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Internet of Things Application in Controlling the Coronavirus Disease Spread in Hajj Season

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Abstract

Coronavirus Disease 2019 (COVID-19), caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is currently a threat to the global human population. Infectious viruses, such as SARS-CoV-2, are easily transmitted from person to person and spread very quickly. These viruses are likely to spread anywhere there are massive crowds in confined spaces—and the Hajj pilgrimage to Makkah, Saudi Arabia is no exception. This work aims to prevent the spread of infection in the early stages of an outbreak. This paper explores the various methods for monitoring and controlling infectious disease during the Hajj including strengthening disease control and methods for providing the Saudi Ministry of Health (MOH) insights to enable them to plan for the specific challenges of controlling Coronavirus disease during the Hajj. This paper proposes a model, based on the Radio Frequency Identification Devices (RFID), Global Positioning System (GPS), wearable watch technology, and cloud computing infrastructure, which detects and monitors infected pilgrims and also aids in the identification of those pilgrims exposed to sources of a virus.

Disciplinary: Information System, Technology, and Application, Healthcare Management.

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1 Introduction

Saudi Arabia houses the two most sacred religious places for Muslims: Makkah and Madinah. Muslims make the pilgrimage to these cities either at a fixed time (i.e. Hajj) or at any time (i.e. Umrah) in a calendar year. One of the most significant regular mass gatherings in the world is the Hajj pilgrimage [1]. Two to three million pilgrims from over 170 different countries and all inhabited continents travel to Saudi Arabia each year for the Hajj. They all spend two to four weeks physically moving amongst Holy places whilst in close contact with each other in and around the two holy cities of Makkah and Madinah. The large gatherings involved in the Hajj, or smaller Umrah pilgrimage, have long been associated with the risks of contagious diseases. This is due to pilgrims being in the same places and at the same time in close contact with each other. Actively assessing and addressing these risks is considered a major challenge for the Ministry of Health (MOH) [2]. One of the major concerns when managing such large numbers, especially at events drawing pilgrims from different nations, regions, and cultures, is the import and subsequent outbreak of infectious diseases, or the export thereof.

Saudi Arabia was one of the first countries to take exceptional steps to prevent SARS-CoV-2 [3] from entering the country and to lessen its effect if it did. Such preparations were taken before the country's first case was reported on 2 March 2020 [4]. Infectious disease forecast models are systems that use data about the current state and development of a contagious disease outbreak to forecast how it will progress in the future [5, 6]. The infectious disease outbreak control system has increasingly been developed to identify and control the spread of infections, but it still has its limits. To detect an infectious disease, there must be an outbreak, to begin with, and so preventing its spread requires real-time information and analytics. Acting quickly with reliance on accurate information can have a profound impact, saving lives and money. The MOH healthcare systems should depend on the early detection of such diseases rather than on delayed intervention and costly treatments. Recent developments in terms of Coronavirus and other previous outbreaks affecting movements globally have highlighted the importance of this aspect of pilgrim management [7]. To help address critical concerns at the Hajj, both Ministries of Health and Hajj in the Kingdom of Saudi Arabia adopted Artificial Intelligence (AI), Information Technology (IT), and Internet of Things (IoT) to collect sensory data in real-time [4-25]. It involves the tracking of pilgrims, health systems, and environments. Figure 1 shows the close contact between uninfected people in green, and the sources of the infections as a red person The people in blue represent those who were not in close contact.

Figure 1: An example of an infected pilgrim and those exposed

2 The Existing Methodology of Monitoring Infectious Disease during the Hajj

As the Kingdom of Saudi Arabia's primary healthcare provider, the MOH is regarded as the primary source of accurate and credible health records for the Saudi population. In 2011, the Saudi

MOH committed to employing electronic communication and IT to enhance the quality, fairness, accessibility, and quality of patient care in the Kingdom of Saudi Arabia. The health care strategy goals for the years 2018 to 2020 in the Vision 2030 National Transformation Program [8] were to enhance healthcare coverage, increase performance, and promote health risk prevention. It recognizes electronic health (e-Health) [9] as a critical enabler of health-care change, and charges the National Health Information Centre with developing multispectral, coherent e-Health services. The Saudi government and the private health care sector deployed existing digital healthcare solutions and created new ones during the above-mentioned community-wide steps to combat the spread of COVID-19.

