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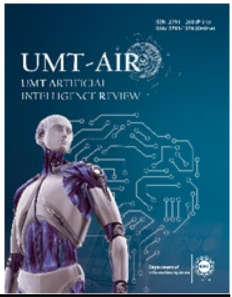

Title: **A Big Data Framework for Crowd Monitoring in Large Crowded Events**

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Big Data Framework for Crowd Monitoring in Large Crowded Events

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ABSTRACT The management of large events with hundreds of thousands of individuals has remained a challenge over the years. Crushes and stampedes occurring in the events of mass gathering have swallowed many valuable lives around the world. Considering the substantial advancement in positional tracking, wearable technology, and wireless communication, many event organizers are embracing the use of these technologies to get assistance in managing large events. Intelligent monitoring of crowd movement and timely analysis of evolving conditions may aid in early detection of critical situations. The current research aims to propose a big data resource framework to model, simulate, and visualize the crowd conditions for actual venue settings. A distributed framework has been presented to monitor the movement and interaction of individuals in large crowded events through localized sensing and geospatial analysis of massive positional data. The pilgrimage (Hajj) has been considered as a case study for demonstrating the effectiveness of the proposed framework. The proposed framework has been with the help of synthetic data that covered some useful and frequent scenarios based on the case study of pilgrimage (hajj), which is an annual event involving more than a million people.

INDEX TERMS agent-based modeling, big data, crowd simulation, crowd analytics, crowd visualization, multi-agent System

I. INTRODUCTION

Crowd management in large events with hundreds of thousands or millions of individuals is a critical challenge for authorities. For instance, physical management and monitoring of individuals in large events, such as the Olympics, Hajj, political gatherings, and live concerts is very tedious. The substandard route and traffic management in such large events may result into congestion which, in turn, creates panic among individuals and causes stampedes to occur. Such stampedes have been a major cause of accidents resulting into injuries and deaths of people. Furthermore, in the large scale events that span for multiple days, for instance Hajj and Olympics, there is a strong chance that people may get disconnected from their main group. Particularly, it is a common issue in case of Hajj where most of the pilgrims are old and are not accustomed to use cell phones. Technology has been used in many different manifestations to manage these large crowds. For instance, computer vision based techniques have been used to monitor the mobility and behaviors of crowds. Despite the substantial advancement in this field, the methods have turned out to be unproductive when applied at a large scale due to viewing angles and ambiguous detection limitations.

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On the other hand, the evolving trend of smart or context-aware environments has led to the proposition of geographically informative systems. In these systems, advanced tracking technologies are used to collect quantitative movement data. Individuals within a crowd are observed as profiled users. Global Positioning System (GPS) localization [1] and proximity based [2] tracking has been used to capture complex crowd dynamics during an event. Although, implementing and evaluating such systems yet adhere to many challenges, such as gathering and processing the data from heterogeneous sources and the expense of equipping the individuals or places with sensors.

Simulation serves as a means to design problematic scenarios and the mechanism in order to evaluate the behavior and operation of the opted solution or system. Crowd simulation, in particular, attempts to give an appropriate abstraction of the domain as mentioned above. For the realistic simulation of such events, the Multi-Agent System (MAS) approach is considered suitable as the agents are expected to move to their goals, interact with their environment, and respond to each other. MAS is also postulated as a preferred approach for emergency evacuation [3] because MAS models problems in terms of autonomous interacting component agents, proving to be a more natural way of simulating the un-predictability factor of large crowds.

It is pertinent to mention that crowd simulation methods for controlling individual agents in high-density crowd,[4] interactive virtual environments, [5] and position-based [6] solutions have already been proposed. The current study, however, distinguishes itself on stipulations related to a systematic analysis of the movement of crowds and its visualization in large events. The continuous tracking of individuals at a massive scale can be done more efficiently through a localized distributed sensing infrastructure along with the existing support of GPS.

The current research presents a big data resource framework that along with the simulation of a physical sensing network includes a parallel computing infrastructure to process large sets of collected positional data for real-time analytics to provide a crowd-monitoring platform for the authorities in any situation. The proposed framework has been evaluated by simulating some useful scenarios from a case study of Hajj.

The rest of the study has been organized as follows. Next section discusses the relevant literature. Some preliminary information has been presented in the subsequent section which defines the proposed framework. The next section provides complete details of the proposed framework and its relevance to one of the frequently organized large-scale event, Hajj. Experiments conducted, for some useful scenarios, involving spatio-temporal analysis of the positional data generated by the simulation for some useful and frequently executable scenarios in Hajj, have been presented in the next section. While, the last section concludes the research.

II. RELATED WORK

Managing and monitoring of large crowded events has been discussed by many researchers. Some the studies have proposed multi-agent systems for crowd simulation and management. While, others have worked on managing crowd based on the capacity of a venue with the help of video data processing and other with the help of multi-agent systems. This section discusses many different studies which focused on this problem in many different ways.

A framework for the simulation of cooperative tasks, performed by agents, was proposed by [7]. The proposed solution was supportive of four basic actions based on real-life scenarios. Managing workers' tasks, avoiding collision, state, and movement of workers was also managed by this framework. They presented an agent-based model to identify the factors which create panic among people. Additionally, they presented a way for evacuating large crowds during an unfortunate event [8].

A data-driven learning technique was proposed for representing the information pertaining to different scenarios of crowd simulation. A method based on the low dimensional crowd space technique was used to analyze crowd simulation accuracy [9].

Some other researchers also developed agent-based simulation techniques by extracting the feature of the crowd from a video. For instance, [10] used global path planning and collision avoidance strategies for evacuating the crowd. A multi agent-based model presented for evacuating the crowd during a violent attack [11]. While, [12] proposed a framework based on multi-agent reinforcement learning to detect congestion in the crowd. Another agent-based crowd simulation framework hase been proposed by [13] that employed AnyLogic libraries for the simulation of a crowd in runtime environment to simulate emergency evacuation strategies. The proposed framework based on analytical simulation environment. A Cluster Verification Model (CVM) proposed by using a Wireless Sensor Network (WSN) to solve the aforementioned problem for pandemic cases by using single cluster approach (SCA) and split cluster approach (SpCA) [14].

An interesting work on managing a massive crowd according to the capacity of the place by counting the number of persons getting in and out from the specific area by using WSN has been presented by [15]. Similarly, [16] proposed a WSN architecture to find an efficient solution in order to provide food items to the massive crowd. The supply of food conducted automatically in cluster form according to a given limit of time to avoid any food shortage. A real-time based crowd simulation solution proposed by authors. The presented model based on the integration of the potential field method and agent-based method. Different fields are used to calculate the real-time interactions and prevent collision among agents [17]. Another relevant and interesting study discussed the self evacuation of passengers during panic and its solution. For modeling of information, the spread ripple effect rule is used, a hypothesis is used to model individuals' behavior and decision-making during self-evaluation [18].

