Inferring Crowd Trip Informatics Using Mobile App in Hajj

Emad Felemban[1], Faizan Ur Rehman[2], Atif Naseer[3] and Sardar Asad Ali Biabani[3]
[1]Computer Engineering Department, Umm Al-Qura University, Makkah, Saudi Arabia
[2]Institute of Research and Consultation Studies, Umm Al-Qura University, Makkah, Saudi Arabia
[3]Science and Technology Unit, Umm Al-Qura University, Makkah, Saudi Arabia

Abstract
Millions of Muslims from different races, sectors, and cultures travel to Makkah Al-Mukarramah, Saudi Arabia, every year to perform Hajj. Because of their diversity, they act and behave uniquely from each other. Studying and understanding their behaviour is the key element to solve many crowd problems and to provide them with high satisfaction services. In this paper, we used smartphones as an instrument to collect crowd data during the Hajj. We developed a smartphone application to collect data from the pilgrim's location while performing a stoning ritual in Mina during the three days of their stay. Every day pilgrims walk to Jamarat building to perform the rituals from their respective camps in groups of 250s. The collected data has been analyzed in space and time domains to identify the path used, starting time of the trip, the duration of the trip, and the speed of the movement. This analysis will help different researchers to understand the behaviour of the large crowd by using invasive and straightforward technology.

Keywords:
Crowd Management, Spatial Analysis, Temporal Analysis, Hajj, Mobile App, Visualization, Mina.

1. Introduction

Hajj is the largest annual religious gathering where 2.5 Million Muslims from all over the globe gather in Makkah every year to perform this Islamic ritual. Hajj is totally based on mobility, Pilgrims gather in Arafat, then move to Muzdalifah and then stay in Mina for the next three days. In Mina, pilgrims walk from their camps to stone the devil statue in Jamarat building and return to their camps, creating massive crowd mobility patterns in Mina road network.

Pilgrims stay in Mina camps, the white tents shown in Figure 1, according to their nationality and group. During their 3-days stay in Mina, pilgrims walk to Jamart building in groups of 250 pilgrims in one group. A group leader is assigned to help the pilgrims navigate through Mina streets and to ensure their save arrival to Jamarat building. Figure

Figure 1 Pilgrims start their trip to Jamarat Building

Figure 2 Map Showing Mina Road Nework

2 shows the road network map for Mina, a sample camp location and Jamarat building in the upper left corner. The flow of all groups and pilgrims will eventually converge into Jamarat building, as shown in Figure 3. Finally, once the pilgrims finish their stoning rituals, they return to their camps, as shown in Figure 4.

Every season, Ministry of Hajj and Umrah (MoHU)[1] and Makkah Region Development Authority[2] issue crowd route plans for Mina including paths to be used from each camp and timetables for each group in each camp for the 3-Days

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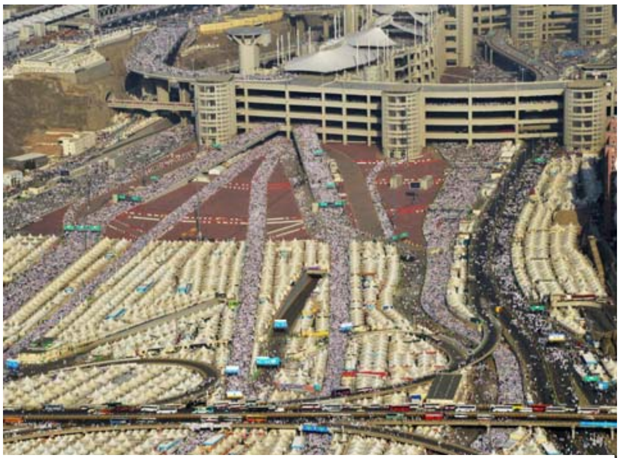


Figure 3 Massive crowd is converged to Jamarat Building from different roads

trip to minimize the risk of congestion and overcrowding.

Figure 4 Pilgrims are returning back to their camps

In this paper, we design and implement a framework for collecting, analyzing and visualizing the mobility patterns and behaviour of pilgrims during the trip from their camps to Jamarat building. The main objective of this exercise is to automate the process of identifying the path taken, the starting time of the trip, speed of walking and duration of trips from camps to Jamarat building. We believe that our framework can be used by Hajj organizers to understand the behaviour of crowd mobility better, measure the compliance with route plans and timetables, and to improve the overall services provided to pilgrims. The rest of the paper is organized as follows. Section 2 provides a short literature review of current related research work. A brief description of our framework and methodology is presented in Section 3 where Section 4 discussed about results and analysis. Section 5 talks about conclusion and future work.

