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In-Depth Survey to Detect, Monitor and Manage Crowd

ALI M. AL-SHAERY[1], (Member, IEEE), SHROUG S. ALSHEHRI[2], (Member, IEEE), NORAH S. FAROOQI[2], (Member, IEEE), AND MOHAMED O. KHOZIUM[3], (Member, IEEE)

[1]Department of Civil Engineering, Consulting Research and Studies Institute (ICRS), Umm Al-Qura University, Makkah 21955, Saudi Arabia
[2]College of Computer and Information Systems, Umm Al-Qura University, 21955, Saudi Arabia
[3]Department of HITM, Faculty of Public Health and Health Informatics, ICRS Consultant, Umm Al-Qura University, Makkah 21955, Saudi Arabia

Corresponding author: Mohamed O. Khozium (mokhozium@uqu.edu.sa)

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ABSTRACT Crowd management is a flourishing, active research area and must be given attention due to the potential losses, disasters, and accidents that could occur if it were neglected. For the last decade, the crowd management field has witnessed significant advancements; however, more investigative work is still needed. The integration of different crowd detection and monitoring techniques can enhance the control and the performance compared to those of more limited stand-alone techniques. Crowd management encompasses an entire process, from the monitoring stage through the decision support system stage. This sector involves accessing and interpreting information sources, predicting crowd behavior, and deciding on the use of a range of possible interventions based on context. This paper shows a fresh conclusive review of the concept of the crowd, discussing it from several perspectives in light of its defining characteristics, its risks, and tragedies, which may occur due to challenges faced during crowd management, where these conclusions are based on a massive number of scholarly articles that were newly published. Besides, a systematic discussion is shown concerning the steps of managing a crowd, including crowd detection, in which several new methods are reviewed, followed by illustrating both direct and indirect approaches to crowd monitoring and tracking monitoring. The primary purpose of this review is to establish a comprehensive understanding of crowd-related processes. Moreover, it aims to find research gaps to overcome the limitations of using stand-alone techniques in each process and provide support to other researchers' future work.

INDEX TERMS Crowd behavior, crowd simulation, thermography, RFID, spatiotemporal.

I. INTRODUCTION

Crowd management is a required field of study due to its direct influence on individuals' lives. When many people gathered with a shared purpose or shared emotions, this is called a crowd. Many different reasons could contribute to a crowd's occurrence, including a religious gathering, a political rally, a sporting event, or a concert. In such public events and mass-gathering, crowd management represents a stressful mission involves deep and thorough planning, tight and precise proceeding, and dynamic and agile controlling strategies. The results of any deficiency or weakness in the management will cause unbearable and unaffordable results, including a loss in souls and properties. Historical records have recorded injuries and fatalities at mass gatherings, especially those of a religious nature. For instance, a stampede happened during Hajj on September 24, 2015, causing over 700 deaths and more than 850 injuries [1]. Therefore, it is crucial to monitor the crowd's safety status efficiently and implement the required management strategies throughout the event. During this process, members are counted to identify potential crowd risks. If a risk is detected, it must be monitored and tracked. Correspondingly, crowd analysis is applied to understand crowd behavior and to improve crowd management strategies.

Researchers struggle to employ the recent computational models and automated technologies to obtain the highest possible accuracy and performance. These techniques help manage and automate as many routines as possible, starting with providing statistical insights about the crowd and proceeding to reach decision support systems and automated crowd controlling systems. During the last two decades,

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crowd controlling and crowd management research developed dramatically due to the vast development in the artificial intelligence (AI) field, which inspired new computerized tools for crowd detection, crowd monitoring and analysis, and crowd management. Eventually, researchers conduct surveys and review papers to summarize the previous studies and reveal the state-of-the-art to be the base for further research.

The first phase of managing the crowd is to detect that crowd and recognize it. Researchers concerned with this topic provided many automated tools based on computers and recent technologies like laser, RFID, Wi-Fi, Bluetooth, and AI, including automatic recognition and Machine Learning (ML). The second phase is to monitor, track, and analyze the detected crowd to obtain reliable insights. Many researchers investigated this topic using theoretical, statistical, data mining, ML, and prediction techniques. The last phase is to employ the findings of the previous two phases to create a crowd controlling system that provides comprehensive description of the crowd, maintains the security level, predicts risks, and, based on that, suggests actions.

