Hajj pilgrimage. The utilisation of tracking and tracing methods to monitor pilgrims throughout their journey may impede their compliance and reception due to variations in their backgrounds, beliefs, ages, approaches to conducting Hajj rituals, level of trust in technology, and literacy levels [3,30].

The challenges brought up by stakeholders are consistent with those identified by [3], especially regarding the end users in our research, who are pilgrims. The stakeholders' worries about potential hurdles from users align with the findings of [3] , suggesting that user resistance may stem from factors such as privacy concerns, lack of motivation, and technological fear.

The viewpoints conveyed by stakeholders and the difficulties they mentioned pertain to service providers and users and align with the concept of effort expectancy in the UTAUT Model. This connection is particularly visible in the financial and operational efforts required to integrate wearables in Hajj.

Data privacy is paramount while collecting user data using wearable devices in any domain. Collecting real-time data is essential for public health surveillance to diagnose infectious diseases promptly and implement appropriate interventions. Gathering sensitive data poses difficulties, especially when considering human rights and data privacy agreements. The use of wearable public health devices, particularly in mass gatherings, may be limited due to considerable challenges arising from privacy considerations.

The issue of data privacy, which is of utmost importance for wearable devices in the context of mass gatherings, is intricately linked to the difficulty of amassing data with user consent. Participants highlighted that addressing privacy concerns and securing user consent presented substantial obstacles, impeding the success of the previous smart bracelet initiative. Meraj et al., 2021 [6] who discussed information privacy, data sharing, and autonomy, brought attention to this layer of complication brought about by using wearables in healthcare.

The stakeholders' willingness to adopt wearable sensor bracelets for disease detection and tracking during Hajj is strongly linked to the idea of Performance Expectancy in the UTAUT Model. The stakeholders' trust in the technology is greatly impacted by the device's performance and its capacity to meet fundamental functions. This is consistent with the concept of Performance Expectancy, which highlights the perceived utility of the technology. Furthermore, assessing the device's utility, including factors like dependability, precision, and compatibility, highlights the significance of Technology Characteristics in the TTF model. These functionalities play a vital role in shaping stakeholders' perceptions and adoption of the technology within the specific context of Hajj.

Considerations promoting acceptance and adoption.

Overcoming current obstacles that hinder the adoption and use of wearable sensor bracelets during Hajj is vital. Participants have emphasised important aspects that play a significant role in promoting the success of the implementation.

Interviews demonstrated that stakeholder‘s believe that user motivation is crucial in shaping their acceptance of the device. The interviews covered several aspects that contribute to promoting acceptance. Improving data availability to enhance accessibility is a primary driver for addressing stakeholders' needs. Furthermore, taking into account the interests of the parties involved in managing Hajj ensures the incorporation of technology into their plans for future development, in line with their particular requirements and strategies.

The wearable's functionality and capacity to collect accurate, dependable, and real-time data were given thoughtful consideration, addressing issues brought up in the literature on the difficulty of guaranteeing wearable accuracy [9,28,31]. Increasing stakeholder trust in technology becomes increasingly challenging when it comes to the known challenges of ensuring wearable accuracy. The need to ensure essential device functions was stressed by participants as a means of promoting wearable trust and dependence. These qualities are essential for overcoming wearable accuracy difficulties, building stakeholder trust, and influencing their choice to use technology for disease detection and Hajj surveillance.

The emphasis on accuracy and different device characteristics are consistent with the concept of performance expectancy in UTAUT. Stakeholders emphasise the necessity for features that qualify the device for successful disease diagnosis and see performance as critical to the technology. In addition to being in line with performance expectations, addressing issues with accuracy and key features is crucial for shaping stakeholders' opinions of the technology.

There was a unanimous consensus on the necessity of incorporating private sponsorship as a business model for providing the device. By leveraging public-private partnerships, [20] propose resolving the obstacles linked to smartification and digitalisation in urban services financing. As suggested by stakeholders, this strategy reduces the financial and operational burden on Hajj stakeholders related to implementing and controlling wearable devices for disease diagnosis and tracking. The fact of private sponsorship coincides with the UTAUT's facilitating condition construct, offering a favourable setting and support for the effective integration of wearable technology during the Hajj.

During the interviews, participants emphasised safety as a crucial factor that significantly affects the acceptance, adherence, adoption, and utilisation of wearable sensor bracelets by pilgrims. Having sufficient user motivation and willingness to acquire and utilise the wearable device is essential for acceptance [32]. Although Saudi Arabia has made significant efforts to guarantee the safety of pilgrims and control crowds in order to minimise the occurrence of stampedes and the spread of diseases, the difficulty continues to remain [33].