The current outbreak monitoring system used by the MOH is highly effective at detecting outbreaks of infectious diseases in a timely manner and works to minimize threats to the safety and well-being of pilgrims even as far as their contacts after the Hajj Season. This system takes two approaches to tackle problems: administrative solutions and technical solutions. With the growing development of wearable systems as part of an Internet of Things (IoT), cloud computing and analytics provide approaches that may be a better alternative for predicting and controlling potential outbreaks, possibly before they even happen. IoT refers to the network system containing interconnected computing devices, including wearable objects, that can transfer data over a network without requiring human-to-human or human-to-computer interaction [10].

3 Administrative Solutions

Administrative solutions were installed at three locations: important points of entry into the country, health providers in Hajj zones, and Medical Missions [11]

a) **Key points of entry:** Public health monitoring teams are deployed at the Kingdom's Hajj entry points and are trained to detect and report public health threats and to monitor the compliance of arriving pilgrims with the health requirements for the Hajj

b) **Healthcare facilities:** Hospital-based surveillance teams comprised of hospital staff trained to rapidly detect and report, manually and electronically, cases of infectious diseases presented to them operate in each hospital within the Hajj areas. Suspected cases of infectious diseases are referred to pre-specified hospitals for confirmation of diagnosis, further management once identified at primary health centers and then the reports are notified.

c) **Medical Office for Monitoring Pilgrims:** The Hajj Medical Office for Pilgrims has healthcare experts from several countries that transport pilgrims to the Hajj pilgrimage and assist them throughout the journey. They may even open clinics or hospitals within the Hajj region to provide healthcare to their own pilgrims, as long as they follow the Saudi MOH's norms and regulations. The medical personnel at each pilgrimage office differ from one country to the next. The Saudi authorities and the medical office for pilgrims have signed agreements to enable successful communication and coordination of the Hajj's public health standards [12]. They must also submit daily updates on specific diseases, develop isolation areas for suspected cases, and work with public health supervisory teams to ensure that these cases are safely transferred as required.

4 Technical solutions

During the Hajj, IT is employed to keep track of public health. Information Technology contributes to the season's performance in a variety of ways. One of the most significant ways is by delivering a reliable means for analyzing and transferring data in real-time so that correct statistics can be prepared. This allows for a better decision-making strategy. In order to simplify the procedure of accessing several critical sites to collect the data required for the Hajj operation team, a centralized and specialized data center has been constructed.

Smart Bracelet: The Hajj Ministry created an electronic wristband that travelers were advised to use at all times during their pilgrimage. The wristband records key demographic data for each pilgrim, such as age and nationality. It is enabled with GPS in order to track pilgrims' locations and to guide the control of the crowd and crisis communication during the Hajj.

Electronic Surveillance Systems (HESN): The MOH is implementing the Healthcare Digital Surveillance System as a web-based health service. HESN is a detailed and adaptable framework that can support all Saudi Public Health Services, such as contagious disease management, epidemic management, vaccination management, alert management, materials/vaccine stock management, family health, task management, and the National Health Safety Network [13].

As soon as the notification is raised by laboratories, emergency rooms, and other departments in hospitals, all data related to that disease is immediately entered by the healthcare teams into HESN at the main locations. The uploaded data is immediately analyzed and displayed on electronic dashboards. Reports are then generated in real-time that can be instantly accessed by public health officials and decision-makers in the administration center.

4.1 Detecting Exposed Pilgrims of Infectious Disease

HESN has the advantage of keeping track of the locations of infected pilgrims by using smart wearable bracelets. However, HESN needs to go further by identifying other possible infected pilgrims (those still in the incubation period) who have been in close contact with infected pilgrims. This is a concern that needs to be addressed immediately by identifying such individuals and taking preventative measures to eliminate the transmission of infection.

