

## Research Article

# Managing Crowds with Wireless and Mobile Technologies

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Thousands of people have lost their lives in stampedes and other crowd related disasters in recent years. Most of these fatalities seem to have been caused by poor control and management of crowds, which is discussed in this article. An efficient and effective crowd management system must also have a plan to deal with the ongoing threat of terrorism and outbreak of various kinds of communicable diseases. In this article, we present a framework of a Crowd Control and Health Management System specially designed to prevent and manage stampedes and other disasters. The system has two subsystems; one for dealing with the management of stampedes and other disasters and the other with healthcare management. As part of the proposed system, an algorithm for an early detection of stampedes, with proof and simulation of implementation, is provided. As part of the healthcare management subsystem, we integrate several mobile applications and develop four of them dealing with relief issues, blood donations, complaints and alerts, and utilizing mobile phones as a sensor device. Our system makes use of various kinds of wireless, mobile, and other technologies and tools including Fog Computing, Smart Phones, Smart Digital Street, IP-Cameras, Radio Frequency Identification (RFID), Voice Alarm, Light Alarm, and Global Positioning System (GPS). We compare merits and effectiveness of RFID and Wireless Sensor Networks (WSNs), as well as those of Cloud and Fog with a view of using them as part of the proposed framework. We also discuss applications of our systems in real-life cases of Hajj, an annual pilgrimage of millions of people to Mecca, and Kumbh Mela, a periodic gathering of tens of millions of people in India, both of which have accounted for the majority of fatalities in stampedes and other disasters.

## 1. Introduction

During 1980-2015, more than twelve thousand people have lost their lives because of stampedes [1–3]. Crowd managers worldwide seem not to have learned from past experiences, particularly regarding significant crowd events; otherwise the death toll (more than seven thousand) during the first sixteen years of this century would not be more than that in the whole of the last century. The root causes of stampedes are overcrowding and mismanagement and, therefore, some would argue that this colossal loss of lives could have been minimized by better control and management.

An increased growth in and spread of highly contagious viruses and diseases have been witnessed in recent years. Of these viruses and diseases are EBOLA [4], HIV Aids [5], Swine Influenza H1N1 and H1N2 [6], various strands of flu

[7], Severe Acute Respiratory Syndrome (SARS) [8], and Middle Eastern Respiratory Syndrome (MERS) [9]. They have occurred mainly in Africa and the Middle East, but also in some other parts of the world. Treatment of these afflictions is a very challenging job [10]. The spread of these diseases in crowds could be catastrophic; and so, the crowd management must take adequate measures to prevent their spread and have treatment plans in place.

Some crowded events attract people from hundreds of different cultural and linguistic backgrounds, which create significant communication challenges for management to deal with. Large crowds would also witness medical and other life-threatening emergencies. As expected, some participants in large crowds go missing for different reasons. Tracking their way back through a dense crowd, especially in a foreign land, with significant communication and transportation problems, could be a very daunting task for them. It is the

TABLE 1: Communication protocols of WSNs/RFID.

Protocol	Range	Devices/Nodes	Power Consumption & Cost	Bandwidth
Wi-Fi IEEE-802.11 WLAN (2,3,4G)	30 m	128 devices	More power and cost	10-100 Mb/s
Bluetooth-802.15.1 WPAN	10 m	8 devices	Less power and cost	1 Mb/s
ZigBee-802.15.4 Low Power	10-70 m	65000 nodes	Lowest power and cost	250 kb/s

responsibility of the crowd administration to manage these kinds of emergencies and issues.

Many parts of the globe are now facing the menace of terrorism [11]. Crowded places have greater likelihood of being subjected to terrorist attacks as observed by the history of previous attacks. Possibilities of terrorist strikes must be taken into consideration seriously and the management should have adequate plans and measures to minimize this threat and deal with the aftermath in case the terrorists do succeed.

The aim of this article is to propose a framework for Crowd Control and Health Management System (CCHMS). The CCHMS will have two subsystems, namely, Disaster Control and Management System (DCMS), aimed at reducing the risk of stampedes and other disasters, and Healthcare Management System (HMS), to ensure safety and wellbeing of the people in crowds.

We shall describe various layers of DCMS and provide the following:

(a) An algorithm for an early detection of an ensuing stampede. We shall also provide the proof of the algorithm as well as its implementation by simulation.

(b) Analysis of various kinds of wireless connectivity, sensors, mobile tools and technologies, and their integration and usage in the system.

(c) A comparison of WSN versus RFID and Fog versus Cloud and their role in the system.

As part of HMS, we shall present the following:

(d) A design of mobile applications, which includes the most critical subsystems dealing with medical issues and emergencies, terror attacks, and other disasters.

(e) Implementation of four mobile applications in (d) for Android and iOS. These include (i) relief issues, (ii) blood donor, (iii) complaints and alerts, and (iv) turning mobile phones to WSNs and active RFID tags.

We shall also analyse the usefulness and effectiveness of CCHMS in real cases of Hajj [12–15] and Kumbh Mela [15–17]. In the next section, we shall briefly describe different kinds of crowds and examine the role of various technologies and tools used in CCHMS.

## 2. Literature Review

Crowds which we witness time to time differ in many ways. A crowd would usually belong to an event, which may be regular or otherwise. Events like Hajj, Kumbh Mela, and Arbaeen [33] are regular and generally predictable, whereas irregular events are usually unpredictable in nature and size and the crowd within them can build up spontaneously. Examples of these are funeral processions, protest or celebration marches, election rallies, sporting events, and musical

concerts. Prediction of the size and nature of the irregular and spontaneous crowds is very difficult due to many uncertainties surrounding them. To illustrate, it was not anticipated that the funeral of South Indian politician, Annadurai, in 1969, would gather fifteen million people.

Table 2 shows properties of WSNs/RFID Protocols (WSNs can be IP-based and non-IP) [18–26].

Management of regular events might seem easier but the reality is quite opposite as most of the stampedes have occurred during Hajj and Kumbh Mela. However, technologies like RFID, WSNs, Cloud, and Fog can be used to manage a regular crowd, which may not be feasible in cases of irregular and spontaneous crowds.

*2.1. Radio Frequency Identification (RFID) and Wireless Sensor Networks.* Radio Frequency Identification (RFID) [19] technology and tools, which are already being used for tracking the movements of people, vehicles, goods etc., can help to manage some of the problems of crowding. The RFID chips, usually in the form of tags, can be linked to a Wireless Sensor Network (WSN) [34, 35], cellular (3G/4G) network, or GPS [36]. Choosing one of these networks would depend on the terrain where RFID chips are deployed or the path they traverse. If deployed in urban areas, density of buildings, width of streets, congestion, and other related issues would have to be taken into consideration. A Wireless Sensor Network (WSN) is a cluster of a large number of sensors, each of them tasked to monitor and detect physical events such as light, heat, pressure, pollution, and RFID tags. Being wireless, they are more flexible in deployment and have larger scalability. Using a WSN for accessing signals from RFID tags is quite effective and provides very accurate longitudinal and latitudinal coordinates. However, their installation and deployment can be costly as well as hazardous in places with limitations. Efficient tracking with a Cellular Network would require many repeaters to ensure access in all areas of RFID tags. For details, see [37].