Another mobile phone-based crowd monitoring framework was proposed by [19] by using Wi-Fi and Bluetooth readings to estimate the crowd and claim their solution is the better and low cost. While, an automated surveillance system by using a computational object recognition system with a video stream was proposed by [20]. This system automatically tracks and identifies the individuals in the crowd by using CNN. Similarly, another framework named 'crowd Probe' was proposed to monitor the crowd in indoor settings. It utilizes hidden Markov model for extracting trajectories of individuals by using Wi-Fi monitor [21].

Another relevant work on the dynamic positions and events to manage the large crowd according to the capacity to avoid causalities was proposed by [22]. They studied a smart queue approach at various entry points to reduce the waiting time in the system as a function of the number of multiple entry/exit loops, social distancing, and arrival rates of pilgrims [23]. The authors designed a WSN based identification model by using grouping techniques and different operational phases to manage the crowd. Optimization of crowd monitoring discussed by authors: a solution for monitoring of crowd is proposed based on Wi-Fi/Bluetooth interface. Firstly, a large number of datasets are prepared and then localization and filtration are performed to estimate crowd density [24]. In [25], the authors proposed a real-time surveillance-based system namely smartiSS. The proposed system worked on the basis of monitoring Mac ids of individual devices.

A spatio-temporal based visualization of crowd movement, by using large-scale data in the form of a transition graph, was proposed [26]. A behavior analysis approach based on using generative model as Hidden Markov model to help crowd managers in order to make good decisions in invoking Internet-of-Things (IoT) services. The proposed approach based on spatio-temporal flow-blocks for marginalization of arbitrarily dense flow field [27]. The researchers studied about adoption and utilization of fences to guide crowd movement. They focused on crowd regarding the optimization of the fence layout for efficient crowd management by using simulation model [28]. The researchers designed a smart image enhancement and quality control system for resource pooling and allocation and IoT applied to crowd management systems [29]. The proposed model is developed by using Unity 3D. A video of persons walking and interacting is used for simulation and the results are presented by using visualization techniques [30]. A framework named 'icrowd' proposed by authors for monitoring and tracking the individuals. The proposed framework comprised of three layers and a real-time view of individuals is presented by this framework using real-time location of individuals [31]. In another effort, the authors presented a method to link the physics-based animations and multi-agent modeling to improve the efficiency of crowd simulation [32].

An improved version of the multi-agent reinforcement learning algorithm for learning is done on extracted information from videos [33]. For simulation of crowd, an algorithm was proposed to utilize the trajectories of pedestrians from videos and simulate these in the form of agents in simulation [34]. Similarly, a solution for simulation of a large number of agents based on nonvolatile ram (NVRAM) and agent based architecture for computing the simulation at a large scale was proposed by [35]. An agents based simulation application was proposed by [36]. The proposed method comprised of three modules including simulation environment for simulating the agents, agent model, and output for visualizing the simulated results. Mass-motion was used to optimize the crowd flow rate with density restricted to a safe threshold value for efficient crowd management. A robust regression model was developed to guide the authorities for the safe and efficient operation of the visiting corridor [37]. For the prediction of stampede in large crowd, authors proposed an architecture by using mobile sensing network combined with wireless multimedia sensing network. They considered mobile devices as nodes for crowd monitoring [38]. A vision-based method, to prevent the collision of agents in simulation environment, was proposed by [39]. By using cognitive science, they also predicted the upcoming collision among agents. By using navigation fields, authors presented a method to direct the agents in the simulation environment to monitor the virtual crowds [40]. They proposed human-like intelligent agents model governed by the rules of fuzzy-logic that model, simulates and visualizes crowd dynamics applicable to emergency situations [41]. The researchers studied that heuristics have multiple roles in crowd management including crowd recognition, tracking, congestion etc. [42].

Literature review shows that multiple solutions based on simulation and visualization methods have been proposed for monitoring and evacuating individuals during any critical situation in large crowds. Some techniques involved real time crowd monitoring or using Wi-Fi/Bluetooth for extracting user information or data generated by simulator for simulation and visualization of crowds. Certain limitations were found in the existing systems as some were tested on limited datasets and were not scalable for large crowds. Similarly, most of them did not discuss the context before and after any incident, and on the other hand, some discussed only crowd simulation. The current research presented a framework capable of modeling, simulation, and visualization of large crowds based on distributed approaches to monitor the movement and interaction of individuals in large crowds through localized sensing and geo-spatial analysis of massive positional data.

III. PRELIMINARY

The applicable entities have been classified as modeling layers. The individual model decides what an individual should do provided the status of the entities around it. The context layer approach smears the relevant context of an individual, whereas the venue model gives information of surroundings as shown in Figure 1.

A. INDIVIDUAL

Individuals in a crowd were proposed to be regarded as the agents in a world. Let's denote the person as p1, p2, p3,...........pn . Every individual has some attributes and behaviors with respect to their identities and places. Let's denote the identity of a person with unique id as id1, id2, id3 .... idm. As every person has unique identity, let's denote the person as referred in (1).

p1.id1, p2.id2, p3.id3 ....pn.i (1)

Attributes exist at more than one level. It starts with a basic level of distinctiveness, for instance, name, age, and gender. On the next level, are some crowd-related attributes, for instance, location and velocity. These multi-level attributes collectively form a profile that helps in identifying the individuals in a large crowd. Some general behaviors are associated with the type of agents, while others are specific to tasks and places. Many related actions are triggered when an individual performs a certain task.

B. VENUE

Large crowds occur due to an event happening at a specific venue which is divided into regions. Let's suppose the region as r1, r2, r3, ... rk. Furthermore, the region is divided into zones and pathways, respectively. Let's denote the zone in the region as z1, z2, z3, ... zs. As one region can have many zones, let's denote regions as referred in (2), (3), and (4).

r1 = z1.r1, z2.r1; z5. r1 (2)

r2 = z1.r2, z2.r2; z9. r2 (3)

rk = z1.rk., z2.rk...............zs.rk (4)

It shows that there are multiple zones in a region. The venue map is used as a background image in simulation calibrated with real-word settings to associate pixel values with specific places inside the simulated environment. The positional coordinates of moving individuals are that of factual surroundings. An event, in general, can hold many sub-events in particular. Those sub-events can also be defined so that a specific place is created for the event and when the sub-event ends, the place is removed from simulation, respectively. The venue of an event generally, has two substances, a point of interest for individuals and the available path to reach there.