5 Strengthening Diseases Control

Because of the speed of air travel, pilgrims carrying contagious diseases at the time of departure may not become unwell until they arrive in Saudi Arabia. This makes possible the transmission of infections and even the development of epidemics. The possibility of epidemic instigation by these techniques is particularly serious during the Hajj when illness transmission is facilitated by high and unavoidable congestion. Infections obtained in this way may be passed on to pilgrims from other nations upon their arrival. The duration between transmission and the manifestation of symptoms is known as the gestation period of contagious diseases [14]. It is highly desirable to be able to identify infections as early as possible for contagious disease monitoring and control, since the development of symptoms may be the only evidence of illness. The contagious time and the gestation period are not always the same. Some viruses, such as chickenpox, can make a person infectious even before symptoms occur. In terms of technical solutions, HESN generates reports immediately and has the benefit of speed since many public health employees in various places may access and coordinate the information management as soon as the data is collected. As a result, HESN continues to track affected pilgrims.

5.1 Dealing with Several Infectious Diseases including Coronaviruses during Hajj Season

Infectious diseases are typically caused by different types of bacteria, viruses, parasites, and fungi, often spread through direct contact. The primary mode of transmission of viral infection is airborne or via droplet

1.1 Transmission through the Air by Droplets

These infectious diseases are transmitted through sneezing or coughing causing small droplets containing infectious agents to be propelled through the air. Because of their small size, these droplets only go a short distance (about a meter) before falling [15]. Those in the vicinity may then inhale these droplets. Poor hygiene, including poor hand washing, can result in self-infection via contact with the nose or mouth. Colds, flu, meningococcal illness, and rubella are types of transmissible diseases spread via droplets [15].

5.2 Transmission through the Air by Aerosol

When infected individual talks, breathe, coughs, or sneezes, small fragments carrying pathogens are released into the air, and these infectious drops are called aerosols. Aerosols move in the air over long distances because of their small size, and they remain in the air for minutes or hours. Examples of these diseases are Chickenpox, Measles, and Tuberculosis.

Table 1: Types of infectious diseases during Hajj Seasons [15]

Influenza viruses	Blood-borne diseases	Pneumococcal sepsis	HIV
Meningococcal	Meningococcal sepsis	Fever	Arboviral
Polio	Leishmaniasis	Brucellosis	Zoonoses
Yellow	Tuberculosis	Coronaviruses sepsis	Gasterointestinal infections
Viral diarrhoea (eg, rotavirus and norovirus)	Food poisoning (eg, Bacillus cereus)	Arboviral infections—eg, haemorrhagic fevers and Alkhurma virus	Acute gasteroenteritis (eg, Salmonella spp, Campylobacter spp)
Cholera, typhoid, and dysentery	Fungal—eg, Tinea spp skin infections	Viral hepatitis B, C, D and E	Bacterial (other)
Parasitic—eg, malaria, scabies, gut parasites, nematodes, trematodes, and cestodes			

Table 1 demonstrates some of the many different viruses tackled by the MOH during past Hajj Seasons [12]. Effective preparedness and response strategies for infectious diseases must be applied to limit the spread of diseases, including infectious disease surveillance, human and financial resource allocation, and coordination between health divisions [16]. We attempt to adopt smart technologies to enhance the control of such communicable diseases. Implementation of such measures is not a viable option at all for the MOH during the Hajj Season when such colossal numbers of people gather in a single place from hundreds of different countries with multiple viruses of various strains, all with their varying causes and effects and varying cures.

6 Solutions for COVID-19 Disease Control

There are two phases to be followed for controlling outbreaks of Coronavirus and other common infectious diseases during Hajj

6.1 At the Entry Points

Each pilgrim is initially registered by filling out a smartphone app with their respective personal and contact information. The system creates a unique identification number (ID) that is provided to each enrolled pilgrim along with their details. The ID is used for all future communication between pilgrims, medical staff, and hospitals.