It is widely agreed that presenting the usage of wearables during Hajj as a personal choice strongly linked to individual well-being greatly increases the chances of pilgrims accepting it. This is

consistent with the participants' emphasis on the significance of selecting the appropriate business model for implementing such devices. Participants also voiced apprehensions over techniques that can be interpreted as intrusive or constraining, emphasising the significance of portraying wearables as instruments for personal safety and independence.

Recommendations

To tackle this difficulty, it is necessary to adopt the method advocated by [3], which involves actively integrating (users) in the design process of the technology or intervention. By involving users in this way, there is a possibility of increasing acceptance and adoption rates.

The successful integration of wearables into the Hajj system depends on certain factors, as suggested by participants. Although there have been notable advancements in the network infrastructure in Saudi Arabia, the integration of wearables during Hajj is still in its nascent phase. Reports have shown inadequate Wi-Fi and internet coverage in the heavily populated regions of Makkah city, as [20] pointed out.

Participants emphasised the importance of implementing wearables for public health surveillance in a gradual and systematic manner. The primary emphasis is on integrating them into the healthcare system, commencing with healthcare trackers. Within this methodology, wearables function as indicators to the healthcare trackers, with each wearable assigned to particular cohorts of pilgrims. For example, a wearable device might notify the healthcare tracker linked to a medical mission, offering a concise overview of prospective situations. Subsequently, the information is elevated to the Public Health (PH) department for additional assessment and determination. The participants' description highlights the significance of initially incorporating wearables within organisational structures before expanding their utilisation to individuals for wider public health monitoring.

The gradual integration focuses on and enables smooth integration by initially guaranteeing the compatibility of the technology with the surveillance system used during Hajj. Compatibility is a vital element inside the Task-Technology Fit Model (TTF) that describes the features of technology.

Participants with technology experience provided valuable comments that highlighted the need to address data availability difficulties faced by Hajj stakeholders. They emphasised the importance of establishing a strong, accurate health data system to resolve these challenges. The proposed solution entails utilising blockchain technology to establish customised Electronic Health Records (EHR) specifically designed for pilgrims. This approach is in keeping with the recommendations presented in [3] research, emphasising the capacity of blockchain technology to tackle issues concerning the secure and decentralised storage and transmission of digital data in healthcare infrastructure.

Participants with backgrounds and expertise in technology implementation and devices underscored the critical components and characteristics of the device necessary for the effective collection and analysis of surveillance data. A robust Internet of Things (IoT) infrastructure emerged as a crucial element in successfully deploying the device. The type of network connectivity and its strength were highlighted as key considerations, emphasising the capacity to handle the volume of users and data transmission, coupled with the availability of free connectivity for all pilgrims.

Moreover, participants recommended using communication range types, such as Ultra-Wideband (UWB), which was deemed beneficial for connecting to sensors while incurring minimal costs and providing enhanced data transmission autonomy. As advised by participants, this strategic choice of connectivity and infrastructure addresses financial concerns by ensuring reliability and cost-effectiveness in implementing the technology.

Technologists and literature underline the use of low-energy Bluetooth as an effective communication channel for IoT connectivity, especially in healthcare applications. This form of communication is characterised by its low energy usage, which has been identified as a critical factor in both interviews and literature [31]. Addressing concerns related to energy consumption is crucial for guaranteeing the efficient collection and transmission of data in wearable devices.

Participants put forth a distinctive suggestion concerning carefully considering and selecting a suitable use case to ensure the seamless integration and utilisation of wearable sensors during the Hajj ritual. Bati et al., 2023 [34] states that smartwatch applications and use cases differ in many fields, offering various services and functions. The wide range of differences among pilgrims during Hajj and Umrah offers a chance to create applications that can improve their overall experience. A novel proposal entails implementing a rental system for individuals who wish to use such devices during their Hajj pilgrimage, either for overall well-being or for specific health concerns.

Opportunities

Implementing wearable sensor bracelets for infectious disease detection during Hajj comes with difficulty, yet the opportunities for this technology's use are considerable.

The utilisation of AI advances greatly enhances the potential of wearables in public health surveillance, representing a promising advancement. Wearable devices, which include communication modules and networking capabilities, possess modern hardware technologies. These devices can supply vital data that power artificial intelligence (AI) procedures [35]. This technological advancement facilitates the uninterrupted transmission of up-to-date information without requiring direct engagement from healthcare staff, thereby establishing wearables as a potent and non-intrusive instrument for augmenting public health surveillance.

The capacity of wearable sensor bracelets to evaluate a wider range of physiological indications gives them a clear edge over other technologies, such as mobile devices. Their ability to adapt and be used in various ways makes them very valuable in the healthcare industry.

Wearable sensor bracelets greatly enhance public health surveillance during the Hajj by carrying out functions like disease identification, health monitoring, tracking, and tracing. They stand out from other devices because of their unique characteristics, which provide real-time health tracking, detection, and monitoring. This helps with the efficient administration of public health during the Hajj. This is consistent with the broader idea of Technology-Task Fit, in which wearables are customised to carry out certain duties and operations that are essential for effective public health management in the special circumstances of the Hajj.