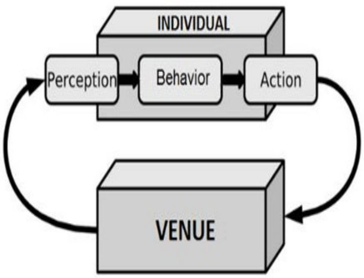

FIGURE 1. System Design

1) POINT OF INTEREST

It is considered as any place inside the created world which may be an originating position for some and a destination site for others. Some places remain throughout the simulation, while others are occasional. For instance, spring festival, in which there are bookstalls in a park during daytime and at night the place is transformed into a party area. Let's pix denote the point of interest as pi1, pi2, pi3 …….......pij are different points of interest in the scenario where the value of x ranges from 1 to j.

2) PATHWAYS

The presence of walls enforces constrictions on the area of movement for individuals. These walls are created by applying an alpha image of background in which walls are white where individuals cannot walk. Whereas, the rest results in pathways and points of interest to facilitate the mobility of agents for their movements. Let's pwk denote the pathways as pw1, pw2 , pw3 .... pwy. where the value of k ranges between 1 and y. Since, it is a known fact that one zone may have many pathways, therefore let's pwi:zj denote the pathway i in zone j. Thus, the pathways in different zones would be denoted as referred in (5), (6), and (7).

z1 = pw1.z1, pw2. z1……....pw5. z1 (5)

z2 = pw1.z2, pw2. z2; pw9. z2 (6)

zs = pw1.zs, pw2.zs; …......pwy.zs (7)

IV. PROPOSED ARCHITECTURAL FRAMEWORK

This section explains all the components of the proposed framework which follows a layered architecture. The layers and different components of the proposed framework have been presented in Figure 2. A distributed positional sensing infrastructure is placed at a physical layer which is the quantitative movement data source. A big data environment, containing distributed computing platforms and a data ingestion component, accumulates the processing layer to systematically preserve and process the anticipated massive geo-spatial datasets. Multiple visualizations of a moving crowd were proposed at the application layer by providing pre-analytics and post-analytics visualization modes.

A. PHYSICAL LAYER

This layer consists of sensing infrastructure which contains devices capable of transmitting positional data and crowd sensing nodes for the reception of that data. Numerous techniques, to sense crowd movement by using location-aware devices have been suggested, such as RFID wrist/ankle bands, and proximity-based sensing via Bluetooth [43]. The sensing infrastructure operates in a distributed fashion as distribution of operations is the essence of system design, maintained at every layer of the proposed architecture.

1) CROWD SENSING NODE

A sensing node is used to capture positional updates from location-aware devices. The node serves the purpose of collecting the data under a certain vicinity and processes the local information about crowd conditions. The collected information, then can further be sent to a nearby participant if requested by its connecting device. These nodes are placed at strategic junctions across the venue to cover the whole event. These connected nodes gather crowd information, create swarms, and then periodically transmit to processing infrastructure.

2) SIMULATION FRAMEWORK

Simulation can be used to design a problematic scenario and the mechanism to evaluate the behavior and operation of the opted solution or system. Crowd simulation attempts to give an appropriate abstraction of this domain. Therefore, another aspect of the current research was to simulate large events along with the usual amount of crowd they comprehend. Large events cannot be recreated to deploy and test the actual viability of the proposed crowd monitoring system at such a scale. However, possible scenarios in a large event if simulated and analyzed beforehand can be useful in devising the appropriate strategies to efficiently manage large crowds on the day of the event.

B. PROCESSING LAYER

The processing layer is composed of several interdependent components. At the bottom of this layer is the data ingestion and mapping component which spans from the collection of data to its filtration and modeling. An important component in this layer is the big data environment, specifically intended to incorporate the composition of several distributed processing frameworks. The layer is designed in a way that the incorporation of heterogeneous elements below and above this layer would not affect the transparency of its operations. Each component of the layer is described in detail below.

1) DATA COLLECTION SERVICE

A data collecting service is induced at the bottom of the processing layer which is responsible for ingesting the data from physical layer or simulator into the system. The service is generic to ensure that the system is not affected by the heterogeneity of devices in a physical sensing infrastructure or the operational difference of distributed processing frameworks.

2) DATA FILTRATION

The collected data needs filtration on certain parameters to reduce the workload of both storage and processing. Therefore, essential features are extracted to uniquely identify the individuals and analyze crowd conditions. Rest of the data is filtered accordingly.

3) DATA MODELLING

The data is modeled for identification of individuals. It is event-specific based on unique ID, group, nationality, age, gender, participants' location, and timestamp, as shown in Figure 3. Data modeling is also subjective to the nature of large events as well as the movement of the individual is tied with the movement of groups which leads to identify the participants in a large crowd.

4) BIG DATA ENVIRONMENT

The influx of the data from physical layer is expected to be huge in terms of volume and velocity. To process millions of records from the simulator and real-time, relational data stores and warehouses have limitations in latency and scalability. Therefore, big data processing frameworks were proposed to be included in the system to be the driving forces behind the extraction of value out of that humongous data.

The environment contains MongoDB, a robust and scalable Non-SQL storage, and Spark, an in-memory cluster computing framework for lighting fast analytics. They together give a vigorous combination for real-time analytics. Although, MongoDB itself has a wide array of query operations that are efficient to work on a huge volume of locational data. However, the inclusion of Spark enhances the capabilities of the environment as different levels of crowd information can be maintained by using Spark for rich analytics at both crowd and individual level. These frameworks use multiple machines to manipulate the data through distributed computing.