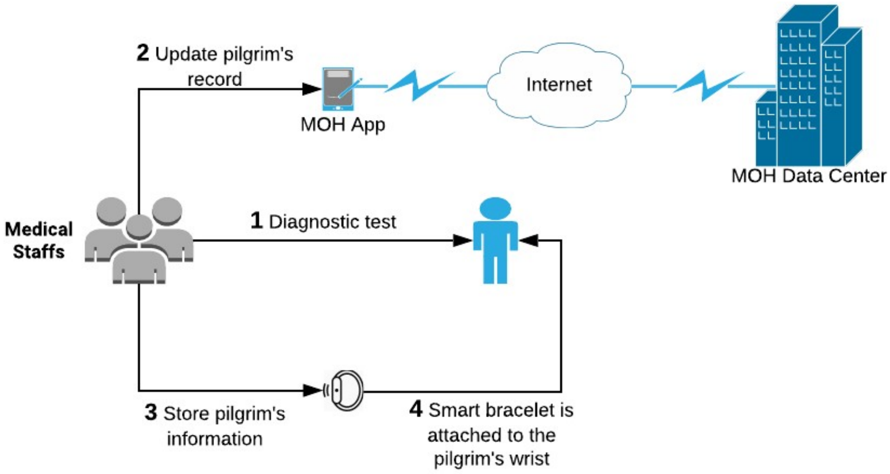

Figure 2: Process of assigning smart bracelet

Typically, there are several steps in assigning a smart bracelet to a pilgrim, as illustrated in Figure 2

6.1.1 Pilgrims will be Assigned with a Smart Bracelet

Wearable smart technology (tracking devices) is provided to be worn on the wrist. Staff assigns the device to the pilgrim via a web application. Basic information about the pilgrim is uploaded to the application in conjunction with the device assignment.

7 Pilgrims will be Subjected to a Medical Examination

Medical staff performs a quick medical check-up on pilgrims to diagnose the disease (if any) and vital signs.

7.1.1 Fever Detection

Sneeze or cough droplets can spread the Coronavirus. Fever is frequently the first symptom to appear [11- 17]. The immune response is combating an infection when the body temperature rises. Fever can be caused by a variety of things and it might be difficult to distinguish whether it is being caused by coronaviruses or other infections. However, every year, millions of pilgrims congregate in one location for Hajj, posing a tremendous challenge for the Saudi Government to regulate such a diverse range of ailments. Coronaviruses are the most common viruses in the world and managing coronaviruses and other predicted viruses during the Hajj is difficult. Fever is the most prevalent sign of many illnesses. As a result, a fever detection method is necessary to assist the monitoring system in the early detection of coronavirus outbreaks.

Detecting pilgrims with a high body temperature and making an early diagnosis of disease as soon as possible can reduce mortality by recognizing pilgrims who require treatment sooner and transferring those

who require additional attention sooner. It can also help target therapies for the people who need them. The technique for detecting a fever is depicted in Figure 3.

7.2 Updating Pilgrim's Medical Conditions at Hajj Places

After updating the data registered through a mobile application, each pilgrim‘s medical conditions are updated at the Hajj places. Pilgrim Medical Center detects positive cases from the pilgrim‘s record and marks them as infected in the MOH data center through the MOH app. Figure 3 also describes the processes to be taken by the health facilities at the Hajj places for potential types of suspected infectious diseases that could be identified for assessment. The pilgrims' records will then be updated into the web application for further action (if any).