2. Literature Review

Different technologies could be used to collect data about crowd movements, including tagging with RFID or smart cards, BLE beacons, Photo and Video Analytic and Mobile Apps [1-6]. Perhaps the most common, quick and cheap way to collect massive data in a short amount of time is through mobile apps installed on crowd phones. Tracking collective crowd movement in cities comes up with a lot of opportunities for both public and private sector. This data will be helpful for many applications including

- Estimating the required capacity of infrastructure and its conditions [7]
- Predicting the need for new facilities in different a reas such as shopping mall, firefighter station, and health services [8]
- Understanding crowd behaviour [9][10]
- Detecting crowd congestion [9]
- Optimizing Crowd Modeling [11][12]
- Scheduling and Rescheduling of Crowd Moveme nt Timetable [13][14]

Hajj is the largest annual gathering event for Muslims that occurs every year in Makkah, Saudi Arabia. Having Millions of people from all over the globe resemble a unique experience and data gathering opportunity to help Hajj organizers to improve services and increase safety measures, especially with massive crowd movements. Mobile Apps has been used in Hajj to provide services and collect crowd sourced data. Thorough research of Google Play's Mobile Apps related to Hajj is presented in [15]; however, most of these applications provided services and never claim to collect any data. The number of mobile apps surveyed was 246, and the features found surpassed 51. Manasikana[3] is the official Hajj mobile app issued by Ministry of Hajj and Umrah, which include queries, scheduling of supplications, the direction of Qibla, temperature, navigation, points of interest, contacting users, conversion of currency, tweets related to Hajj and messages from the ministry in different languages.

A system which functions as a crowd-sourcing mechanism for identifying pilgrim service data based on spatial-temporal needs is proposed in [16]. A mobile application to direct pilgrims to nearby facilities is presented in [17] by tracking and analyzing user locations. In [12], a mobile app is used to collect the walking velocity

[3] https://manasikana.haj.gov.sa

of pilgrims in Mina to validate the crowd modelling equations used in their scheduling algorithms for pilgrims.

Solutions exploiting wearable devices were proposed to be used in Hajj. Authors in [18] suggested a platform called *iCrowd* to capture, interpret, archive, evaluate and extract spatial and medical information collected through in-built sensors from the wearable smart devices of the pilgrims. In [19], the authors suggested a streaming server to extract data from build-in sensors in smart devices. Buses used to transport Pilgrims in Hajj are being tracked using AVL devices. Authors in [20][21] presented a fast platform to retrieve and analyze big spatial data related to bus movements. Authors in [22] proposed multimodal evacuation by analyzing a large amount of GPS data of buses to detect assigned and allowed path for buses during Hajj. Authors in [23][24] use smartphones to collect data. The author in [23] recommends an optimized path for the large crowd by gathering information and traffic constraints using mobile app and tweets and the author in [24] proposed Hajj crowd management and navigation system for people tracking and providing location-based services.

In this paper, we collected the location data of groups from the locations of their camps to Jamarat building using a simple mobile app. Up to our knowledge, there is almost no available work in the literature that shows an in-depth analysis of collected sensory location data from Hajj, including path identification, speed calculation and time comparison in a single framework.

3. Methodology and Framework

In order to collect and analyze the data, we are using the general methodology shown in Figure 5. First, location and time data is collected from mobile apps distributed to known users. The information is collected for all 3-Days, i.e. 10th,11th and 12th days of Dhul Hijja[4] from multiple groups originating from numerous camps. Data is stored locally in the smartphone, then streamed to our cloud spatial database in off-peak times.

Figure 6 shows an overview of our data collection framework. The server side consists of a server to handle the front-end request, a framework to visualize the data on the map, a push notification service for sending notifications to the front-end, and a relational database for storing the data. The front-end of the system has been developed in React native and backend developed in PHP

Figure 5 Proposed Methodology

Laravel with MS SQL database, as shown in Figure 6. The front-end communicated with the back end using HTTP RESTful APIs, which passes and receives the parameters in JSON format. The backend server runs on 2.5 GHz Intel Scalable Processor with 32 GB RAM on Amazon Web Service (AWS EC2 t3.2xlarge[5] instance), the relational database used MySQL and setup on db.t3.2xlarge[6] amazon relational database service (RDS), the front-end application has been developed using React native framework for IOS and Android application.