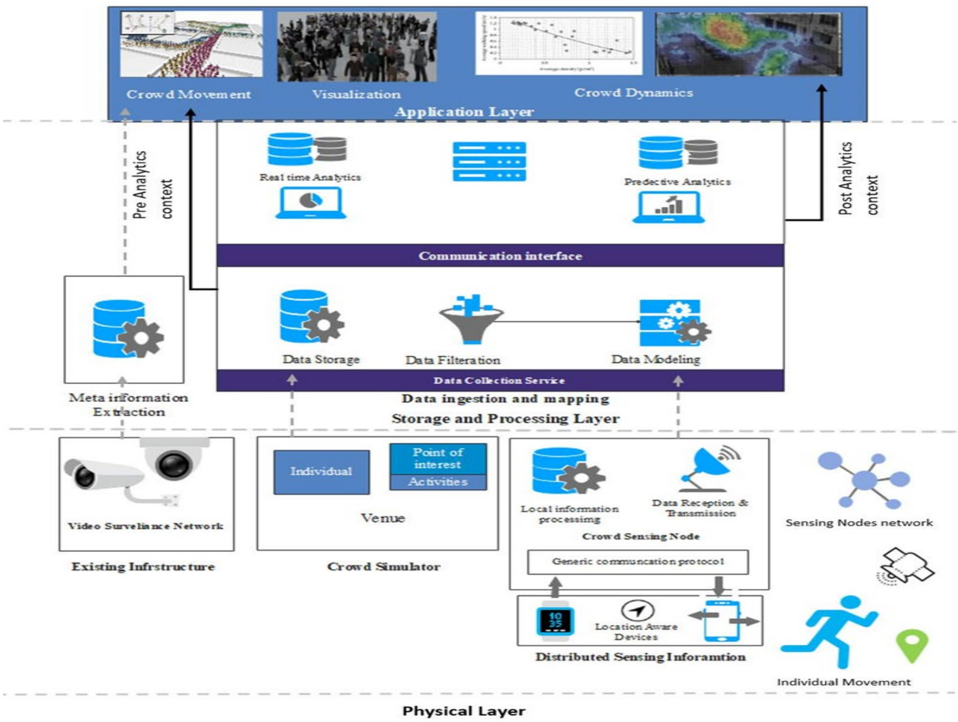

FIGURE 2. Proposed Architecture Framework

5) REAL TIME ANALYTICS

The current study intended to enhance and ensure the safety of individuals involved in an immensely crowded event. Therefore, information on crowd situations in real-time is of utmost importance. The data collected by the system is analyzed and processed concurrently to deduce the required output and have an insight into the crowd situation.

6) REAL TIME ANALYTICS

Stampedes and crushes can be avoided if crowd managers and authorities are proactive in terms of devising strategies to deal with critical situations. The imminent knowledge of crowd conditions attained through predictive analytics can help them to a significant extent. These predictions are formulated by analyzing the previous data and making models out of that data.

Unique ID
Name
Age
Gender
Nationality
Group ID
Group Role
Location (Latitude, Longitude)
Timestamp

FIGURE 3. Participant's Data Model

C. APPLICATION LAYER

The purpose of setting up the processing infrastructure is to build applications, which enables the crowd modelers and crowd observers to effectively manage large events, on top of it. The authorities can visualize crowd movement and formulated analytics to have an insight on rapidly changing conditions as shown in Figure 4.

1) PRE-ANALYTICS VISUALIZATIONS

The portrayal of the on-ground crowd condition is important for the assessment of the situation before analysis. Pre-analytics visualizations are, therefore, provided for the thorough monitoring of crowd movement at large. The movement of individuals, in a real crowd, can be observed as moving agents in a simulated environment. The context of every individual is changed to its position, point of heading, or on-going activity. Therefore, information on the participant's context is provided in a way that monitoring authorities can specifically track a participant.

2) POST-ANALYTICS VISUALIZATIONS

The visualizations formulated after the transformation and processing of individuals' positional data are of extreme importance to monitor and organize massive crowded events. These visualizations are formed by deducing the information on different crowd parameters, such as crowd density and crowd flow. The articulated graphics are relative to the population of participants under a certain vicinity over various time frames. Heatmaps generated on crowd density can give a bird's eye view of the crowd situation and perhaps allow crowd monitoring authorities to easily determine the congested and free-flowing areas in large events.

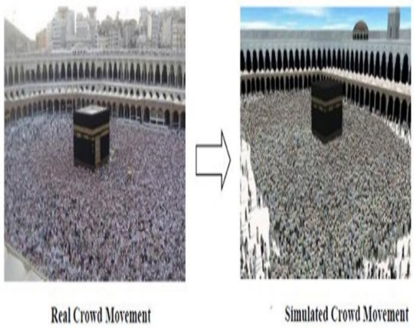

FIGURE 4. Crowd Movement

V. IMPLEMENTATION DETAILS

A proof-of-concept cycle of the proposed framework has been presented in the current study. The development work includes simulation of large events, real-time analytics on positional data of individuals in those events, and multi-dimensional visualizations on crowd conditions. Java is used as a development language at every layer of the architecture as comprehensive APIs of the opted frameworks were available in Java.

A. PHYSICAL LAYER

JAVA based simulator has been used at the physical layer, however, the proposed architecture suggests the placement of distributed sensing infrastructure to gather the positional data.

1) LOCATION AWARE DEVICES

Numerous devices exist which are capable of acting as location-aware gadgets, for instance smartphones, smart devices, such as GPS wrist/ankle bands, smartwatches, proximity-based sensing via Bluetooth/WLAN scanners, and infrared-based human presence sensors as shown in Figure 5.

FIGURE 5. Location Aware Devices

Therefore, information on participant's context is provided in a way that monitoring authorities can specifically track a participant.

2) DATA COLLECTION NODES

A data collection node is used to capture the positional updates from location-aware devices. In notion of large events, a data collection node serves the purpose of collecting the data under a certain vicinity and processes some local information about crowd condition. The collected information can further be sent to a nearby participant if requested by its connecting device. These nodes are placed at different junctions and distributed across the venue to cover the whole event.

3) SIAFU TOOL FOR SIMULATION

For the simulation of large crowds, a comprehensive tool named Siafu is used which is a multi-agent system. The simulation includes agents, the context therein. Siafu can generate its context . Moreover, simultaneously it can also augment real context coming from the sensors. Simulation serves as a means to design a problematic scenario and the mechanism to evaluate the behavior and operation of the opted solution or system. Crowd simulation attempts to give an appropriate abstraction of this domain. Therefore, the other aspect of the proposed framework is to simulate large events along with the usual amount of crowd they comprehend. Firstly, large events cannot be recreated to deploy and test the proposed crowd monitoring system's actual viability at such a scale. Moreover, possible scenarios in a large event if simulated and analyzed beforehand can be useful in devising the appropriate strategies to efficiently manage a large crowd on the day of the event.