It is well known that GPS does not efficiently function in tunnels and densely built up locations [38]. Likewise, some of the RFID tags may not be detected in very dense crowds, and the local sensor network may not be deployed in places with a lack of space. Despite limitations, these technologies have revolutionised tracking and obtaining information from obscure places. These technologies have also created a launching pad for the Internet of Things (IoT) and hence paved the way for abundant applications [39]. Table 1 provides a comparison between WSNs and RFID.

*2.2. Fog and Cloud Computing.* Fog is a model for computing, introduced by CISCO in 2012 to reduce or eliminate some limitations of Cloud Computing. Fog can be defined as an

TABLE 2: Comparison between RFID and WSN.

Factor	WSN	RFID
Main goal	Monitor and sense environment [18].	Detection location and Identity [19].
Tasks	Collect, Process, Transfer, and Store [20]	Usually reflects RF signal transmitted from Reader for identification of location of the attached object [21].
Element	(i) Sink aggregates the information from sensor nodes. (ii) Sensor node with sensing, Computing, and communicating elements [21].	(i) Tag (Passive/Active) stores the unique serial number, and it provides memory for some additional info. Passive tag is used only for reading info by a Reader. Active tag supports two ways communications with higher signal strength and can store some information, but it is costly. (ii) Reader can read or write data on Tag and pass it to the host. Capable to send messages to an individual tag or broadcast to all tags within range. (iii) Host Computer analyses data [22].
Range	Can't support long range of communication, so it uses multihub to reach the Sink Node and increase the range [21].	Usually small Range of communication, where Passive Tag (2-3 meters), Active Tag (100-200 meters), but it is costly relative to its abilities [22].
Application	Applications in many fields including Safety and Wellbeing, Healthcare, Smart-Grid, Environment [23].	The main applications are Tracing, Security & Access Control, Healthcare, Crowding, Clothes stores, etc. [22].
Protocol of connection	Wireless connections: Wi-Fi 802.11WLAN but is High on power, Bluetooth 802.15.1 WPAN, ZIGBEE 802.15.4 Low Power WPAN [24].	RFID Protocols (Air-Interface) (IOS-x), LF, UHF, NFC, etc. [25].
Communication and Connection	Multi-hop to increase strength of signal, and WSNs can link to each other (Ad hoc) [24].	Single-hub and there isn't communication between RFIDs [21].
Mobility	Usually Static	Usually Mobile
Programmability	Supported	No Support
Deployment	Random or Fixed	Attached to or embedded in objects
Power and energy	Battery for sensors, and power supply for Sink Node [20].	No need of battery for Passive Tag, but powered-battery is needed for Active Tag, and power supply for Reader. [26].
Usability	Car, phone, clothes, electronic devices, etc.	Card, bracelet, phone, car, etc.
Limitation	Range, Architecture, Massively heterogeneous, Real-Time Apps, Privacy & Security, etc. [23].	Power, Communications, Cost of Active Type, Security & Privacy, etc. [21]

extension of Cloud to the edge of a network with smaller memory and processing power—it can be any device with an ability to do some computing and storage. Therefore, unlike Clouds, Fog is close to the end-user and supports the distributed computing model. More information about Fog is available in [40, 41]. Here we provide a comparison between Fog and Cloud.

- (1) Fog can be any device with the ability to compute and cache data in addition to network, whereas Cloud is a set of servers.
- (2) Fog supports time-sensitive applications like the ones dealing with emergencies, where usage of Fog reduces latency, increases response speed, and decreases traffic on the links, which are difficult to achieve with Clouds.
- (3) The Fog Node is close to the end-user, which makes it suitable for filtering and processing data before sending it to the Cloud, resulting in a reduction of the

overhead processing on the Cloud as well as traffic on the links and network. Fog can process images and detect features and then send these features instead of images to the Cloud. The use of Clouds is to store entire data and apply big-data applications to explore unknown associations within the data.

- (4) Fog may also implement some access restrictions on data before sending it to Cloud, which increases the security, especially for IoT objects not having enough memory and processing power to perform similar tasks.
- (5) Fog can be used as smart traffic to support mobility apps and manage crowds better than Cloud.
- (6) Fog increases the availability service as compared to Cloud, which is very beneficial in crowd management.
- (7) Fog nodes can be spread intensely to completely cover any area (like the areas of intense crowding in Hajj

TABLE 3: Tools and technologies for CCHMS.

Name	Usages in our System
WSNs	Monitor and sense important indicators about environment based on some conditions like the level of oxygen, pressure, pollution, heat, which are very important managing health and crowd conditions.
RFID Tags	Detection of location and identity of objects in local area, which is critical in calculating the count of participants in specific area, as well as for searching objects in the crowd.
Drones	Observe crowd vertically from overhead positions in all directions. Additionally, we can use them to promptly deliver some material and medical supplies in areas where ground transportation is not feasible [27, 28].
Airships	Deploy them if GPS, Cellular network and Internet Connection do not work from ground [29].
IP Cameras	Take photo frames for headcount of segments of a crowd and then send them for processor as an input for our stampede detection algorithm included in this article [30].
Smart phone and devices	Use them instead of WSN, RFID or Alarm where Cellular/Wi-Fi connection is available. Also, use them for other applications provided in the article [31].
Digital Street	Turn venerable areas into a screen of LEDs to make it a tool for alerting and controlling crowds [32].
GPS	For finding global location of objects and tracking
FOG	Caching and expediting processing of the data generated by various tools and devices included in this table. If were to use cloud instead, there would be latency in communicating, transferring data, and decision-making. Latency in a sensitive system like ours can lead to the system failure.
Cloud	Storing and processing historical data into a data warehouse for the purpose of data mining and big data analytics.

or Kumbh Mela). In other words, Fog supports the distributed model of computing better than a Cloud.

- (8) Unlike Clouds, a Fog Node has limited resources, and hence the need for Clouds persists.
- (9) Fog supports awareness location, which is not achievable in Clouds.
- (10) Users can have full control on Fog, whereas in Clouds there are three different control models, namely, SaaS, PaaS, and IaaS.

To make the best use of the Fog technology, the crowded area needs to be divided into many cells, each containing Fog to enable connection to all objects in the given cell. In this way, Fog can calculate the number of participants (usually with tags) in its cell and manage them by facilitating specific services. Fog's node in each area will feed the aggregate of the result of processing of data in a given cell to the Core Fog, which could also perform some operations before sending the data to the Cloud. Data in the Cloud can be mined and/or big-data analysis can be performed. In case of an emergency, Fog can directly take decisions without latency [42, 43].

### 3. Merit and Integration of Technologies for the Proposed System

Many of the sensors, wireless devices, and new technologies available today are helping to manage many businesses and

real-life operations. Table 3 explains the usefulness of the technologies, which we use in our systems [31].