The android and IOS based front-end applications are compatible with Android 8+ and IOS 10.3.3+ operating systems. To support other functionalities and map-based visualization, the following framework, service and APIs are used:

- Twilio SMS API: We used Twilio[7] SMS APIs to authenticate the mobile number of the group leader at the time of registration.
- Push Notification Service: We used Firebase[8] Cloud Messaging (FCM) push notification service to remind the group leaders about their upcoming trip. The reminder was sent 15 minutes prior to their scheduled time. In case there is reschedule of group time due to any external parameters such as Rain or overcrowded, the notification has been sent to the group leader mobile app for the same.

[4] 12th month of Islamic Year
[5] https://aws.amazon.com/ec2/instance-types/
[6] https://aws.amazon.com/rds/mysql/pricing
[7] https://www.twilio.com/sms
[8] https://console.cloud.google.com/marketplace/details/google-cloud-platform/firebase-cloud-messaging

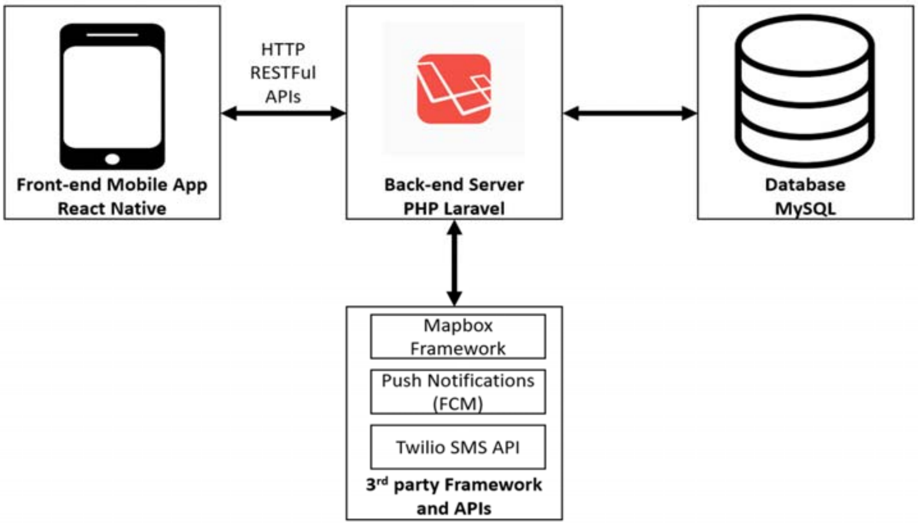
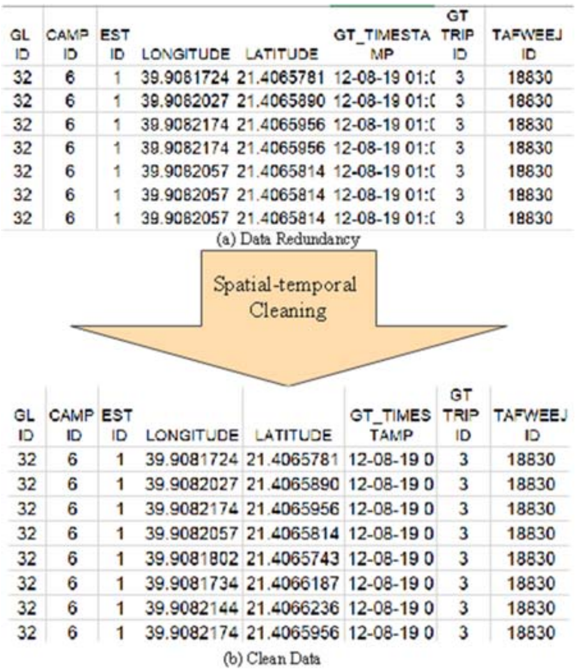


Figure 6 Proposed Data Collection Framework



GL ID	CAMP ID	EST ID	LONGITUDE	LATITUDE	GT_TIMESTAMP	GT TRIP ID	TAFWEEJ ID
32	6	1	39.9081724	21.4065781	12-08-19 01:(	3	18830
32	6	1	39.9082027	21.4065890	12-08-19 01:(	3	18830
32	6	1	39.9082174	21.4065956	12-08-19 01:(	3	18830
32	6	1	39.9082174	21.4065956	12-08-19 01:(	3	18830
32	6	1	39.9082057	21.4065814	12-08-19 01:(	3	18830
32	6	1	39.9082057	21.4065814	12-08-19 01:(	3	18830
32	6	1	39.9082057	21.4065814	12-08-19 01:(	3	18830