A generic context simulator was used [44] for the basic modeling of entities in a scenario. The simulator itself is broad in terms of information sources, however, it is limited in terms of event-driven activities and behaviors. The concept was extended towards immensely crowded events and activities of individuals that it comprehends. The simulator works as a Multi-Agent System (MAS). For the realistic simulation of such events, MAS approach is considered suitable as the agents are expected to move to their goals, interact with their environment, and respond to each other. MAS is also postulated as a preferred approach for emergency evacuation simulations [3], because it models the problems in terms of autonomous interacting component-agents, which is proving to be a more natural way of simulating the unpredictability factor of large crowds. The simulator can generate its own context and at the same time can also augment the context coming from real-time data sensors. The simulated world includes models for agents, the world, and the context therein. In order to create random participants, every participant is assigned a unique ID, group ID, age, nationality, and activity. The gender of the participant is assigned colors. Moreover, color is also assigned to the group leader as explained in algorithm I. To create random population world w, the population count is assigned a variable C, group limit, and group check is assigned variable L and G, respectively. After iteration, random agents are created and the list is returned as explained in the algorithm II.

```
Algorithm: CREATE RANDOM PARTICIPANT (World w, C, G)

let P be the object of participant's class
let R be the random number between -2 and 1
let COLOR be the participant's color
let L be the group limit
let C be the population count
P.set(ID, unique_ID)
P.set(GROUP ID, G_ID)
P.set(AGE, Call Random(Age))
P.set(NATIONALITY, Call Random(NationalityList))
  P.set(ACTIVITY, Call Random(Activity))
   if R = 0 then
       COLOR := Blue
       P.set(GENDER, male)
   else
       COLOR := Brown
       P.set(GENDER, female)
   if C % L = 0 then
       COLOR := Magenta
       P.set(ROLE, leader)
  else
       P.set(ROLE, normal)
```

Algorithm I. Create Random Participants

MongoDB Java driver is selected as Java the development language. It provides both, synchronous and asynchronous interaction with the application. Four shared collections are created to meet the required functionality of the system. Collections with their primary function are shown in Table I. Spherical GeoJSON objects are used to store the locational data. The participant's position is stored as a point, while zone bounds are saved as a polygon. Every participant is assigned a unique ID, group ID, and role object of MongoDB for participant role. By using MongoDB query, every participant with a unique ID, group ID, role, location, and coordinates of the participants are inserted in DB as shown in Figure. 6 to continuously update the information of individuals by which every individual can be monitored and located based on his/her trial. An inclusion geospatial query, to find points confined in a polygon, is executed which eventually returns the number of participants in that defined region. MongoDB creates a unique index on ID field by default upon the creation of a collection. A geo-spatial index is created on the location field of a record and a single field index on timestamp. These indexes collectively increased the performance of queries. Spark's Java API is used to write scripts to analyze the operational data managed by MongoDB.

Algorithm - II : CREATE RANDOM POPULATION (World w)

```
let C be the population count
let P be the list of participants with size C
let L be the group limit
let G be the group check
G:=1
For i =1 to C do
  if i % L = 0 then
    INCREMENT G
  End if
    P.add( CALL CREATE RANDOM AGENT(w ,i, G))
End For
RETURN P
```

Algorithm II. Create Random Population

TABLE I

SHARED COLLECTION

Collection	Primary Function	Frequency of Use
Participant	To store participant' data record.	The records are inserted continuously.
Zone	To store information on zones.	The records are inserted and retrieved for zone based crowd analysis.
Real-Time Analytics	To store crowd parametric information with respect to zone or elsewise	The results are stored and retrieved continuously.
Predictive Analytics	To store predictive information on crowd situation.	The results are updated after a certain time

B. APPLICATION LAYER

The application layer plays an important role in terms of modeling and monitoring of large events. Initially, a desktop application is developed which intended to capitalize the processing infrastructure and to give crowd modelers and authorities a platform in order to model and monitor the crowd movement at large.

C. CROWD ANALYTICS APPLICATION

This application is developed by using JavaFX to build most of the extensive chart libraries. The application is categorized into three modes. Each mode is designed and developed to give a specified set of functionalities. The whole application is built on a customized framework of screens to incorporate modifications and adjustments with ease.

GeoJSON (Point):

```
"geometry": {
"type": "Point",
"coordinates": [lat, lon]
}
```

GeoJSON (Polygon):

```
"geometry": {
  type: "Polygon",
  coordinates: [ [ [ lat , lon ] , [ lat , lon ] , [ lat , lon ] ,
[ lat , lon  ] ] ]
```

MongoDB Geospatial (Inclusion) Query:

```
loc: {
      $geoWithin: {
         $geometry: {
            type: "Polygon",
            coordinates: [
               [
                  [ lat, lon ]<1st Point>,[ lat , lon ] <2nd Point>,
[ lat, lon ] <3rd Point>, [ lat, lon ]<4th Point>, [ lat, lon ] <1st
Point>
```

FIGURE 6. GeoJSON Objects and Query

1) DEPLOYMENT MODE

The application allows the modeler to generate resources that are required in the simulation. The modeler can specify coordinates of the venue to get a real map to be used as a background in the simulation. Pathways and points of interest can be created with just a mere click. Moreover, the modeler can drag and drop a polygon over the venue map to categorize the venue into different zones. The polygonal bounds attained in pixels are converted into positional coordinates, provided that bounds of the venue are defined.

2) SIMULATION MODE

Few batch scripts are created to resolve the dependencies involved in the working of a simulation. These scripts are triggered and run in the background while using the functionalities given by the simulation mode. The simulation model is used to update the simulation by loading the newly created resources created in the deployment mode. The observer can start the simulation once it is laden.

3) ANALYTIC MODE

This mode is developed for the monitoring of crowds. Real-time information, on several crowd parameters, can be observed. The crowd observer can also get hold of the historical crowd conditions. Moreover, zone level analysis can also be articulated to monitor the individual's trial in case of any critical misadventure or a violent attack. Individuals existing at the place of the crime scene before or after the crime can be tracked from their trial. It is easier to determine a critical situation when extracted information from the data is displayed in the form of graphs, maps, and alerts are generated for the capacity information. Zone on the image is assigned values and the value of color is assigned by a variable C as presented in algorithm III.

Algorithm - III: HEAT MAP GENERATION (Overlay O)

```
let TX be the top left horizontal point of zone on image
let TY be the top left vertical point of zone on image
let BX be the bottom right horizontal point of zone on image
let BY be the bottom right vertical point of zone on image
let C be the color value
  FOR i = TX to BX do
     FOR j = TY to BY do
        O.setPixelValue(i j,C)
     END FOR
  END FOR
```

Algorithm III: Heat Map Generation

4) CROWD INFORMATION CHARTS

The information attained through analytics on positional data is portrayed in the form of charts given in Figure 7. A dynamic line graph, illustrating real-time crowd flow, is generated. Moreover, a static line graph, to show historical crowd flow with respect to recorded timestamps, is also formulated. For crowd information charts, zone area is calculated as shown in the algorithm IV.