In Figure 1, we have integrated some of the tools and technologies mentioned in Table 3 into a Fog architecture, which forms an integral and important part of our proposed Crowd Control and Management System. We have divided the crowd-assembly area to a number of cells, each of them with many IP-cameras, RFID, WSN, and Smart Devices for collecting data. Then the data would be processed locally in the Fog Node, which would be available in each cell to make a decision without latency. The results from Fogs would then be sent to a Core Fog Node for rigorous processing and organizing. Finally, all data would be stored in a data warehouse in the Cloud for mining and analysis [44].

### 4. Algorithm for Stampede Detection

Here we provide an algorithm based on image processing for detecting and preventing stampedes. This is an integral part of the proposed system. A stampede occurs when many people simultaneously lose grip under their feet, which usually happens when a sizable body of a crowd stops moving while the others keep on moving towards them. To stop its occurrence, crowd monitoring technology or field observers should identify abnormal crowd behaviour as soon as it is noticed. We focus on detecting the likelihood of a stampede due to a sudden change in the number of heads in a segment of a crowd and provide an algorithm for that purpose. There are already many methods/approaches to calculate

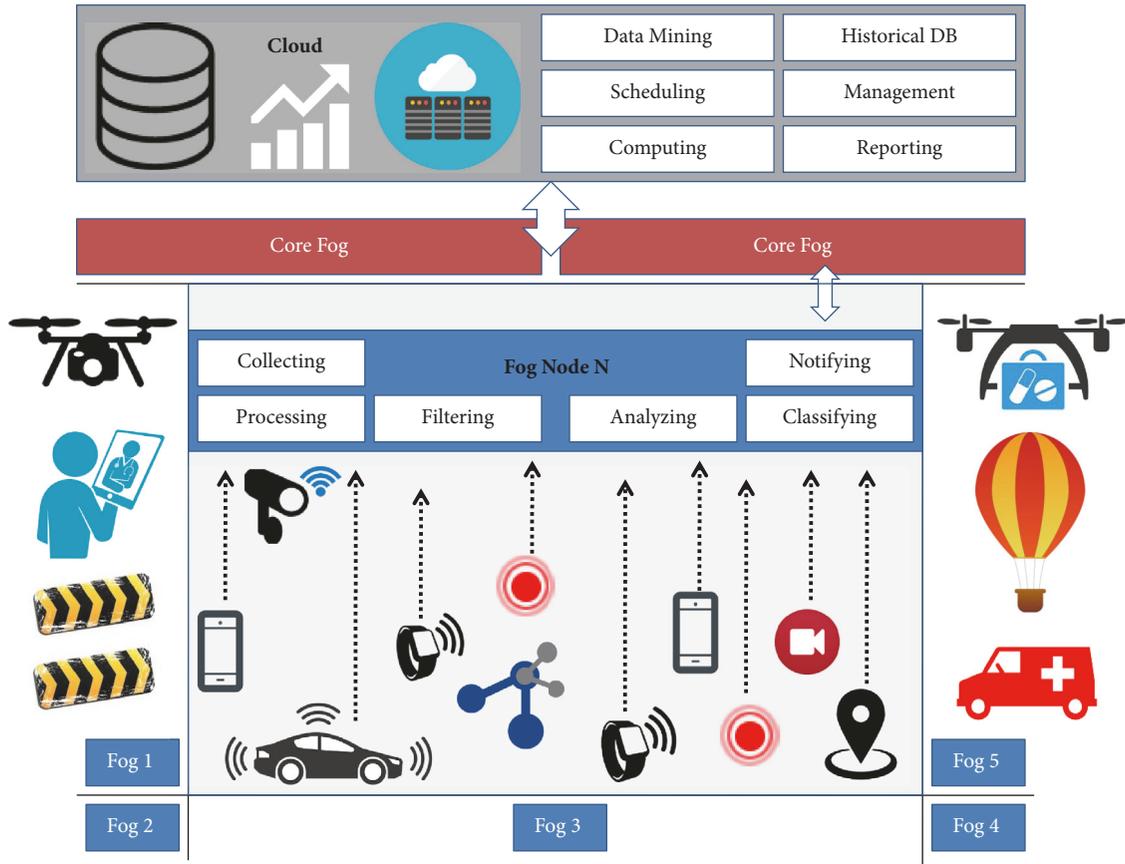


FIGURE 1: Integration the technologies in the proposed system.

the number of heads in an image; some of them are listed below.

- (i) Rely only on the number of objects in the image [45, 46].
- (ii) Rely on the colour and number of objects as in Viola Jones Algorithm [47].
- (iii) Rely on motion to separate the background from objects and then estimate the number of objects according to the number of pixels. Here gradient orientation can be used, block matching, or histogram orientation and colour distribution [48, 49].
- (iv) Rely on the edge detection or skeleton (Thinning) and then number of pixels [47].
- (v) Detect the deviation and then use clustering, regression, training techniques as neural network to estimate the number [50, 51].
- (vi) Rely on texture feature to estimate the density [48].
- (vii) Convert the image from special domain to frequency domain by many transformation functions (HAAR, DCT, DFT, HOUGH, HOG, SIFT, SVM, GABOR, EIGEN, etc.), and then apply estimate or training to find the number of objects [52, 53].

**4.1. Proposed Algorithm for Stampede Detection (ASD).** Proposed algorithm (ASD) relies on integration among the number of objects, edge detection, and Hough transformation to insure higher reliability when sending notification to human observer to take suitable decision and action promptly. ASD processes images to find the number of heads; the images are continually transmitted by the IP-Camera to Fog, which saves them and records the number of heads in the cache. The process is repeated to find and record the number of heads in successive images, which are compared. If the deference in the number of head-count exceeds the threshold, the observer would be notified. As a result, security personnel on the ground would be alerted to either make the crowd thinner or break into different sections and zones. While the crowd was in motion, the number of participants could be reduced by cropping a crowd-rectangle from the middle. Other ways of crowd downsizing could also be employed.

**4.2. Steps of ASD for Finding Number of Heads.** As mentioned before, here we provide steps to find the number of heads.

- (1) `X = imread(Image.png); // Read Image`
- (2) `X1=rgb2gray(X); // Convert Image to Gray`
- (3) `Threshold_Head_Size=1800; //Can be changed according to the camera position and far.`
- (4) `X2=edge(X1,'canny',0.3); // Edge Detection`