This paper aims to shed light on these three phases through a complete literature survey, addressing crowd detection, monitoring, and management.

This paper consists of five sections. The first section is this introduction. The second section provides an overview of recent reviews and surveys on the same topic and summarizes the works related to this paper. Next, the third section presents background on the topic. The fourth section talks about the discussion. Finally, the last section is the conclusion.

II. RELATED WORK

This section provides a comprehensive literature review on crowd detection, monitoring, and management. First, it provides insights about other survey research of the related fields revealing this paper's contribution. Second, it explores some of the related works which have impacts upon this research.

This paper contributes to the crowd study fields by summarizing and categorizing the state-of-art in crowd detection, crowd monitoring, and crowd management. This fact involves the survey papers and review papers of the three fields.

Starting with crowd detection surveys and reviews, [2] is one of the earliest surveys investigating the psychological factors of crowd applied to mass-gathering settings. It drew a proto-image of the crowd potentials based on the psychosocial domain. Later, [3], [4] investigated the role of social context and policing in crowd conflicts through different disciplines. This paper advances farther in accumulating a wider scope of research that studied those potential roles.

Besides the social context, a more technical and most common approach used in crowd detection is the visual recognition approach. Many surveys and reviews occasionally conducted to summarize and reveal the state-of-art of computer vision recognition. Paper [5] observed computer vision research about crowd density estimation and counting methods. It was followed by [6] which reviewed the crowd investigation methods in computer vision research highlighting crowd detection, counting, tracking, and anomaly detection. It discussed the strengths and limitations of each reviewed approach. Later, [7] reviewed the machine learning (ML) techniques used in automatic image processing and visual recognition of crowd activities. After that, many surveys and reviews were conducted to feature estimation methodologies for crowd density using ML and deep learning techniques [8], crowd and violence detection using intelligent video surveillance [9], abnormal behavior and crowdsensing [10], and deep learning methods for crowd counting and how to address the challenges [11]. A recent modern approach involves mobile devices in crowdsensing under the name of Mobile Crowdsensing System (MCS) surveyed in [12] followed after two years by [13] which added new perspectives from task scheduling, resource management, and random arrival tasks.

Detecting and recognizing the crowd is the first step to monitor, track, and analyze that crowd. There are many perspectives to describe the state-of-the-art crowd behavior, as in [14], which reviewed studies considered with the crowd analysis and proposed a framework to detect abnormal behavior in crowd scenes. Physics and biology represent another perspective to survey crowd behavior as in [15]. Generally, surveys and reviews considering crowd monitoring and crowd analysis which highlight crowd behavior detection and analysis techniques classifications as in [16], observe crowd dynamics and its safety impacts as in [17] or focus on abnormal crowd behavior as in [18].

Moreover, this paper involves the managerial aspect of crowd study, which adds crowd management surveys and reviews to this paper's literature review. This fact involves surveys and reviews concerned with the technical practices and the role of technology in crowd management [19], methodologies for crowd monitoring and density estimation [20], technological advancements in planning and monitoring techniques for the crowd [21], and crowd management and monitoring techniques to address the challenges with proposed solutions [22].

In summary, the surveys and reviews above used wide varied perspectives and methodologies. Some of them focused on crowd detection based on the social context. Others focused on the detection based on modern technical inventions like the laser, radio-based detection, or computer vision. Some of them investigated and classified crowd analysis methodologies while others surveyed the managing techniques and crowd management strategies and applications. However, in this paper, we summarize all the results and combine them in a defined and comprehensive classification, as revealed in the discussion section. It incorporates crowd detection, monitoring, and management featuring the latest techniques in each aspect. In comparison to the previous studies, this approach provides a broader view and coverage of crowd studies. It includes some recent unobserved researches tackling challenges to keep the researchers with state of the art in the crowd studies field.

FIGURE 1. Black lives matter protest in australia.

FIGURE 2. Muslim pilgrims at Mina, Makkah during Hajj.

This paper investigates the following related works by briefly reviewing their methodologies and classifying them according to their scope. The related works belong to one of the following three levels: crowd detection, crowd monitoring and analysis, and crowd management. Table 1 highlights this matter.