(a) Data Redundancy

GL ID	CAMP ID	EST ID	LONGITUDE	LATITUDE	GT_TIMESTAMP	GT TRIP ID	TAFWEEJ ID
32	6	1	39.9081724	21.4065781	12-08-19 0	3	18830
32	6	1	39.9082027	21.4065890	12-08-19 0	3	18830
32	6	1	39.9082174	21.4065956	12-08-19 0	3	18830
32	6	1	39.9082057	21.4065814	12-08-19 0	3	18830
32	6	1	39.9081802	21.4065743	12-08-19 0	3	18830
32	6	1	39.9081734	21.4066187	12-08-19 0	3	18830
32	6	1	39.9082144	21.4066236	12-08-19 0	3	18830
32	6	1	39.9082174	21.4065956	12-08-19 0	3	18830

(b) Clean Data

Figure 7 An Example of Data Cleaning

- Mapbox Framework: Mapbox[9] framework consists of APIs, Software Development Kit (SDK), custom map layers, icons, and live-updating map capabilities. We used Mapbox to visualize trip records collected through the mobile app on the top of the map, as shown in Figure 6.

[9] https://www.mapbox.com/

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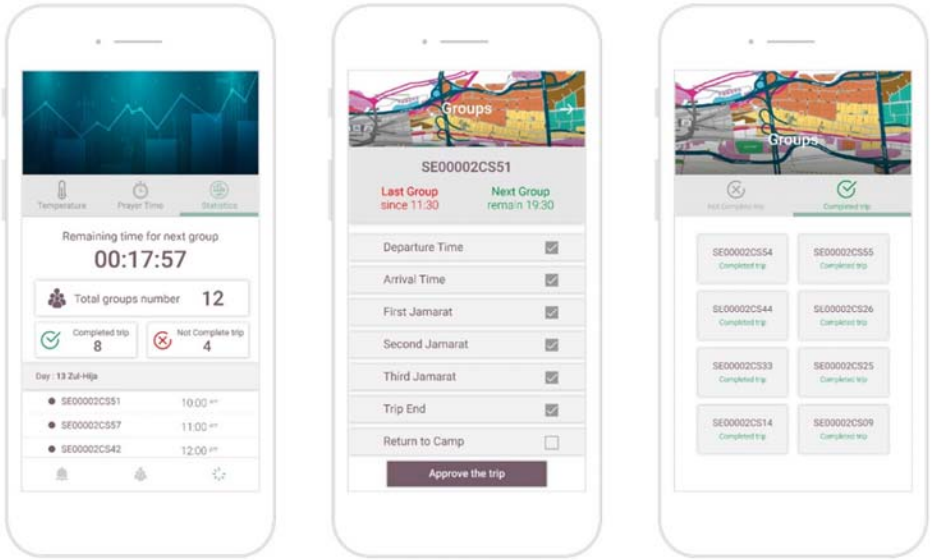
After the data collection phase is done, we cleaned the data using spatial and temporal filters. We found several duplicates and missing records in our database. We also found a lot of misbehaved data showing GPS locations outside Mina boundaries. Also, some of the mobile app users did not switch off the mobile app when they lift the site showing traces of their personal movements. These records are removed from the database to store in a clean format for analysis. Figure 7 shows an example of data cleaning applied to our collected data set. Figure 7(a) shows the redundant data in multiple rows that are removed by using some spatial-temporal techniques, and the cleaned data is shown in Figure 7(b). As part of this phase also, we did data transformation processing such as data normalization, data reduction, attribute selection, discretization, and hierarchy generation.

Finally, we perform analysis on data to calculate our metrics, including Paths used, Starting time of the trip and Walking velocity. Data collection is the primary building block in developing any system. This analysis helps us in the future to plan the scheduling of pilgrims more efficiently and effectively. The analyzed data is visualized to view the movement pattern of pilgrims' groups, their speed, behaviour, and duration of the trip. We used Mapbox to visualize trip records collected through the mobile app on the top of the map.