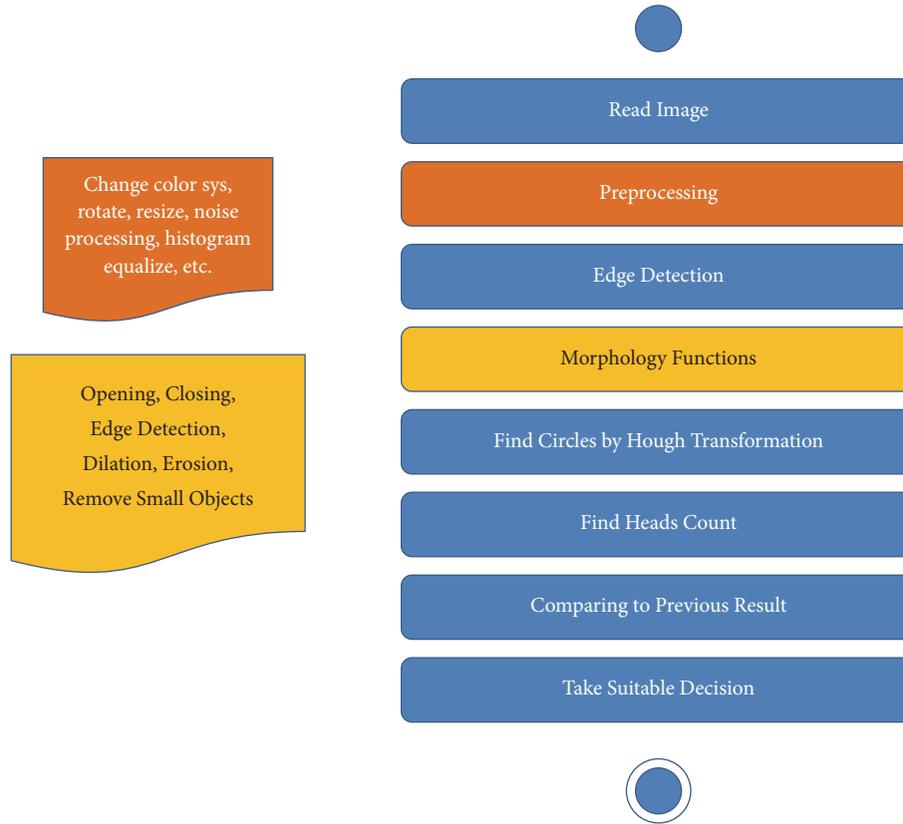


FIGURE 2: Flow diagram of ASD.

```

(5) X3=bwmorph(x2,'close',1); // Morphology Processing
(6) X4=1-x3; // Reverse Colour
(7) X5=bwmorph(X4,'open',inf); // Morphology Processing to separate the objects (heads)
(8) X6 = bwareaopen(X5,Threshold); // Remove objects with size lesser than the threshold
(9) // Find Circles Functions and its Attributes
(10) [centers, radii] =
    imfindcircles(X1,[Min Max], 'ObjectPolarity', 'bright',
    'Sensitivity', 0.95, 'EdgeThreshold',0.1, 'Method',
    'TwoStage');
    // 'Min & Max' would determine the radius of the head according to camera position.
    // 'Object Polarity' can be dark or bright according to light condition
    // If 'Sensitivity' value lies in [0 1]; if it was smaller, the sensitivity would be lesser.
    // If 'EdgeThreshold' value lies in [0 1], it would determine the degree of difference among object boundaries.
    // 'Method' can be Two-Stage (Hough Transformation) of Phase-Code (Atherton)
(11) H = VISIRCLES (centres, radii); // This is for drawing circles

```

```

(12) Count=size(centers,1); // This is to find head-count
(13) Title (num2str(count)); // This is to print the head-count
(14) Calculate the "Deference" between current 'Count' and previous frame 'P-Count'
(15) If 'Deference' > Threshold → send alert.
(16) Save last 'Count'
(17) Repeat all steps.

```

4.3. *Flow Diagram for ASD.* Figure 2 shows a flow diagram of ASD

It is worth mentioning that the proposed system does not rely on ASD alone. There are other inbuilt mechanisms to detect stampedes, which will be discussed in the next section.

## 5. Proposed Crowd Control and Health Management System

Crowd management is a highly critical operation as it is linked to the safety of human beings. An oversized crowd could be very difficult to manage. Technology can play a significant and crucial role in controlling and managing crowds and, in particular, alerting about an ensuing stampede. Here we present a framework for Crowd Control and Health Management System (CCHMS), which has two subsystems: Disaster Control and Management System (DCMS) and

Healthcare Management System (HMS). As part of DCMS, we propose a number of ways and techniques for predicting a stampede and other disasters before they occur. For HMS, we propose integrated mobile applications with a number of modules for dealing with health issues in crowds. Our techniques in CCHMS rely on coordination and integration of different technologies and tools including Cloud Computing, Fog Computing, Smart Phone Application, Smart Digital Street, RFID, WSNs, GPS, IP-Cameras, Sound Alarm, and Flasher/Light Alarm. Integration of these technologies would enhance efficiency, reliability, and success in providing life-saving applications [54].

*5.1. Disaster Control and Management System (DCMS).* In order to manage crowds successfully, cooperation and education among all stakeholders are highly desirable. In particular, participants must obey the signals and commands; otherwise, the system would not attain its desired goals. Another factor critical to a stampede (or another disaster) aversion is the response time. Here we provide a detailed description of layers of DCMS.

*5.1.1. Overview of DCMS.* We divide areas and places of crowd build-ups into a number of cells and distribute crowd data from the sensor networks continuously to many computing (Fog) nodes, enabling each of them for speed processing and decision taking. Each set of Fog nodes is connected to the core of the Fogs to control the integration and cooperation between them and to ensure data processing before relaying the information to Cloud, where an extensive data analysis for the detection of new knowledge is performed. The new knowledge will be very beneficial for the prediction of future health and crowd cases and preparing advance solutions to deal with the aftermath of a disaster if it occurs.

*5.1.2. Layer 1: Collecting/Sensing Data.* Described below are different types of tools for collecting data in each cell of the crowded area.

(i) Attach RFID-Passive (low-cost) tags (cards/bracelets) to the body parts (wrist, waist) of individuals of the crowd for determining their whereabouts and the size of the crowd in each and any moment of time. Tag Readers can be in the Fog Node, or many Readers can be distributed in the cell and the Host will be in the Fog. The Identity can be used to get more details and information about each individual from the Cloud based central database. In situations where GPS and Cellular network do not work, airships may be used. In cases where other methods of reading RFID and WSNs are not usable, drones [27] may be effective to use.

(ii) Deploy different purpose WSNs in each cell for sensing parameters, conditions, and situation, namely, for example, pollution, temperature, and pressure sensors, which provide important information about environment of cell and play a vital role in alerting about a potential danger of a disaster. Moreover, the data sensed by them can be stored and analysed for future purposes.

(iii) Use IP-Cameras to take high-resolution images of the crowd in each cell and then process these images in Fog to detect the likelihood of any accident or some other disaster

without latency or delay. In addition, it would lighten up the size of data transferred on links and the data storage in the Cloud because Fog nodes would only send the features of each image instead of their parts. The stampede detection algorithm, provided in the next section, would rely on matching the features of new images with previously stored features. Extensive data processing on Cloud can enhance and increase the accuracy of features of each case. We can also use images to analyse the mood and emotions of the people. In case of apparent signs of sickness or distress, remedial action can be taken [55].

(iv) Use Mobile Applications (Android and IOS), which should be installed on participant Smart Phones to enable them to notify the management by a simple click about any eminent danger on the location and time of their being there. In this manner, each participant would act as a sensor.

(v) Collect information from social media like Twitter, which is considered as one of the fastest ports for news nowadays. However, because of the size, the management would need to perform big-data analytics for processing social media data or environment to expedite the notification of information as quickly as possible [56].