III. BACKGROUND

A ***crowd*** is a situation in which a large number of people are gathered in one physical place. These people might have similar interests or emotions, or they might be casually linked [28]. Other research confirms that a crowd may exist regardless of the reason for the gathering [2]; its members need not share goals or interests [19]. However, when a large number of people with shared goals attend an organized event in a defined space, this constitutes a ***mass gathering***. In addition, any crowd may be quantified by the number of individuals per unit area at a given moment [22].

Mass gatherings may occur as political riots or protest movements, as seen in Figure 1, as well as religious gatherings, sporting events, concerts, or festivals. An example of this event is when Muslims make the pilgrimage to Makkah, which is called the Hajj. During this annual religious event, more than two million pilgrims come from all over the world and move between different sites. Figure 2 illustrates the pilgrims' path to the Jamaraat Bridge. Another religious crowd gathering is Kumbh Mela. This gathering is one of the largest religious gatherings in Allahabad, India, where an estimated 100 million pilgrims head to a sacred river over a span of one month every 12 years. Unlike in the Hajj, these pilgrims are Indian locals. However, other smaller Kumbh Mela events also take place at different sites across India, each iteration, including many movement rituals among the dense crowds [25]. Elsewhere in the world, the annual Notting Hill Carnival in Central London, UK, is another type of crowd involving a musical parade, which attracts 1 million visitors over the two-day public holiday [42].

The most crucial thing in crowded events is to ensure safety, especially in dense crowds. Such gatherings must be contained to prevent catastrophes. These situations can also facilitate the spread of incurable and/or contagious viruses and diseases [42].

Some of the most common crowd risks may include stampedes, congestion, mobbing, and fires, among other security issues. In 2015 there was a stampede during Hajj in Makkah, which resulted in more than 700 dead and more than 850 injured [1], [21]. These kinds of tragic accidents happen at gatherings all over the world, and some of those from the last ten years can be briefed in Table 2.

The main aim of crowd management is to prevent tragedy. Crowd management had been studied involving different fields, including theoretical physics, sociology, psychology, computational science, and artificial intelligence [19]. This concept will be more widely explored later on within this section.

Crowd analysis is thus an essential process for understanding crowd behavior and providing crowd management solutions. Many crowd aspects have been analyzed, such as crowd detection, crowd tracking, crowd density estimation and counting of people, and crowd behavior [10].

Lately, crowd analysis and management have been more focused on employing methods for computer visual surveillance.

Despite the many efforts that have made to further crowd management, there have also been many challenges. One of these is the unpredictability of crowd behavior.

In addition, some visual methods fail in analyzing high-density crowd scenes because they are so difficult to penetrate; also, the insufficient datasets that represent the crowd scenarios [22].

A. CROWD DETECTION

To control a crowd, it is essential first to know when the crowd will be formed, which requires proper methods for crowd detection. A crowd could be discovered in various ways. Traditionally, one would be reported by people who have witnessed congested areas. When a crowd is anticipated, its location should be monitored. In such cases, it is likely to be detected using surveillance devices or other intelligent solutions that give warnings whenever there is overcrowding.

There are some factors considered in detecting crowd. These factors include events, places, times, and catastrophes. For example, some well-known events creating extremely dense crowds are religious pilgrimages (Hajj, Kumbh Mela);

TABLE 1. The related work.