The degree to which wearable sensor bracelets can fulfil the unique requirements of Hajj

stakeholders is one of the key elements determining the desire to use them for disease detection during the Hajj. The connection emphasises the importance of performance expectancy as a critical element in (UTAUT), which affects Providers' desire to embrace the technology. Furthermore, achieving successful implementation relies on facilitating conditions, underscoring the need for a supporting environment for efficient adoption.

Furthermore, the Technology Characteristics component, as defined by the Task-Technology Fit (TTF) model, has a crucial influence on the intention to utilise. The characteristics and qualities of the technology have a substantial influence on providers' inclination to embrace it. The relationship between UTAUT and TTF highlights how users' intention to adopt and use wearable sensor bracelets for disease detection during Hajj is influenced by their perception of the technology's performance, facilitating conditions, and technological characteristics.

Strengths, Limitations and Future Work

Strengths

This study is the first to address the opportunities and limitations of wearable sensor bracelets for Hajj. It provides a thorough understanding of these issues from the perspectives of key stakeholders. The thoroughness of investigation provides useful insights into the complex dynamics surrounding the implementation of these devices.

Moreover, the combined use of the UTAUT and TTF models proved advantageous in comprehending stakeholder viewpoints comprehensively. This method enabled a thorough investigation of the possible uses of wearable devices for detecting diseases, specifically during the Hajj pilgrimage.

Limitations

One potential limitation is requiring a more diverse range of stakeholders from different disciplines to be included in the interviews. Broadening the pool of respondents would enhance our understanding of the system and the interconnectedness between its components.

In addition, a possible drawback arises from the sole involvement of a single researcher in the coding and analytic process. This limited worldview may lead to the potential for misjudging participants' perspectives. Adding numerous analysts or external assessments could have enhanced the coding process by incorporating varied perspectives and increasing its rigour. Considering the expansion of the analytical team in future studies may help limit any biases in interpreting participant replies.

Future Work

To optimise the efficient deployment of wearable sensor bracelets, further studies should prioritise acquiring perspectives from end users. Gaining insight into their perspectives and embracing their adoption of the device is essential for formulating tactics that align with user requirements and preferences. This would additionally enhance the successful integration and utilisation of wearable sensor technology in pertinent contexts.

Conclusion

The significant contribution of this work lies in its thorough investigation of crucial factors in implementing wearable sensor bracelets for the detection of infectious diseases during the Hajj event. This underscores the need to resolve crucial issues to guarantee the efficient implementation and use of wearable sensors in this specific case. The study highlights multiple problems pertaining to suppliers, users, and technology, which impose a cost on Hajj stakeholders. Significantly, the specific attributes and functionalities of technology play a vital role in building confidence among providers when it comes to using wearables during Hajj. The study highlights the importance of having the ability to access pre-Hajj health data for healthcare providers to gain a more comprehensive understanding of pilgrims' requirements. Although there have been some breakthroughs, it is crucial to further develop the current infrastructure to support wearables fully. Wearables stand out from other devices due to their exceptional capacity to gather vital signs, and their potential is further amplified by encouraging outcomes from AI algorithms. The study suggests choosing a suitable use case that is customised to meet the specific demands of the users in order to ensure a successful deployment. A crucial element of this implementation entails creating a complete infrastructure marked by a strong and reliable network capable of prompt data transfer and accommodating a large user population. Furthermore, the unique characteristics of the devices should be in line with cost-effective advantages to guarantee a sustainable implementation.

However, deploying wearable bracelets for detecting infectious diseases during Hajj may face difficulties. Therefore, it is important to conduct pilot tests and thorough evaluations to ensure their usefulness before implementing them on a large scale. This prudent approach recognises the intricacy of the Hajj environment and highlights the importance of conducting evidence-based evaluations to determine the feasibility and effectiveness of the wearable technology. Notwithstanding these difficulties, there is a pervasive conviction in the innate capacity of these wearable devices, cultivating optimism for their ultimate and widespread use in the context of Hajj.

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Conflict of Interest

None declared.

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Abbreviations

AI: artificial intelligence
COREQ: Consolidated criteria for reporting qualitative research

COVID-19: coronavirus disease
EHR: electronic health record
HRV: heart rate variability
IoT: Internet of Things
MoH: Ministry of Health
MoH&U: Ministry of Hajj and Umrah
MoI: Ministry of Interior
NUSUK: electronic platform for local and international pilgrims in Saudi Arabia
NVivo: software program for qualitative and mixed-methods research
UTAUT: Unified Theory of Acceptance and Use of Technology
SARS-COV-2: Sever acute respiratory syndrome coronavirus 2
TTF: Task-Technology Fit
WHO: World Health Organization