*5.1.3. Layer 2: Take Decision.* DCMS uses Fog Computing nodes to improve the efficiency of processing to meet the critical requirement of the system and analyses the collected data without latency. In addition, it uses Core Fog for the organization and integration of the cells and so makes them more flexible and faster in dealing with emergency situations.

*5.1.4. Layer 3: Notify Crowd.* We propose a number of tools (hardware/software) for notifying and alerting the participants, whose details are as follows:

- (i) Create Digital Streets in the areas prone to disasters, which are considered very important for controlling and notifying crowds in critical situations, which no one has used so far. If an alarming situation was detected, Fog would send an alert to Smart Streets to light up the ground by red colour as a result of which the participants would sense the danger and stop moving any further. Moreover, Digital Street can guide to a safer way of movement in the same way as in the case of aeroplanes directing passengers in their movement.
- (ii) Participant Smart Phones would be registered and used to send alerts from the management.
- (iii) Voice/Light Alarm, Announcement, and other traditional methods, if deemed safer, can be used to notify and guide the crowd.
- (iv) Drones can be used to send some urgent medical supplies to an event, which may have access problems by other means.
- (v) An E-health services application made for Android/iOS can be used to guide participants to take safety precautions and to provide general guidance.

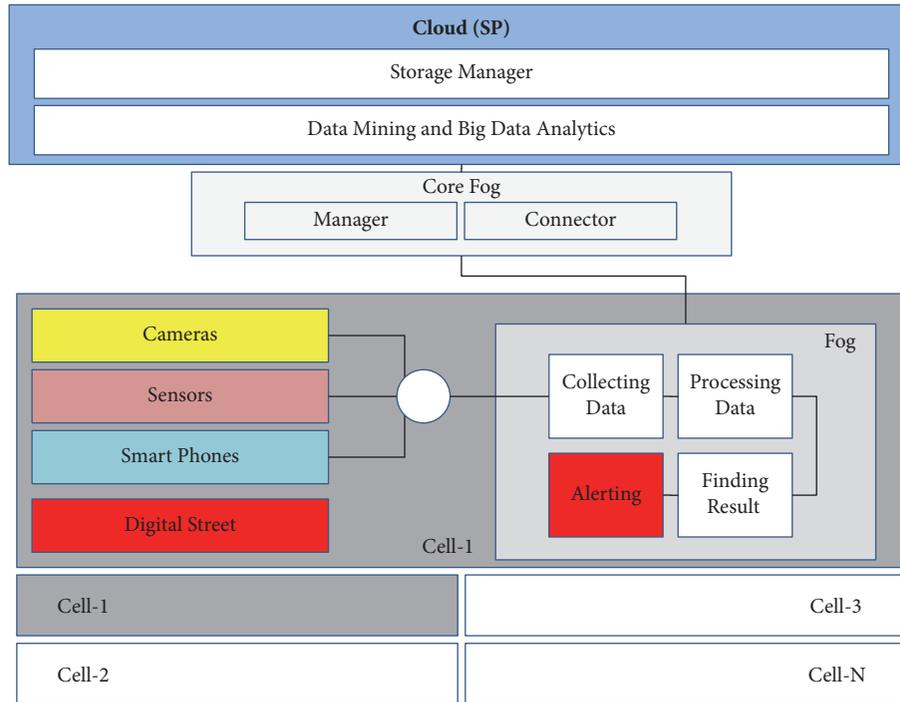


FIGURE 3: Architecture of DCMS.

5.1.5. *Layer 4: Cloud Computing.* Data received from sensors and other management tools can be collected, stored, cleaned, refined, and analysed. All of this can take place on the Cloud (data center), where deep processing and mining can detect new relationships of data to provide comprehensive knowledge for future management of the same or similar events to minimize the chances of disasters.

Figure 3 provides a framework of DCMS. As discussed earlier, the success of this or any other system would depend on the cooperation between participants and management. In particular, participants must promptly act on alerts and notifications and follow the instructions.

We are aware that the proposed system may at times encroach into participants' privacy. We endeavour to return to the issue of preservation of privacy in the future.

5.2. *Proposed Healthcare Management System (HMS).* The health and wellbeing of people in crowds should not be compromised. Management should use a comprehensively developed healthcare system, which makes use of the best available technology. Regular and recurring crowded events must capture and store medical information about their participants. If people with contagious viruses and diseases are allowed to participate, they must be isolated and properly managed. Here, we provide a design of HMS, a comprehensive health management system, built on several mobile application subsystems. Figure 4 exhibits a screen of mobile apps of this system, as they would appear on the mobile devices of the participants. The mobile apps can also be exhibited as icons to help those with reading difficulties. The system can also be multilingual [57, 58]. A brief description of various subsystems or mobile applications follows.

- (i) **Poison System:** this mobile application aims to tell participants about the presence of poisons in artefacts, alert about issues or conditions that can spread poisons, and guidelines to avoid situations of contamination.
- (ii) **Drug System:** it is a search engine to suggest general-purpose drugs and their usage and to list forbidden and unsafe drugs with their side effects.
- (iii) **Food System:** it provides beneficial information about unhealthy foods; especially the ones that can quickly become contaminated in crowding and environment conditions.
- (iv) **Survey System:** this will send a questionnaire every day to find people with illnesses and to direct them to follow a course of action.
- (v) **Relief System:** This system would empower participants to provide First Aid in the case of an emergency. The system will have videos on key aspects of healthcare, which can be played at times of need until the medical relief arrives.
- (vi) **E-File System:** this is for users to record some indicators about their health, such as heart rate, pressure, and sugar, to help the government to capture real statistical health data to enhance and improve the level of services.
- (vii) **Advices System:** this system can frequently provide health advice and tips to the participants.
- (viii) **Medical Appointment System:** this system would enable patients to make online booking for appointment with a health center.



FIGURE 4: Proposed application and services for crowd control and management system.

- (ix) **Question (Consultation) System:** this system enables users to ask for electronic consultations from physicians with selected specialists.
- (x) **Monitor System:** this system uses GPS and Location Based Servers for tracking old and weak persons in order to take fast action.
- (xi) **Health Centers:** this system helps users to search for the nearest health centers or pharmacies by name, location, and other details, in conjunction with Google maps.
- (xii) **Paths System:** this system provides information about the paths that have less traffic and less pollution for some participants with conditions of breathing and other issues. In reality, Google maps and GPS cannot scan all areas of some crowded events.
- (xiii) **Blood Donation System:** this system will send a request for blood donations and would enable participants to opt for it. The donors can provide personal details including the blood group and their locations. Based on the details, the system can organize blood collection and can call them to any position by one click.
- (xiv) **Autism System:** this system provides videos and beneficial links for families that have a child with autism, in addition to providing some specialised mobile games for this group of children.
- (xv) **Drone System:** this system would be used for keeping an account of drones used for supplying medical supplies to obscure locations.

(xvi) **Alerts:** This system would send alerts and notifications to participants to manage their movement and behaviours.