Level	Topic	Title	No
Crowd detection	Laser-based detection	Laser-based detection and tracking of multiple people in crowd	23
	Radio-based detection (RFID)	RFID technology and crowded event management	24
		Crowd management with RFID & wireless technologies	25
		Hajj crowd management and navigation system: People tracking and location based services via integrated mobile and RFID systems	26
		Radio frequency based navigation and management system for KUMBH	27
	Radio-based detection (Wi-Fi)	Estimating crowd densities and pedestrian flows using Wi-Fi and Bluetooth	28
		A privacy-aware crowd management system for smart cities and smart buildings	29
	Radio-based detection (Bluetooth)	Sensing the crowds using Bluetooth low energy tags	30
		Mobile crowd sensing based on CICN	31
	Vision recognition	Integration of background removal and thermography techniques for crowd density scrutinizing	32
		Online real-time crowd behavior detection in video sequences	33
		Autonomous crowds tracking with box particle filtering and convolution particle filtering	34
		A survey of recent advances in CNN-based single image crowd counting and density estimation	35
		A study on crowd detection and density analysis for safety control	36
		Congestion detection in pedestrian crowds using oscillation in motion trajectories	37
		Attend to count: Crowd counting with adaptive capacity multi-scale CNNs	38
		Scale driven convolutional neural network model for people counting and localization in crowd scenes	39
		Fast video crowd counting with a Temporal Aware Network	40
Crowd monitoring and analysis	Crowd detection and analysis	The fundamental diagram of pedestrian movement revisited	41
		Crowd and environmental management during mass gatherings	42
		Real-time crowd monitoring using infrared thermal video sequences	43
		A mobility network approach to identify and anticipate large crowd gatherings	44
		Understanding crowd dynamics at ghat regions during world's largest mass religious gathering, Kumbh Mela	45
		Experimental study on pedestrian contact force under different degrees of crowding	46
		Method for guiding crowd evacuation at exit: The buffer zone	47
	Understanding crowd behavior and abnormal behavior recognition	Understanding Crowd Behaviours	48
		An energy model approach to people counting for abnormal crowd behavior detection	49
		Abnormal crowd behavior detection by using the particle entropy	50
		Social network model for crowd anomaly detection and localization	51
		Abnormal crowd behavior detection using motion information images and convolutional neural networks	52
	Crowd counting	Research on crowd gathering risk identification based on cell sensor and face recognition	53
		Decision support system for real-time people counting in a crowded environment	54
		Relevant region prediction for crowd counting	55
	Crowd data visualization	Crowd data visualization and simulation	56

TABLE 1. (Continued.) The related work.

crowd management strategies and crowd control plans	Extending monitoring systems toward developing decision support systems	A proposed computer-based system architecture for crowd management of pilgrims using thermography	57
		A hybrid intelligent information system for the administration of massive mass of Hajjis	58
		SmartCrowd: Novel approach to big crowd management using mobile cloud computing	59
		A landscape of crowd-management support: An integrative approach	60
	Crowd planning and safety precautions in different scenarios	Efficient wireless sensor network rings overlay for crowd management in Arafat area of Makkah	61
		Managing crowds in hazards with dynamic grouping	62
		Safety forecasting and early warning of highly aggregated tourist crowds in china	63
		Optimising crowd evacuations: Mathematical, architectural and behavioural approaches	64
		Crowd Management and Special Event Planning	65
	Crowd modeling	An intelligent decision computing paradigm for crowd monitoring in the smart city	66
	Simulation	A simulation-based framework for checkpoint design in large-scale crowd management: Case study of the papal mass in Philadelphia	67

TABLE 2. Examples of crowd disasters [1], [5], [68].

Place	Year	Death Cases
Kerman, Iran	2020	> 56
Moshi, Kilimanjaro, Tanzania	2020	20
Diffa, Niger	2020	20
Bihar Sharif, India	2018	> 58
Mumbai, India	2017	> 22
Pilgrimage, Mena, Makkah	2015	> 700
Hindu festival, Datia District	2013	115
Love parade music festival, Duisburg	2010	21
Water Festival, Phnom Phen	2010	> 380

the World Cup; and music festivals, such as Coachella. There are also some places that always have a high degree of congestion, including the following places in India: Haridwar (Ganga River); Prayag (confluence of the Yamuna, Ganga, and Saraswati Rivers); Nasik (Godavari River); and Ujjain (Kshipra River) Hindus often gather to bathe in such rivers, according to FPJ Web Desk [69], so there are times when crowds are expected. During Nafra, for instance, 3 million Muslim pilgrims move from Arafat to Muzdalifa before sunrise, as illustrated by Abuarafah *et al.* [43]. From a catastrophe perspective, a fire outbreak could cause congestion at the exits, leading people to panic, potentially turning aggressive.

According to Abuarafah *et al.* [43] and Neufert [70], the typical number of persons that occupy one square meter while walking is 2.14, whereas the figure increases to 3.75 persons per square meter when people are still. On a similar note, the maximum density should be six persons per square meter. Meanwhile, the maximum density observed in some of the crowded places mentioned above was around this maximum of six persons per square meter. The maximum density of Kumbh Mela observed by authors [41] was seven persons per square meter, similar to the conditions in Hajj, both considered to be dense crowds.

Furthermore, Khan [37] studied the relationship between oscillation and average trajectory speed. He concluded that a higher oscillation would display lower average speed and trajectory length. This means that people able to move freely will move at their desired speed, resulting in long, smooth trajectories. Therefore, when a place is congested, pedestrians will have limited movement, which may incite conflicts.