(a) Main screen dashboard (b) Logging checklist (c) List of completed groups

4. Result Analysis

Our proposed framework has been developed and used in Hajj 2019 to collect the data of the group's movement while performing stoning ritual on their 3-Days stay in Mina.

GL_ID	CAMP_ID	EST_ID	Longitude	Latittude	TRIP ID	TAFWEEJ ID
35	603	6	39.871277801184070	21.422606050097090	1	15315
35	603	6	39.873452610624600	21.421906838848820	1	15315
35	603	6	39.873452610624600	21.421906838848820	1	15315

Table 1 Sample Raw Data

The mobile app was distributed to around 700 group leaders. We asked them to enable the mobile app once they have a group scheduled to visit the Jamarat building. When the group leader starts his trip from the camp to Jamarat, he will create a trip session manually. The mobile app will begin logging the GPS location of the leader every two minutes interval. This data is uploaded in the database instantaneously except when no internet connectivity is available. Once the group leader arrives back to the camp after the trip is made, he will manually end the trip. The application collects the data for both the routes, i.e. while going towards to Jamarat and coming back from Jamarat building. Figure 8(a) shows the main dashboard of the mobile application, whereas Figure 8(b) shows the data collection checklist that group leader needs to click when he starts his trip till he returned back to his camp and Figure 8(c) shows a dashboard with the list of a completed trip by the same group leader.

During the 3-Days stay in Mina, we were able to collect 300K records representing data from around 200 group leaders who activated the mobile app. Many data were missing that was due to a couple of reasons including

- The mobile app was not started during trips
- Mobile phone GPS sensors misbehave
- Various Mobile app bug issues and/or Operating System updates problems
- Mobile phone battery issues
- Group Leaders did not perform the task

Table 1 shows a sample raw data stored into our database showing the locations and time recorded. In this paper, we present a case study of a round-trip movement of one group of pilgrims. To visualize the collected location points, we used Google maps, as shown in Figure 9. When compared with the Ministry of Hajj and Umrah records, we found that the group leader had followed the specific path dedicated to his camp, as shown in Figure 10. We have also found that for this trip, the pilgrims should start their journey to Jamarat building at time 01:15 PM according to timetable scheduled by the Ministry of Hajj and Umrah. Based on the data collected, this group started their trip around 01:26 PM, which is about 11 minutes late than their scheduled time.

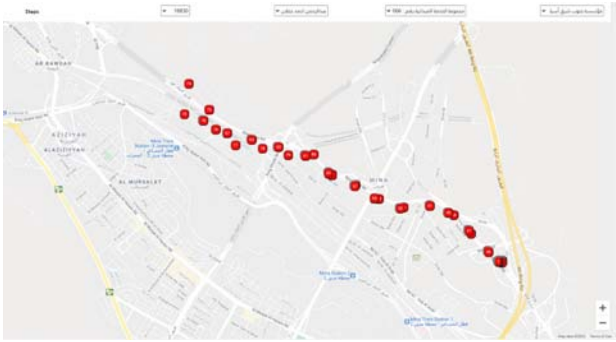


Figure 9 Visualizing a single round-trip data

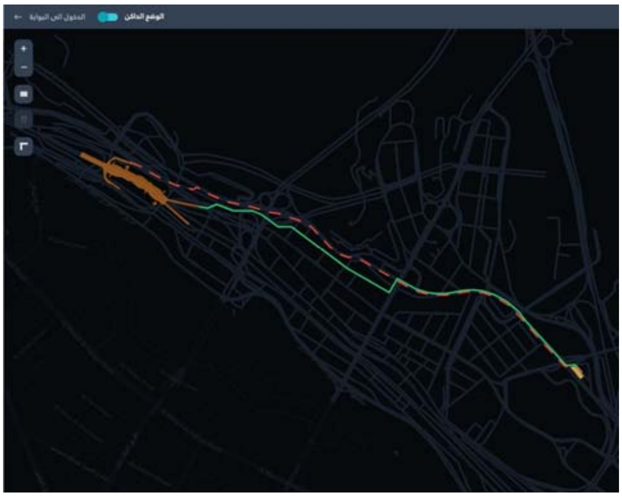


Figure 10 Camp Dedicated Path Visualization Comparison

5. Conclusion and Future Work

In this paper, we have collected and analyzed location data from group leaders in Hajj walking from Camps to Jamarat building and backwards again. We analyzed the collected data to extract important trip informatics such as path is taken, starting time of the trip, duration of the trip, and walking speed of pilgrims during this trip. This paper presents only a framework and a simple analysis process. We have selected a trip for a random group. We found that the leader for the random group has complied with the planned path and timetable specified for that group. In the future, we are planning to automate the whole analysis process to help speed up the analysis.