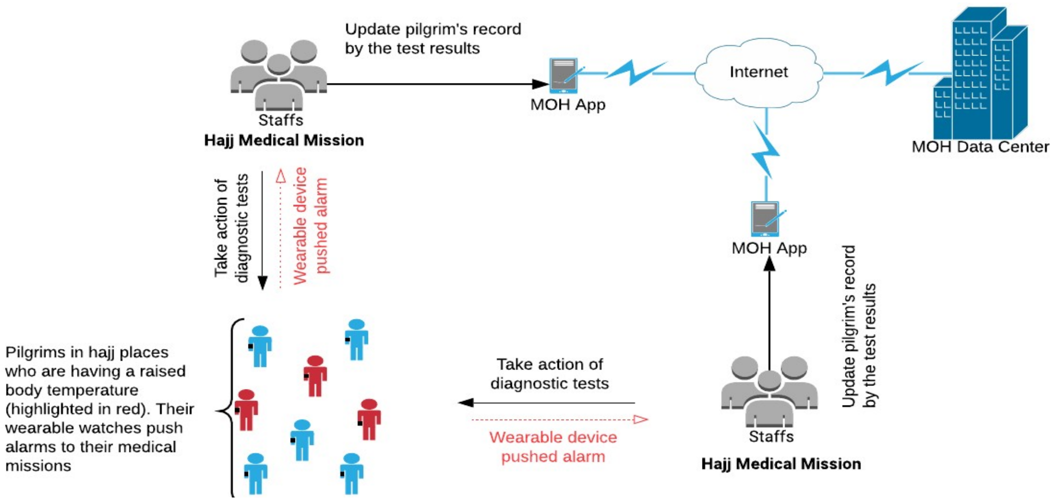

Figure 3: Fever detection and Process of updating pilgrims‘ medical conditions at Hajj places

8 Proposed Architecture of COVID-19 Control System

Information Technology is used to maintain the healthcare system during the Hajj. IT makes a range of contributions to the season's success. The most important strategy is to provide a dependable system for analyzing and distributing data in a timely manner. It is possible to prepare accurate data, which allows for improved decision-making. The objective of this work is to design a cloud-based model for predicting and monitoring outbreaks of disease efficiently and in real-time using cloud computing-based techniques. The proposed system will keep track of the current status of the outbreak and identify infected users who are potentially able to spread the disease, in particular identifying individuals coming into contact with infected pilgrims and taking preventive measures to eliminate the transmission of infection. To achieve these objectives, a real-time disease monitoring system is proposed based on wearable devices and cloud computing, as illustrated in Figure 4.

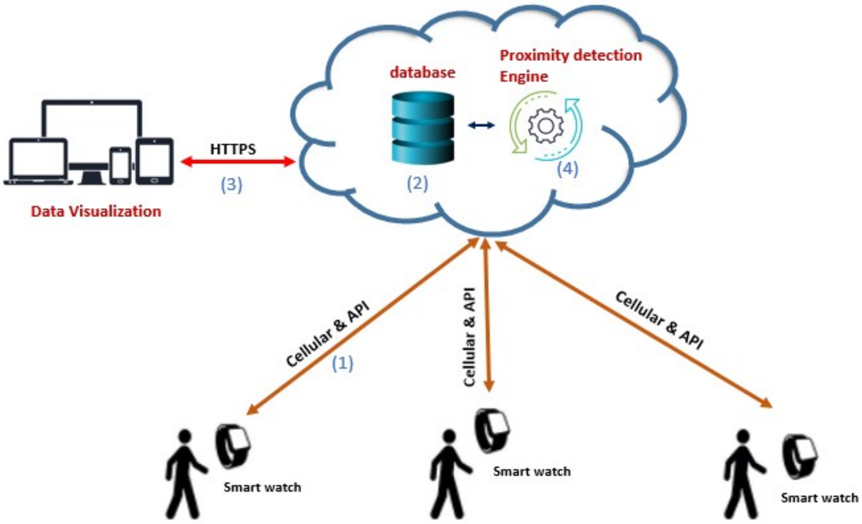

Figure 4: Proposed cloud-based System of a real-time prediction of infectious diseases

8.1 Fever Detection

In Figure 5, the fever detection method uses data that is frequently sent to the database from pilgrims' wearable watches via the pilgrims' health center using a cellular data connection (GSM). A chart can be constructed using the GPS location from the database of the web application used by a physician in their health screening. This will display the location of pilgrims who have been detected as having an elevated body temperature via their wristwatches. The team of doctors will then be able to see the pilgrims' precise location. Furthermore, a cluster of markers in one region suggests that it could be a potential breeding site for coronaviruses. As shown in Figure 5, health officials at the MOH can use this critical data and diagnosed test findings to determine whether or not the pilgrims are infected by coronaviruses and hence control disease transmission (if any). The following steps are included in the fever detection process:

- The location and vital signs data are captured by the smart watch and published to the device API.
- The data received by the device API is stored in a database.
- The notification alarm sent to the physician staff for immediate diagnosis.
- If any positive cases, the pilgrims' medical status and GPS data are sent to the proximity engine (Figure 6) to identify other pilgrims who are in close contact.
- The data can be rendered through a standard web browser as a visualization platform for the stored data.