Afiq *et al.* [10] covered some of the detection techniques that are applicable to intelligent video surveillance systems. Ji *et al.* [71] and Al-Shaery and Khozium [22] discussed the concept of the Gaussian Mixture Model (GMM), which generates a model based on the Gaussian probability density function by calculating intensity, mean, and frame variance. Another model, the Hidden Markov Model (HMM), is a double stochastic process consisting of hidden and observed processes such as initial states, transitions, and observation probability distribution, as discussed by Ji *et al.* [71].

Another concept, optical flow (OF), is used to describe the movement pattern of points, objects, or shapes illustrated by Fortun *et al.* [72]. Afiq *et al.* [10], Chaker *et al.* [51], and Al-Shaery and Khozium [22] discussed spatiotemporal technique (STT), in which the features from the spatial and temporal dimensions are combined for scene anomaly detection. A hybrid approach between these detection methods was recommended to increase accuracy.

Furthermore, Pennisi *et al.* [33] described a real-time online crowd behavior detection algorithm called FSCB. It consists of feature detection, temporal filtering, image segmentation, and crowd behavior detection. Along the same lines, Arandelovic [73] introduced an algorithm for crowd detection in still images. This algorithm is appearance-based, employing a statistical, Poisson model of occurrences of quantized Scale-Invariant Feature Transform (SIFT) words across an image. Then Khan [37] proposed a method that can detect and localize congestion locations in videos by using motion features to generate oscillation maps in a spatiotemporal way.

The study of Chaudhari and Ghotkar [36] introduced a Convolutional Neural Network (CNN), which involves deep learning approaches to detect crowd congestion and to perform density analysis. CNN employs non-linear functions to calculate crowd numbers. In another vein, a particle entropy approach was proposed by Gu *et al.* [50] to represent crowd distribution using GMM, while Xiong *et al.* [49] developed a method by building histograms on the axes and obtaining the probability distribution of the foreground object, which represented crowd entropy. This Crowd Distribution Index combined the people counting results with crowd entropy to represent the crowd's spatial distribution.

Branching out from visual surveillance techniques, Gong *et al.* [4] used social media posts for four sub-events in Amsterdam, detecting crowds is by clustering points of interest (PoIs). Another contribution was made by Huang *et al.* [44], the development of anomalous mobility networks, which employ a topological measure in discovering congested locations and events in their early stages.

B. CROWD MONITORING AND TRACKING

Monitoring and tracking crowds can prevent unanticipated situations and help in highlighting abnormal behaviors at earlier stages to prevent future incidents. This is a continuing process of detection, an intermediate phase between crowd detection and crowd management. In this way, these monitoring approaches may be divided into direct and indirect approaches according to data sources and tracking methods.

A direct approach is when a crowd is treated as a specific target to be monitored. This approach can be achieved by using wearable devices such as bracelets or wireless tags that are attached to pedestrians. Such instruments are used to monitor and track each individual, which provides highly accurate data.

Radio Frequency Identification (RFID) is one of the most ubiquitous technologies used for monitoring pilgrims [24]–[27]. The RFID consists of RFID tags given to pilgrims and readers to scan. A wireless sensory network overlays the device [61], and an additional mesh network was also proposed [59], with RF readers as topology nodes used to monitor the crowd and help with the evacuation. The authors introduced an intelligent agent, applying a scheduling technique to guide and monitor the crowd with the help of the RF reader mesh network [59]. Another tool is Bluetooth Low Energy (BLE), in which the device advertises itself on dedicated channels to be discovered by a BLE-enabled smartphone listening for the advertised packets. The BLE tags are distributed on people to monitor and track the crowd using beaconing technology [30], [31].

All of these methods are some of the latest that have been used in the direct approach of crowd monitoring. On the other hand, the indirect approach to monitoring is when a group of people is treated as a single entity, which helps with high-density crowds, which makes it difficult to track every single person.

Unlike the direct approach, which gathers data from an individual agent, the indirect approach monitors the crowd as a whole using a specific device, such as in video surveillance.

Satellite images also are useful to support the analysis of high-density crowds. The only drawback found is that the resolution is not high enough to see each person clearly. However, this system's ability to detect color changes at the place of existence helps in overcoming this problem [22].