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References

[1] [1] M. Mohandes, M. A. Haleem, A. Abul-Hussain, and K. Balakrishnan, "Pilgrims tracking using wireless sensor network," in 2011 IEEE Workshops of International Conference on Advanced Information Networking and Applications, pp. 325–328, 2011.

[2] M. Mohandes, "An rfid-based pilgrim identification system (a pilot study)," in 2008 11th International Conference on Optimization of Electrical and Electronic Equipment, pp. 107–112, 2008.

[3] M. Mohandes, M. Haleem, M. Deriche, and K. Balakrishnan, "Wireless sensor networks for pilgrims tracking," IEEE Embedded Systems Letters, vol. 4, no. 4, pp. 106–109, 2012.

[4] M. A. Mohandes, "Mobile technology for socio-religious events: A case study of nfc technology," IEEE Technology and Society Magazine, vol. 34, no. 1, pp. 73–79, 2015.

[5] S. Jamil, A. Basalamah, A. Lbath, and M. Youssef, "Hybrid participatory sensing for analyzing group dynamics in the largest annual religious gathering," in Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing, UbiComp 15, (New York, NY, USA), p. 547–558, Association for Computing Machinery, 2015.

[6] A. Basalamah, "Sensing the crowds using bluetooth low energy tags," IEEE Access, vol. 4, pp. 4225–4233, 2016.

[7] A. Ghose et al., "Road condition monitoring and alert application: Using in-vehicle smartphone as internet-connected sensor," IEEE International Conference of Pervasive Computing and Communications Workshops, 2012.

[8] R. Szabo et al., "Framework for smart city applications based on participatory sensing," IEEE 4th International Conference on Cognitive Info-communications (CogInfoCom), 2013.

[9] M. e. a.Wirz, "Probing crowd density through smartphones in city-scale mass gatherings," EPJ Data Science, vol. 2, pp. 1–24, 2013.

[10] Z. B. T. X. and W. X., "Learning collective crowd behaviors with dynamic pedestrian-agents," International Journal of Computer Vision, vol. 111, pp. 50–68, 2015.

[11] "A hybrid simulation-assignment modeling framework for crowd dynamics in large-scale pedestrian facilities," Transportation Research Part A: Policy and Practice, vol. 86, pp. 159 – 176, 2016.

[12] M. K. S. M. K. Haase, M. Kasper, "A pilgrim scheduling approach to increase safety during the hajj," Operations Research, vol. 67, 2019.
[13] E. A. Felemban, A. Fatani, and F. U. Rehman, "An optimized scheduling process for a large crowd to perform spatiotemporal movements safely during pilgrimage," in 2019 IEEE International Conference on Big Data (Big Data), Los Angeles, CA, USA, December 9-12, 2019, pp. 6049–6051, IEEE, 2019.
[14] F. U. Rehman and E. A. Felemban, "A preference-based interactive tool for safe rescheduling of groups for hajj," in 16th IEEE/ACS International Conference on Computer Systems and Applications, AICCSA 2019, Abu Dhabi, UAE, November 3-7, 2019, pp. 1–2, IEEE Computer Society, 2019.
[15] E.Khan and M.Shambour, "An analytical study of mobile applications for hajj and umrah services," Applied Computing and Informatics, vol. 14, no. 1, pp. 37 – 47, 2018.
[16] S.Basalamah and F. UrRehman, "A survey on hajj mobile applications," International Journal of Computer Science and Network Security, vol. 20, no. 1, pp. 15– 30, 2020.
[17] A. Ahmad, M. A. Rahman, I. Afyouni, F. Ur Rehman, B. Sadiq, and M. R. Wahiddin, "Towards a mobile and context-aware framework from crowd sourced data," in The 5th International Conference on Information and Communication Technology for The Muslim World (ICT4M), pp. 1–6, 2014.
[18] S. Snoussi and Y. Wahabi, "Arabic document segmentation on a smartphone towards big data hajj rules extraction," in 2017 1st International Workshop on Arabic Script Analysis and Recognition (ASAR), pp. 109–113, 2017.
[19] S. Saeed, Abid A., "icrowd – a framework for monitoring of identifiable crowd.," in 12th International Conference on Innovations in Information Technology (IIT), pp. 1–7, IEEE Computer Society, 2016.
[20] S. Atta, B. Sadiq, A. Ahmad, S. N. Saeed, and E. Felemban, "Spatial-crowd: A big data framework for efficient data visualization," in 2016 IEEE International Conference on Big Data (Big Data), pp. 2130–2138, 2016.
[21] E. A. Felemban, F. U. Rehman, A. A. Biabani, A. Naseer, and U. AlAbdulwahab, "Towards building an interactive platform for analyzing movement of buses in hajj," in 2019 IEEE International Conference on Big Data (Big Data), Los Angeles, CA, USA, December 9-12, 2019, pp. 3775–3778, IEEE, 2019.
[22] E. A. Felemban, F. U. Rehman, H. Wadood, and A. Naseer, "Towards building evacuation planning platform using multimodal transportation for a large crowd," in 2019 IEEE International Conference on Big Data (Big Data), Los Angeles, CA, USA, December 9-12, 2019, pp. 4063–4066, IEEE, 2019.
[23] F. Ur Rehman, A. Lbath, B. Sadiq, M. A. Rahman, A. Murad,I. Afyouni, A. Ahmad, and S. Basalamah, "A constraint-aware optimized path recommender in a crowdsourced environment," in 2015 IEEE/ACS 12th International Conference of Computer Systems and Applications (AICCSA), pp. 1–8, 2015.
[24] R. O. Mitchell, H. Rashid, F. Dawood, and A. AlKhalidi, "Hajj crowd management and navigation system: People tracking and location based services via integrated mobile and rfid systems," in 2013 International Conference on Computer Applications Technology (ICCAT), pp. 1–7, IEEE, 2013.