Algorithm - IV: ZONE AREA CALCULATION

```
let TL be the top left point of zone
let BR be the bottom right point of zone
let R be the earth's radius
let Area be the zone area in square units
let PI be the value of pi
Area = (PI/180) * (R*R) * SIN (PI/180*TL.latitude)
  – SIN (PI/180*BR.latitude)*(TL.longitude - BR.longitude)
```

Algorithm IV: Zone Area Calculation

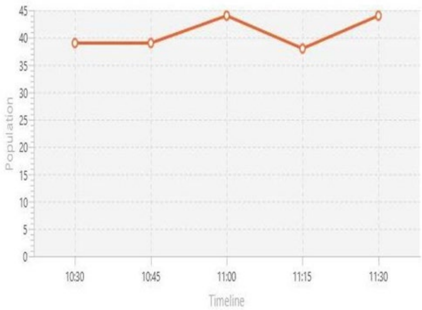

FIGURE 7. Zone Population Over Time

5) HEATMAPS

Heatmaps are based on crowd density of a specific zone. Values are associated with five colors, that is, blue, cyan, green, yellow, and red. Red is the immensely populated area as shown in Figure 8. Heatmaps depicting real time crowd information are rendered in every iteration of the

Simulation. Whereas, predictive heatmaps are rendered after one hour to forecast the next hour's conditions. The results of predictive analytics attained through Spark are stored in a specified collection of MongoDB which is queried for the generation of a predictive heatmap according to the number of participants in a zone as shown in Figure 9.

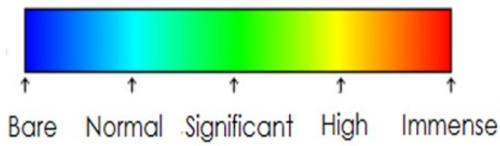

FIGURE 8. Color Scheme to Illustrate Crowd Density

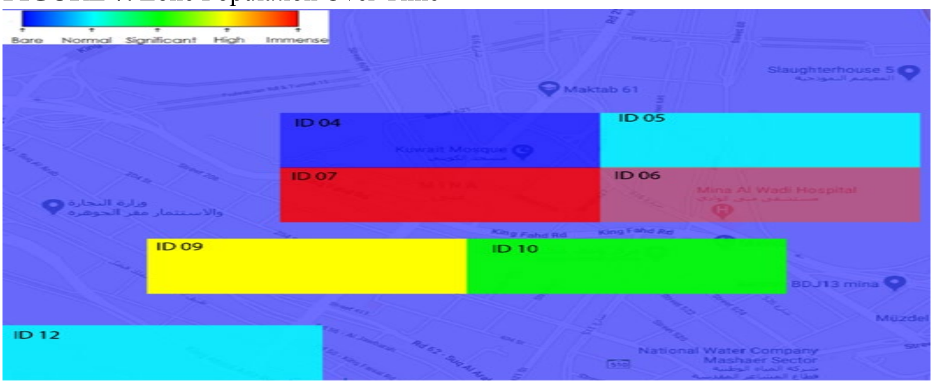

FIGURE 9. Heatmaps Depicting Crowd Density in Two Different Zones

6) ALERT GENERATION

With the generation of heatmaps for crowd analysis, alerts are also being generated based on crowd density in a zone, as zone information is updated continuously in shared collection. The system is designed in such a way that the modeler can set the limits of participants in defined zones and easily manage and monitor the crowd. If the capacity of the moving crowd (number of the participants) approaches to maximum limit in a zone then, an alert would also be generated with the heatmap system as shown in Figure 10. Additionally, by using the breadth first search technique, the system suggests to modeler to redirect the crowd towards nearby zones having maximum empty space (available capacity). For instance, zone capacity is 5000 participants, when it reaches to 4000 it would generate an alert that zone capacity is approaching to its maximum. When it reaches to 5000 approximately, then a No Entry alert would be generated which would stop the crowd outside the zone.

FIGURE 10. Alert Showing Crowd Capacity Warning

VI. CASE STUDY: HAJJ

The venue holding large crowds contains possible random events related to time and place that can be known and unknown. Situational contexts are regarded, such as location, environment, or state of the agent is dependent on the situation. The repertoire of their behavior relies on the dynamicity of an event. Hajj is the annual pilgrimage of Muslims to Makkah, Saudi Arabia. This pilgrimage contains more than 3 million Muslim participants from around the globe and is considered as one of the large mass gathering. It is conducted every year in the last month of the Islamic calendar (Dhu-al-Hijjah) on specified dates, that is, from 8^{th}-13^{th}. Receiving, managing, and monitoring this crowd with cameras and manually is not feasible, as all the Islamic religious activities of Hajj, named as rituals are required to be performed simultaneously and in the same place for all crowd. On one side, the organizers are struggling to conduct the event without the occurrence of any accidents or critical incidents, such as stampedes, fire, or medical emergencies. On the other side, the participants and their local/native organizers struggle to keep their groups combined, avoid dispersing their groups during crowded rituals, finding the lost, and missing ones from their group.

The proposed system will be connected with a command and control center to share the information of any disaster or mishap with the authorities and official relevant departments including rescue teams, police, army, and fire brigade to start the rescue operation. Since, the number of pilgrims keep on increasing every year and to model the event, some related activities of individuals and places have been defined to store the information of individuals for finding, tracking, and trailing every individual and group leader. A pilgrim's unique profile comprises of their name, ID, gender, origin, maktab, and location. Hajj has many sub-events, such as Situational Context Tawaf, Rami, Halaq Analytics Flow, and turbulence density. Therefore, Hajj areas have been divided into regions which are further divided into multiple zones as shown in Figure 11.

FIGURE 11. Sample Zone Division of Arafat Plain (Makkah)

A. ANALYTIC

Productive information on the movement and influx of large crowd, in a simulated scenario, is attained by performing analytics on parameters at both individual (agent) and crowd (multi-agent) level. Different functions are provided to analyze the movements of individuals as shown in Figure 12. Analytics can further be utilized to estimate and visualize the possible outcomes. For instance, an increase in crowd density at the junction of less capacity may result in an unfortunate event, that is, stampede. Therefore, efficient analytic plays an important role in seeing ahead of the ongoing state of affairs. The predicted upshot can also be communicated within individuals in a crowd for situation awareness and alertness.

FIGURE 12. Movement of Agents in Simulator

B. VISUALIZATION

Visualization is an important aspect of simulation since it is the form of graphical communication. The interactive interface allows users to analyze the status of an individual with respect to different levels of information. Textual information is not sufficient at times to realize the analytical spectrum of a situation. For that purpose, context overlays and heat maps are provided to graphically signify the surroundings.

VII. RESULTS AND EXPERIMENTAL SETUP

A. DATA SETS

The data generated by simulator is used to conduct the experiments. Three different sets of operational data are selected based on crowd population, crowd observation time, and data collection time difference for each set as shown in Table II.

TABLE II

OPERATIONAL DATA

Parameters	Data- I	Data II	Data III
Crowd Population	10,000	50,000	100,000
Crowd Observation Time	180 Min	180 Min	180 Min
Data collection Time Difference	3 Min	3 Min	3 Min
No. of Records	10000 x 180/3 = 600,000	50000 x 180/3 = 3,000,000	100,000 x 180/3 = 6,000,000

B. TESTING SCENARIOS

The proposed framework has been evaluated on following three frequently executing scenarios covering different aspects of crowd monitoring, management, and analytics. To this end, different variations have been incorporated in the volumes of the data and indexes.