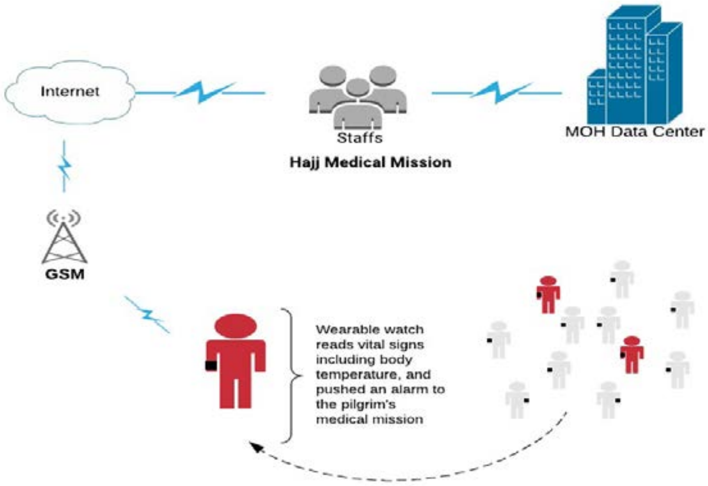

Figure 5: Fever detection using GPS and Cellular

8.2 Proximity Detection

To develop a proximity-based system for detecting pilgrims in direct contact with each other, there are two basic ways geofencing is technically implemented [18]

8.2.1 Proximity Engine Using GPS

Locations are determined by navigation satellites transmitting timing signals, which are used by a GPS receiver to determine location [19, 20]. The proximity engine is responsible for detecting close-range contact between pilgrims during the Hajj. The proximity detection process [21, 22] defines a virtual perimeter around every pilgrim's smart watch location, known as geo-fencing. Geo-fencing [23] is a virtual perimeter set to define the limits of a geographical space, such as smartphones and smart watches within a predefined area. This allows us to recognize when the user or device enters and exits this area, as displayed in Figure 6. As soon as the user enters the area that is previously defined, a notification is sent via Email or message. The virtual boundary is statically set as within 1.5 meters of a pilgrim's location. When other pilgrims enter the defined boundary, the system notes the entry time and exit time and saves the data to the database.

Figure 6: Sample of the predefined virtual boundary

Weak GPS signals due to high buildings, bridges or atmospheric conditions, creates a requirement for a reliable mechanism to create effective geo-fences and to support positioning with sufficient accuracy. Therefore, we suggest the use of connectivity combined with GPS [24, 25] for tracking and positioning pilgrims at Hajj places due to the geographical obstacles.

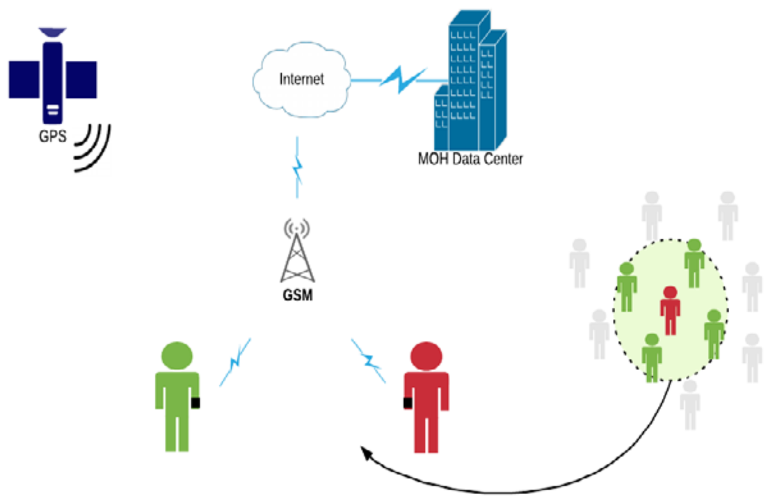

Figure 7: Close contact detection using GPS and Cellular.