Emad A Felemban is an associate professor in the Computer engineering department of Umm Al-Qura University. He is the founder of Crowd Management Technologies, a consultation office specialized in applying advanced technologies for crowd and mobility management. He graduated from Ohio State University with PhD and Master degrees in 2009 and 2003, respectively. His research interests include Wireless Sensor Networks, IoT, Optimization, and Scheduling, Mobility, and Crowd Management. He won many research funding projects from KACST, NPSTI, SABIC, and the Ministry of Education. He is a consultant with the Ministry of Hajj and Umrah. Contact him at eafelemban@uqu.edu.sa

Faizan Ur Rehman is a Research Associate and Consultant in Umm Al-Qura University, where he is working as a Principal Investigator in couple of projects. He is also a post-doc candidate in Department of Computer Science at University of Grenoble Alpes, France from where he has completed his PhD in 2018. He received the Bachelor's and Master's degree in Computer Applications from Jamia Hamdard, Delhi, India in 2005 and 2008 respectively. He has previously worked as a research assistant in Science and Technology Unit, Umm Al-Qura University. He also has industrial experience, working as a Software Engineer in Aricent and Samsung Engineering Lab, India. His research interests include spatiotemporal databases, algorithms, and human-computer interaction. Contact him at fsrehman@uqu.edu.sa.

Atif Naseer is an academician and researcher by profession and is currently serving as a researcher at Umm Al Qura University. He has been attached with academia for over ten years and has been part of many research and development projects. He is currently pursuing his Ph.D. degree with Universidad de Malaga, Spain in Video analytics. His current research interests include Artificial Intelligence, Computer Vision, Big data analytics, Internet of Things, Middleware modeling of Wireless Sensor Networks and Semantic Interoperability. Contact him at anahmed@uqu.edu.sa

Sardar Asad Ali Biabani has received a Bachelor's degree in Engineering from Jawaharlal Nehru Technological University (JNTU), Hyderabad, India during the year 2006. He did a Master's degree in Microelectronic & Communications Engineering during the year 2008 from the University of Northumbria Newcastle U.K. He worked as a Research Assistant and Project Management Consultant at Center of Research Excellence in Hajj and Umrah and later joined as a Research Projects Manager at Transportation and Crowd Management Centre of Research Excellence (TCMCORE) at UQU. He is currently working as a Research Associate and faculty member at the Science and Technology Unit at Umm Al-Qura University, Makkah, Saudi Arabia. His current research interests include Artificial Intelligence, Crowd Management, Knowledge Engineering, Big Data, Internet-of-Things (IoT), Traffic Engineering, Intelligent Transportation System (ITS), Data Visualizations and Visual databases. Contact him at sabiabani@uqu.edu.sa