(xvii) **Terrorist:** This system is included in the Alerts App to get or send notification about any terror case, to protect people and request police assistance.

## 6. Implementation and Results

Here we shall present the results of implementations of various constituents of CCHMS.

*6.1. DCMS Implementation and Results.* In Figure 5, we provide results of ASD applied to a virtual image, with five successive frames. We have numbered these frames F(1-3), F(2-4), F(3-5), F(4-6), and F(5-End). After counting heads in each frame, we did not find any significant difference.

Next, we apply the same method on real frames and obtain the same head-count as shown in Figure 6. In Figure 7, we depict the results of successive steps of ASD, first on a picture without making any change to it and then that on the same picture after making some manual alteration. A remarkable difference can be seen in the results. Figure 8 demonstrates the accuracy of the head-count by ASD, applied on real and virtual images. We notice that the accuracy of head-count by ASD was more than 94% in most of the cases.

*6.2. Superiority of ASD.* In order to obtain better results, we combine elements of some of the existing approaches in ASD. Description of the function of four of these approaches

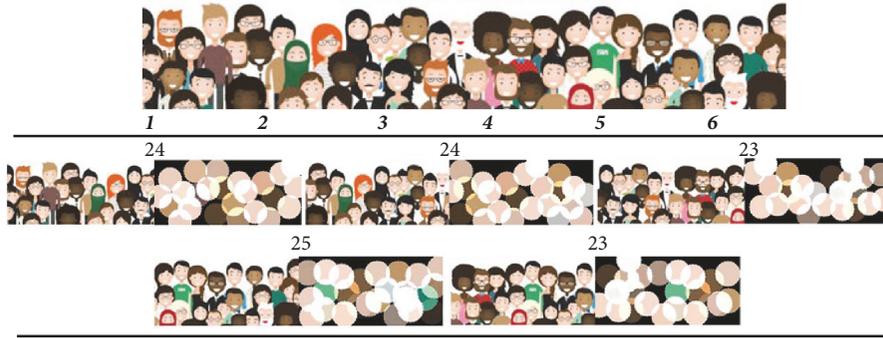


FIGURE 5: Head-count in frames of a virtual image.

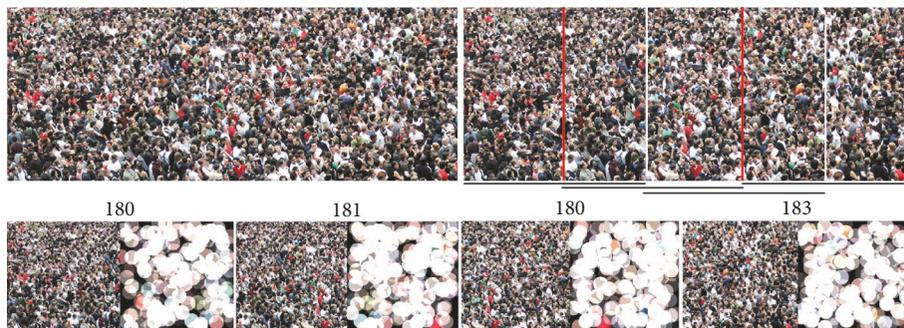


FIGURE 6: Head-count in frames of a real image.

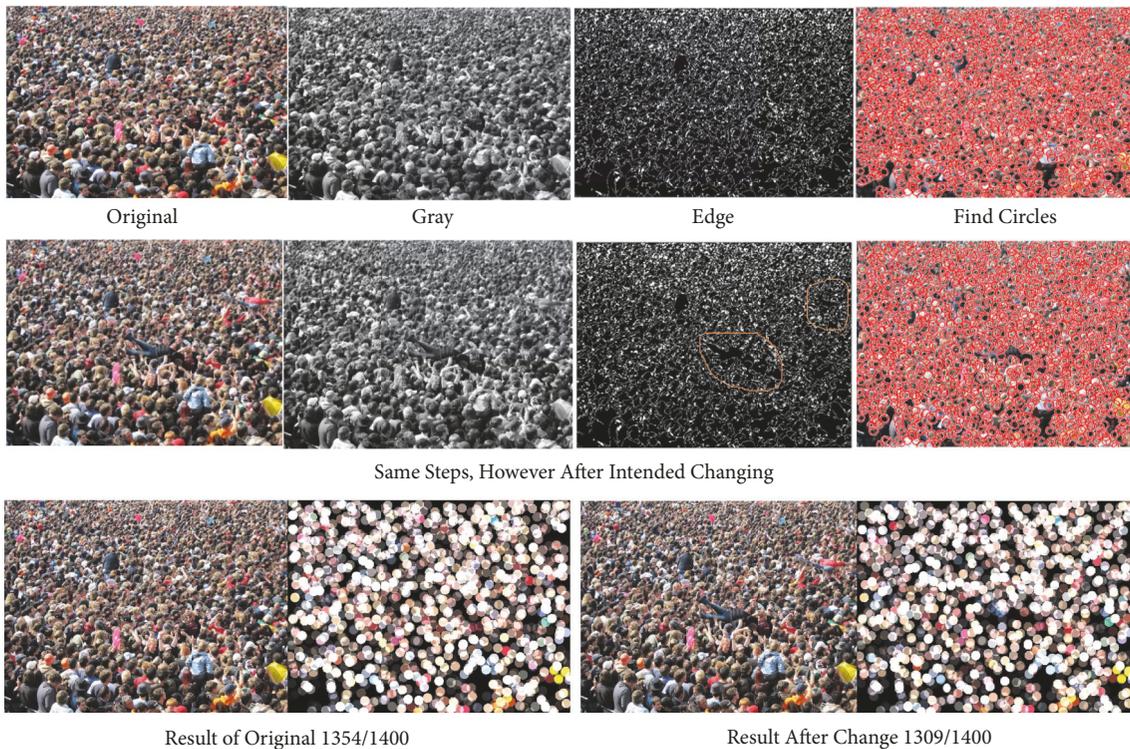


FIGURE 7: Head-count in frames of unaltered and altered images.

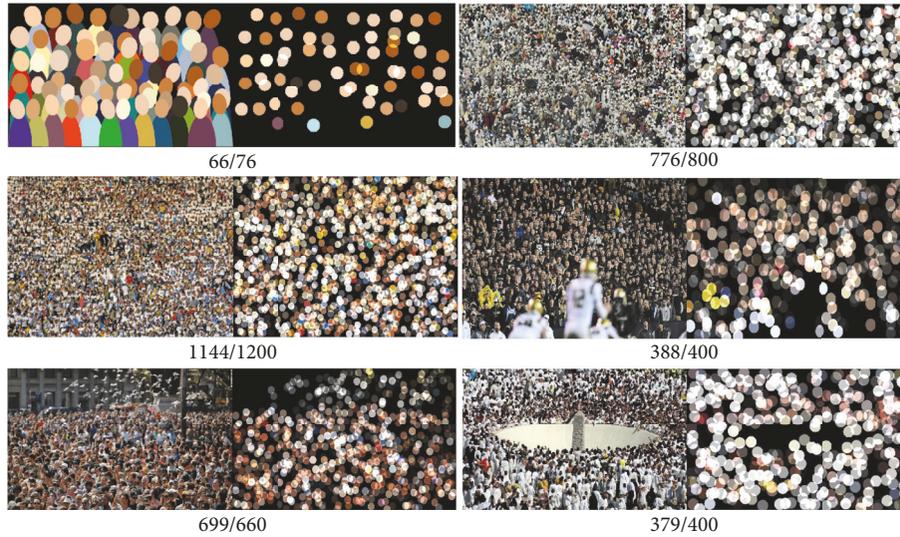


FIGURE 8: Accuracy of head-count in ASD.