As illustrated in Figure 7, the following steps are used to identify the proximity of pilgrims' close contacts:

- The location data are captured by the smart watch and published to the device API.
- The data received by the device API is stored in a database.

The infected pilgrims' medical status and GPS data are sent to the proximity engine to identify other pilgrims at risk.

8.2.2 Scenario-based Explanation

Let's assume 'A' is the infected pilgrim, and 'B' is the uninfected pilgrim, see Figure 8.

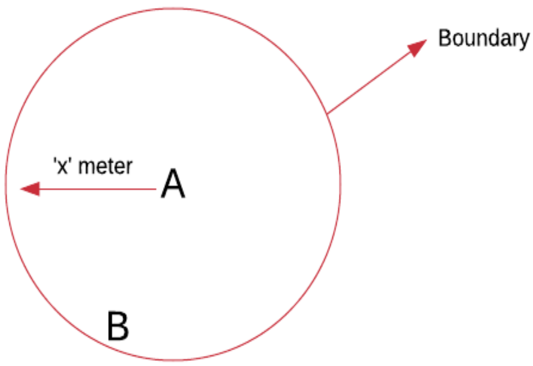

Figure 8: Proximity engine based on a geo-fence with a circular boundary

There are two service levels to be carried out by the proximity engine. The two services will be running simultaneously as explained below.

Service Level 1 basically deals with identifying uninfected pilgrims when in proximity to infected pilgrims (i.e., the uninfected pilgrims cross the defined boundary of the infected pilgrims). Figure 9 shows the mechanism of the proximity engine, which is based on the attributes in Table 4. It measures the geofence for A as 'x' meters. When B enters this area at 09:30, the engine will store a new record as "the non-infected pilgrim's ID, the infected pilgrim's ID, and the proximity enter time” into the database table “PilgrimMonitoring” (the name is for reference only). As a result, the stored data in the database will be (B’s ID, A’s ID, 09:30)

Table 4: The attributes of proximity engine

No	Proximity close Attributes	Description
1	ID of pilgrim	Bracelet ID
2	ID of pilgrim close to	Bracelet ID of close contacts of pilgrim
3	Medical condition	Infected or Uninfected
4	Entering time	The time once the pilgrim enters the geo-fencing of other pilgrims
5	Existing time	The time once the pilgrim exits the geo-fence of other pilgrims

Service Level 2: The engine will send requests every 30 seconds for GPS data of A and B. Assuming two minutes is the duration of the contact time (i.e., B exits A’s area after two minutes), the engine will store the new data record into the database table as **(B’s ID, A’s ID, 09:32)**

We define an in-contact time in service level 1, i.e., ‘z’ minutes. If the above calculated time reaches and breaches ‘z’, the engine will send an alert to the officials. Once stop time is reached, it will update the values in the database. The following figures illustrate a single pilgrim entering the boundary of an infected pilgrim. Figure 9 shows the pilgrims cross the defined boundary and Figure 10 depicts the total time duration of the pilgrims in close contact