1) SCENARIO-I

The first scenario aims to calculate the number of people in a zone at a given point in time. This, in turn, can help in calculating the total population of a region.

2) SCENARIO-II

The second scenario is a very common problem during the Hajj and helps finding the lost individuals, as there are a large number of old-age personnel performing Hajj and they get disconnected from their caretakers very frequently due to many reasons.

3) SCENARIO-III

The third scenario is related to data analytics. It intends to find people near the place of any incident at the time of that incident. This is a useful scenario that helps in conducting the investigation of an incident.

C. EVALUATION

The performance of an index is evaluated on three different volumes of data. The quantum of positional data varies with respect to the crowd population. The performance of a query with or without an index is measured with respect to its execution time.

D. OPERATIONAL DATA

Queries execution times are given in Table III.

TABLE III

QUERY EXECUTION TIME

Query-I	Parameter (Time Milliseconds)	Data-I	Data-II	Data-III
	Time (without Index)	550	3093	6484
	Time (with Index)	53	788	1230

Query-II	Parameter (Time Milliseconds)	Data-I	Data-II	Data-III
	Time (without Index)	6123	23587	52138
	Time (with Index)			
Query-III	Parameter (Time Milliseconds)	Data-I	Data-II	Data-III
	Time (without Index)	312	1596	3303
	Time (with Index)	1	1	1

1) SCENARIO-I CALCULATING ZONE POPULATION

The compound query incorporating this scenario was executed against different sizes of positional data generated by the simulator to calculate the number of participants present in a specified zone to ensure the number of participants is not exceeding the zone's defined capacity. Since, the number of participants exceeds the defined capacity, chances of stampede and crushes increase as well. The performance of a query was measured with respect to its execution time. Figure 13 shows that the execution of query took 550 milliseconds without an index, whereas 53 milliseconds with a compound index for data set I. However, for data set II, it took 3093 milliseconds without an index, and 788 milliseconds with a compound index. While, for data set III, it took 6484 milliseconds without an index and 1230 milliseconds with a compound index to execute. The line graph presented in Figure 14 shows that without the compound index, the query response time grows exponentially, whereas with compound index it grows linearly.

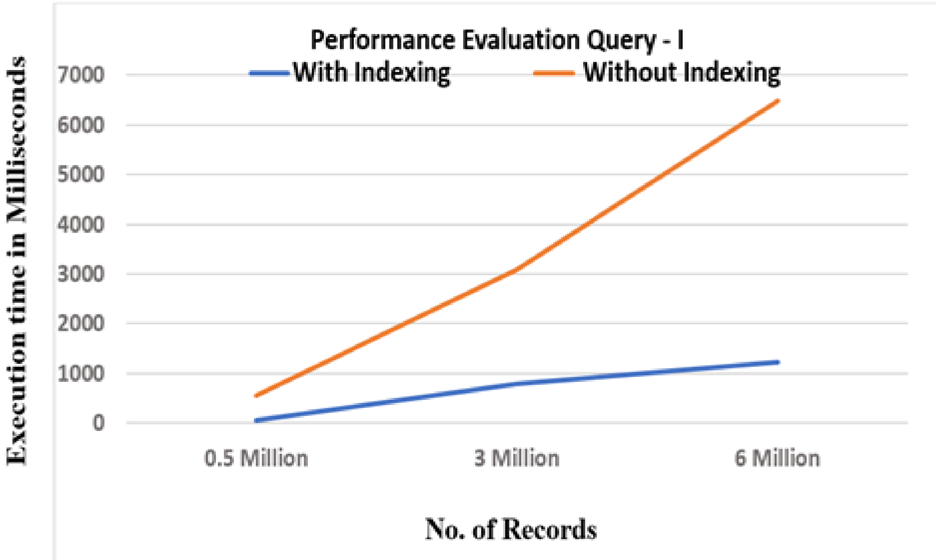

FIGURE 13. Query-I Participants Present in a Specified Region Within a Certain Time Frame

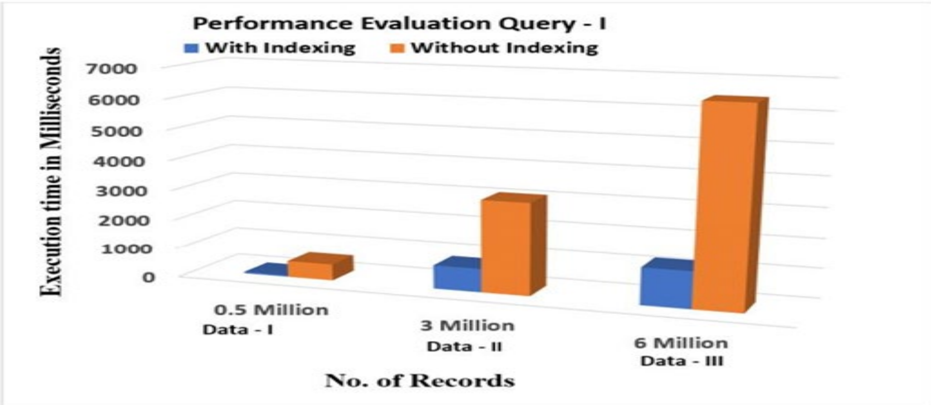

FIGURE 14. Query-I Participants Present in a Specified Region Within a Certain Time Frame

2) SCENARIO-II LOCATE A LOST INDIVIDUAL DURING HAJJ

A compound query, incorporating scenario II, was executed against different sizes of positional data generated by the simulator. It intends to locate the lost individual from his/her current position and through the trial of the individual's movement. Since, it is almost impossible to locate a lost individual in such a large crowd. The performance of a query is measured with respect to its execution time and the evaluation results are presented in Figure 15 and 16, respectively. The query execution time for Data-I is 312 milliseconds without an index and 53 milliseconds with a single field index. Whereas, for Data-II, it took 1596 milliseconds without an index and 23 milliseconds with a single field index. While, with Data III, it took 1596 milliseconds without index and 11 milliseconds with a single field index. It is important to mention that the data model is designed carefully to accommodate this use case. As a matter of fact, each individual's trail is stored in a separate file along with relevant meta information. Thus, finding an individual's trail and current location are possible very quickly with the help of index.