TABLE 4: Accuracy of headcount approaches.

ASD (Finding Cycle)	Number of Objects (Using Morphology)	Fourier & Estimation	SHIF & Estimation	Motion & Separate background	Cluster & Estimation
94%	85%	60%	70%	92%	93%

follows. The first of these approaches, to be identified as “Number of Objects,” depends on the count of objects. This approach uses morphology to separate the objects and converts them into black and white images. Then morphology filters separate the objects and find their sum by dividing the size of each object on the threshold [45–47]. Another approach uses transformation filters like “Fourier & Estimation” or “SHIF & Estimation.” Once a transformation filter is applied, the image is converted into a frequency image. In the frequency image, white pixels are used to estimate the number of heads in the new frequency image [48]. The third approach, known as “Motion & Separate Background” uses an earlier approach, like Number of Objects, to enhance the result by isolating the background of the image from real and moving objects [49]. Finally, an approach known as Cluster & Estimation divides the image into many sections and then estimates the count of objects in each section with different factors of density [50]. Table 4 and Figure 9 provide simulation results of ASD compared with the four approaches that have been described.

Superiority of ASD is evident from its implementation on virtual and real images. Moreover, ASD, unlike other approaches, relies on the difference of head counts between successive frames of images to determine abnormal crowd behaviour. The importance of head-count difference can be understood by the following example. Suppose ASD gives an inaccurate count  $C_1$  for a frame  $F_1$ , the head-count  $C_2$  in the next frame  $F_2$  would approximately be the same. Thus, the difference between  $C_1$  and  $C_2$  would be negligible and hence would not affect the overall result unless a sudden unusual event occurs. If an unusual event does occur, the difference between  $C_1$  and  $C_2$  will be significant, and the

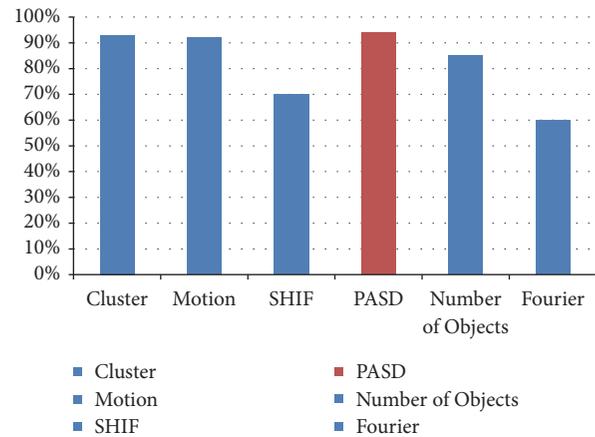


FIGURE 9: Accuracy comparison.

difference between  $C_2$  and  $C_3$  of another frame  $F_3$  would also be significant.

6.3. *Implementation and Results of HMS.* Here we provide implementation of four applications (subsystems) of HMS, namely, emergency, blood donor, complaints and alerts, and turning mobile phone to act as a sensor device. Figure 10 depicts an interface of these applications on the mobile device, and Figure 11 shows the server and admin side of these applications.

## 7. Applications of CCHMS in Real-Life Cases

Here we provide some cases where CCHMS can be successfully used.

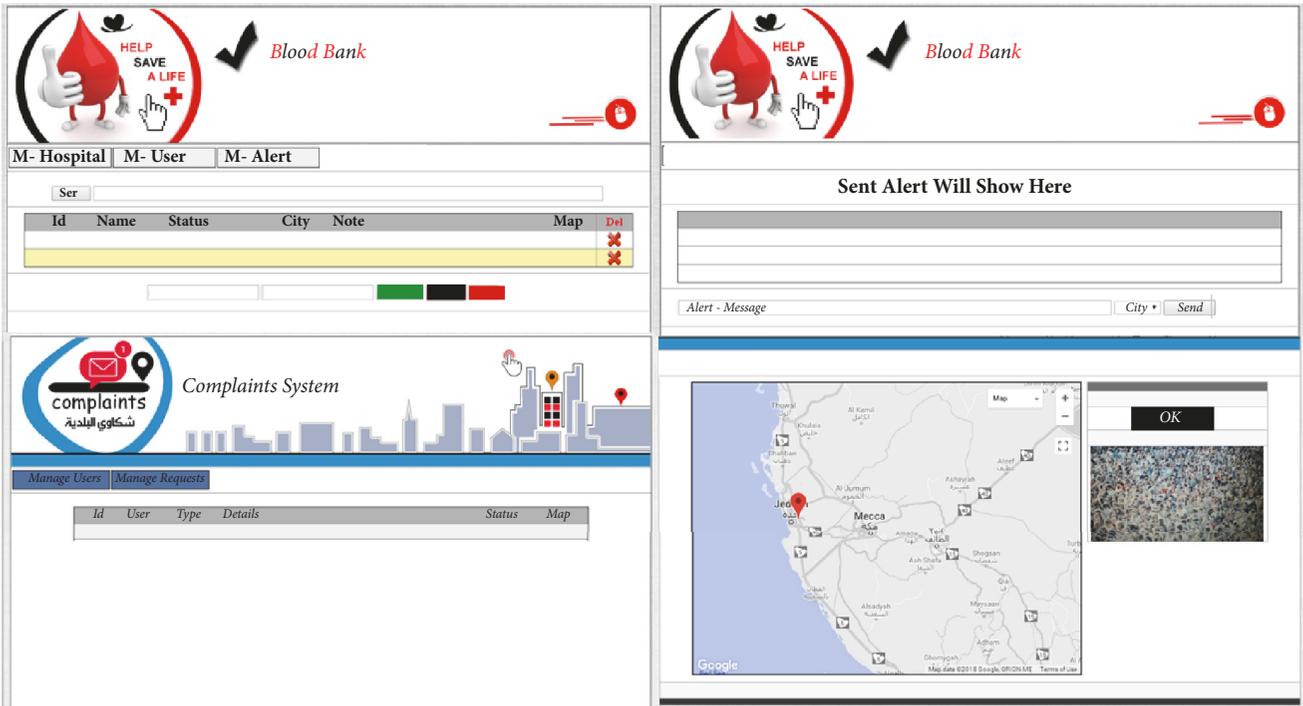


FIGURE 10: Mobile apps interface.