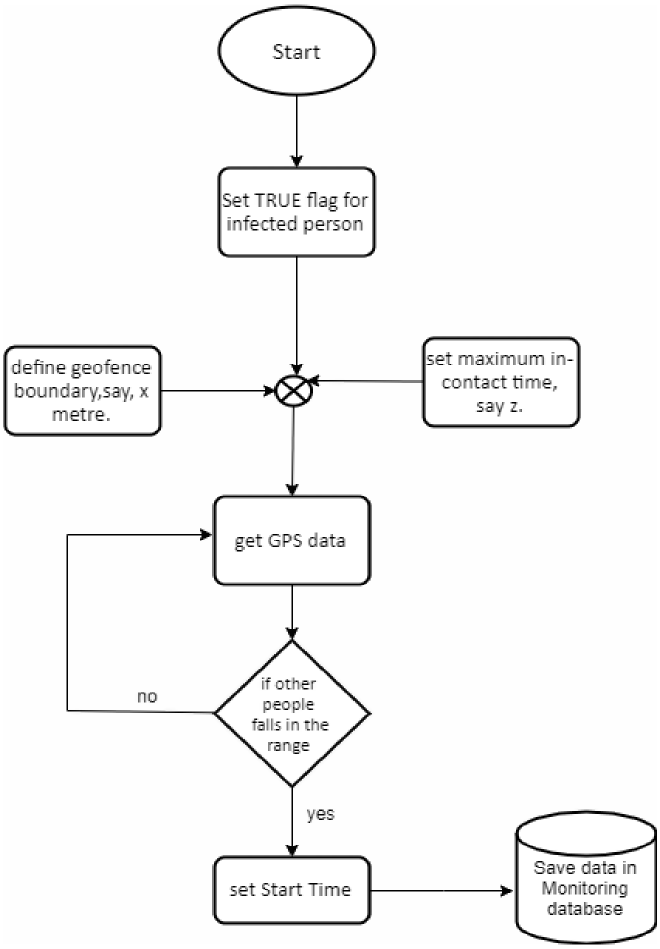

Figure 9: Pilgrims cross the defined boundary

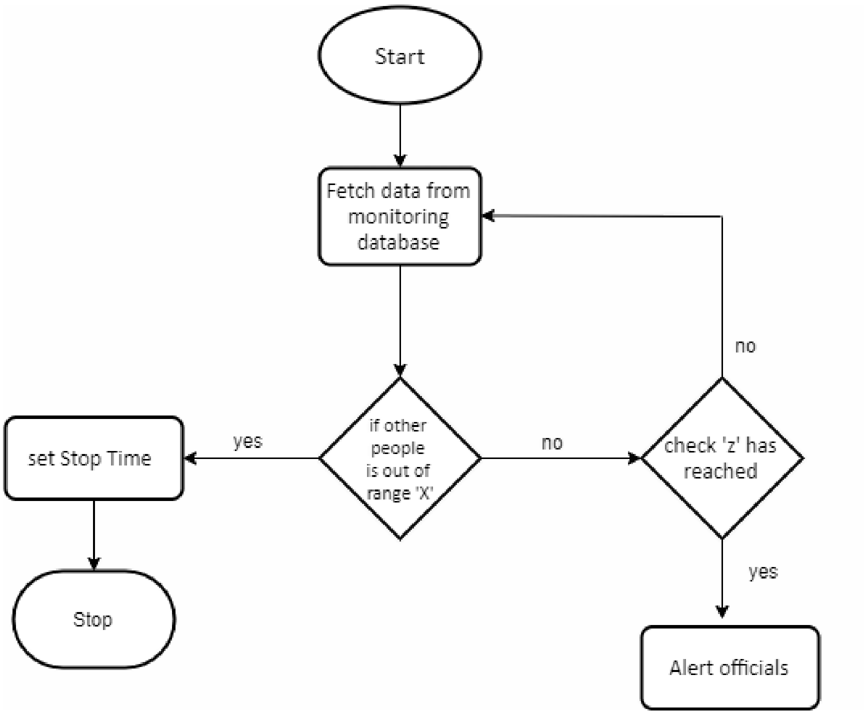

Figure 10: Total time duration of the pilgrims in close contact

9 Conclusion

Coronavirus disease is a global concern to the human population right now. Before the first COVID-19 instance was recorded in Saudi Arabia, the country implemented a variety of restrictions on social movement, social and religious gatherings, travel, and enterprises. One of the significant breakthroughs for the intelligent healthcare system is the use of IoT to control the spread of COVID-19. In this paper, a detailed case study for controlling the Coronavirus Disease Spread Control in crowds especially during the Hajj season is presented. This paper explores the various methods for monitoring and controlling infectious disease during the Hajj and also strengthens the diseases control mechanism in controlling the Coronavirus disease during the Hajj. This paper also proposes a model based on the Global Positioning System (GPS), wearable watch technology, and cloud computing infrastructure, which detects and monitors infected pilgrims and aids in the identification of those pilgrims exposed to sources of a virus. Future work can be the implementation of the proposed methodology in the Hajj season to identify the merits of the proposed methodology and to curtail the spread of COVID-19.

10 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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