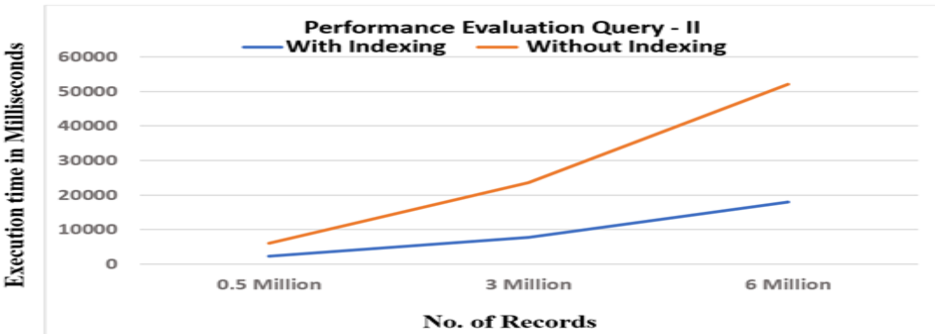

FIGURE 15. Query-II Participants Present at a Certain Distance from a Specified Point

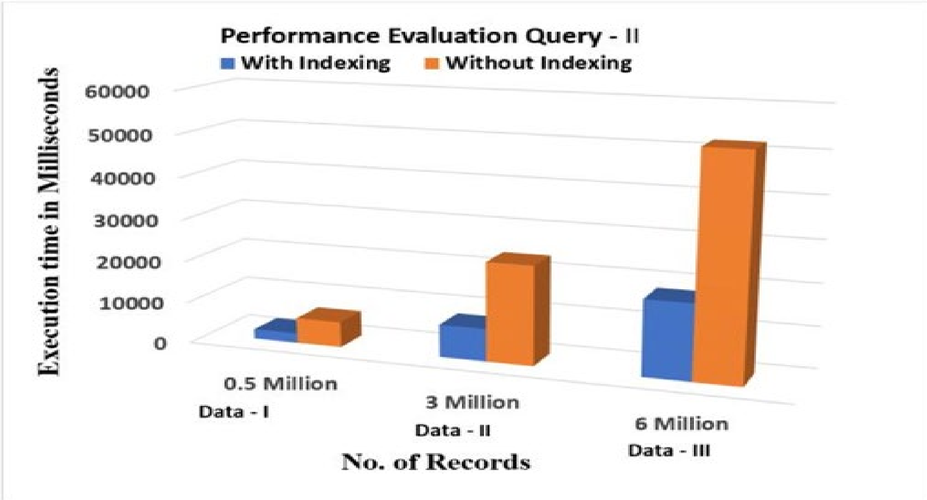

FIGURE 16. Query-II Participants Present at a Certain Distance From a Specified Point

3) SCENARIO-III PARTICIPANTS PRESENT AT A CERTAIN DISTANCE FROM THE PLACE OF THE INCIDENT AT THE TIME OF THE EVENT

A compound query, incorporating scenario III, was executed against different sizes of positional data generated by the simulator to locate the individuals and their distance from specified points, such as boundary walls, pathways, entry, and exit points defined in the region. This query helps to monitor the individuals present around the place of incident at the time when the event took place. It is pertinent to note that such queries will be executed on analytical engine and not on real-time monitoring site. The performance of a query is measured with respect to its execution time and the evaluation results are presented in Figure 17 and 18, respectively. Figure 17 shows that for data I, the query execution time was 6123 milliseconds without an index, whereas 2347 milliseconds with a geo-spatial index. For data II, it took 23,587 milliseconds without an index and 7800 milliseconds with a geospatial index. While, for data III it took 52,138 milliseconds without an index and 18,022 milliseconds with a geospatial index point. On the other hand, it can be observed from Figure 18 that the execution time without indexing is approaching to exponential trend. While, the execution time with index is slightly higher than the linear behavior. It is pertinent to mention here that this query is not meant for live data monitoring, rather it will be executed on analytical engine for post-incident investigations. The performance of a query is measured with respect to its execution time and the evaluation results are presented in Figure 17 and 18, respectively. Data I includes positional data of 10,000 participants observed with a time difference of 3 mins resulting in 0.6 million records. In this case, the query took 312 milliseconds without an index, whereas 53 milliseconds with a single field index to execute.

FIGURE 17. Query-III Trail of a Participant

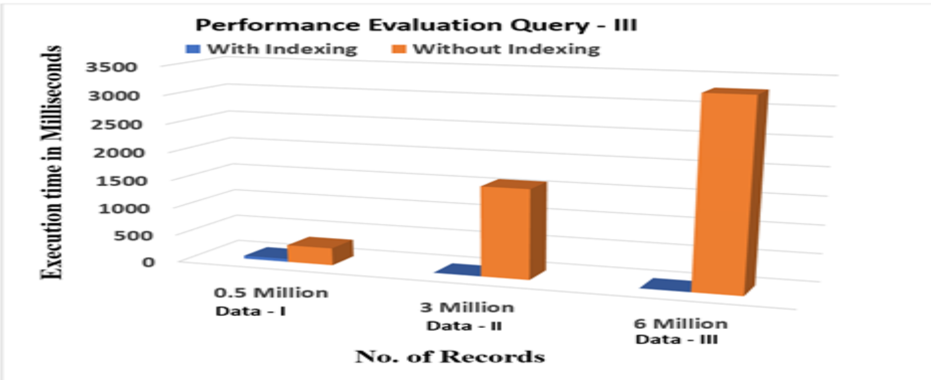

FIGURE 18. Query-III Trail of a Participant

VIII. CONCLUSION

A big data resource framework has been presented in the current study to store and analyze positional data of large crowds. This framework allows the crowd modelers to model large events and enables them to: a) design event-centric simulation by using a generic context simulator to incorporate large events; and b) to crowd monitoring authorities in order to analyze current crowd conditions to prevent any problematic situation. A proof of concept application has also been implemented to model and simulate large events, analyze, and visualize crowd dynamics from different aspects. Whereby, heatmaps and graphs have been employed to visualize the crowd movement and density in different zones and regions at a given point in time. The proposed processing infrastructure comprises of a) MongoDB a distributed data store to store the data and process geospatial queries; b) Spark a distributed processing framework for performing real-time and predictive analytics; c) a data ingestion component to facilitate pre-processing of data utilizing filtration and modeling; and d) a simulation component to generate data. The efficiency of the proposed framework was evaluated on simulated data by executing geospatial queries for some frequently occurring scenarios including visualizing crowd density, locating an individual, and finding people near the place of an already occurred event. To this end, the impact of indexes on different queries has also been assessed, which considers their frequent expected usage.

In future, this work can be extended further by implementing its physical layer to gather real data. Whereby, the operations of the developed infrastructure would be assessed as well on a real event in order to practically evaluate the efficacies and limitations of this system.

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