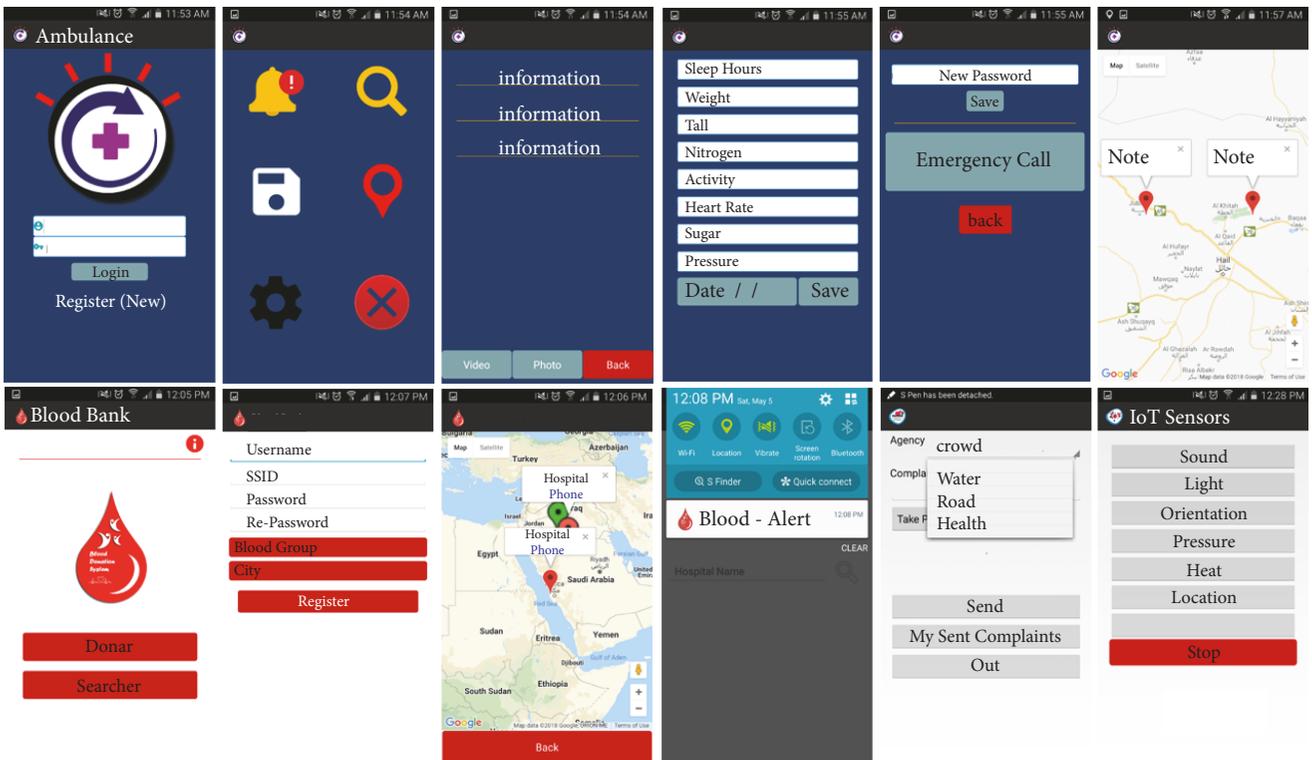


FIGURE 11: Admin view of mobile applications.

**7.1. The Case of Hajj.** Hajj [12–15, 59] is an annual pilgrimage in which more than two million people from different parts of the world travel to Mecca in Saudi Arabia. For several days, the pilgrims are required to travel en masse to different places of the Hajj precinct with very tight schedules. These movements in the past have witnessed several stampedes, resulting in thousands of deaths. In order to perform Hajj, participants must furnish personal and medical information months before the journey. This allows Hajj management to capture data of pilgrims. Hajj is a perfect case for using CCHMS as places of gathering of pilgrims and disaster-prone areas are well known, which can be conveniently divided into cells. A critical requirement of Step (2) for attaching RFID tags to the pilgrim bodies can be easily achieved, where Fog Node can read data from the RFID. In some places wireless sensor networks can be installed whereas in other places GPS can be used. Different purpose WSNs can be easily deployed in the majority of areas with an expectation of open spaces of intense crowding. As the mobile devices would have been registered in the central database, pilgrims would be able to access Hajj Mobile Apps easily.

Creation of Digital Streets in selected walkways, as in Step (3), can be achieved easily. As for Step (4), sensors' data with that of the pilgrims can be stored in a Cloud for mining and analysing. Hajj is a perfect case for using healthcare applications of HMS. Pilgrims can download these apps on their mobile devices.

**7.2. The Case of Kumbh Mela.** Kumbh Mela [12, 17] takes place every three years in one of the four Indian cities, namely, Allahabad, Haridwar, Ujjain, and Nasik, all situated along one or the other river. It attracts several millions of participants over a period of eight weeks. Unlike Hajj, the pilgrims mostly come from India and do not require prior permission, and hence there is no mechanism for collecting personal data of the pilgrims. Therefore, layers of CCHMS dependent on personal data, like those requiring medical and communication media, will not work. However, many other tasks and applications, including stampede detection algorithm, would work. If the crowding of the Kumbh Mela is to be properly managed, the management should introduce a mechanism for data collection.

**7.3. Case of Irregular Crowds.** There is no way of collecting personal data of participants of irregular and spontaneous crowds. As in the case of Kumbh Mela, CCHMS will be applicable in all those areas that do not require personal data.

## 8. Conclusions, Suggestions, Limitations, and Future Research

The framework within the CCHMS takes into account the nature of crowding and has built-in mechanisms to deal with them with the help of sensor and mobile technology. When applying CCHMS in real crowds, it is expected that the system would require some minor operational changes and adjustments. We believe that CCHMS can be adapted to manage crowded events around the globe. Analysis of stampedes in the last fifteen years reveals that the crowds in

some of those events were neither contained nor controlled. Personal experience of the authors of this article affirms that participants generally lack education and training of the usage of facilities and proper performance of various functions of the event. It is suggested that event participants must be provided with adequate education and training with simulations. Out of bounds crowds are very difficult to manage and hence it is the responsibility of the relevant authorities to limit the size of the crowd. Providing adequate facilities for managing crowded events would be very helpful in reducing the chances of disasters.

Going forwards, we would like to conduct a proof of concept for the layers in CCHMS while utilizing the required technology. This is however a difficult undertaking as most of the crowded events are organized and managed by the state. It is not feasible to access data or test and validate our algorithm for detecting and preventing stampedes from occurring, as it would require a lot of resources, permissions, and cooperation from various stakeholders of the event. For example, organization and management of Hajj involves interior, Hajj, foreign, and health ministries, as well as other historical stakeholders of the Kingdom of Saudi Arabia. The authors are making efforts to propose CCHMS to the stakeholders of the Hajj management for the purpose of adapting and implementing it in a phased manner.

If in the future we gain access to data for Hajj or other crowded event/s, we would trial the proposed Mobile Applications of HMS. If the access to Hajj data was granted, we would mine historical data which we believe would be very beneficial in organizing and managing future events. Our future research would also focus on privacy of security of participants' data and prevention and management of terror attacks as part of CCHMS.

## Data Availability

There is no data used to support this study.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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