Another creative type of indirect detection used laser-based tracking to scan pedestrians' feet using laser range scanners [23]. Horizontal scanning occurs at ground level so that cross-sections at the same horizontal level of about 16 cm, which contain the data of both moving and still objects, are obtained in a rectangular coordinate system of real dimension. Those laser points of movement are obtained through background image subtraction. Then the moving points from multiple laser scanners are temporally and spatially integrated into a global coordinate system.

The innovations for indirect monitoring did not stop at that point. On the contrary, thermography images were eventually used as a crowd control approach. It employs a forward-looking infrared (FLIR) camera, which quantitatively measures surface temperatures of objects, with pixel intensities representing temperatures. In addition, some authors [43] introduced a real-time crowd density estimation and monitoring software. The software module calculates and processes the image frames to produce crowd density after specifying image frames and temperature range. This module generates warnings and a graph of the calculated density against frames.

Beyond these developments, a system was proposed consisting of two main components [57]. The information management component contains the thermal video analyzer and a fuzzy logic module. The decision support system module, on the other hand, includes the operation research module and the expert system module. It determines the mass of crowd participants, such as those on pilgrimages, monitors crowds in real-time, and displays preferred routes and closed roads.

The author proceeds to illustrate the system architecture and a detailed description of different system components and their integration [58]. Capacity-weighted priority technology has been proposed based on matrix calculations. Due to the shadows in the background, the calculated crowd density is prone to inaccuracy. The authors introduced an enhanced way of integrating the background removal image processing technique and the thermography approach [32].

Other visual surveillance and camera sensors, including CCTV cameras, are used to monitor a crowd. However, the obstacles and limitations associated with such visual-based technologies may involve loss of vision due to darkness, smoke, fog, or some other occlusion. Visible imaging also raises concerns regarding privacy and other security-related issues [21].

This tracking problem involves locating each individual in a frame as a function of time. A ground truth density Fo(p) is presented as a kernel density estimation based on the positions of annotated points as in (1). In this equation, ϑ is the size of the feature in the feature map, ϵ is ground-truth annotations of feature positions, and p is a pixel in an image [16].

$$Fo\,(p) = \frac{1}{2\pi\vartheta^2}\sum\nolimits_i exp(\frac{\parallel \epsilon_i - p \parallel}{2\vartheta^2}) \tag{1}$$

Two different types of filters were used here: a box particle filtering (PF) framework and a convolutional particle filtering (CPF) framework for tracking large crowds [34]. The Box PF works with box particles, whereas the CPF represents the probabilistic distributions with point samples. CPF is more adaptive and thus more capable of dealing with several measurements, especially at high levels of crowding. Meanwhile, the box PF deals with a smaller number of box particles. The PF subdivided particle is based on the dimension with the largest box face, (2), where q stands for the maximum number of clutter measurements.

$$q = \rho_k \frac{A_{CT}}{4} \tag{2}$$

The clutter measurement rate is used to obtain an approximate solution for equation (3).

$$\rho_k = \frac{\lambda_{Ck}}{A_{CR}} \tag{3}$$

The area of the clutter region is given by $A_{CR} = A_S - A_T$, where A_S is the total area observed by the sensor, and A_T is the area of the crowd. The area, A_{CT}, also includes the region inside of the crowd, where no clutter measurements are found, hence, the factor of 4.

The algorithm is fairly robust for the value of q, as this represents the maximum possible number of clutter points, not the actual number. A comparison of Box PF and the CPF was made with the generic standard sequential importance resampling (SIR), and PF was included. The advantage of the CPF approach is that there is no need for the estimation of the clutter and measurement rates when only the kinematic states and extent parameters are of interest.

The detector was also combined with a particle filter to track multiple people in dense crowds [74]. Two strategies were presented to simplify the computation for the case of independent tracking using Kalman filters and the case of joint tracking of multiple targets using RBMC-DAF [23]. An extended Kalman filter-based technique and a KL divergence–based approach were used to evaluate the differentiation of the individual features and the holistic features of crowds [66]. The extended Kalman filter-based approach mitigates noises and provides the smoothed feature sets.

C. CROWD MANAGEMENT

Crowd management is the systematic planning and supervision of the orderly movement and assembly of people, and it involves the assessment of people who examine the capabilities of spaces prior to their use [22]. Crowd management is the organized and substantiated planning and the direction given to the orderly progress of mass gatherings. As part of crowd management, measures can be taken to direct or limit the behavior of groups of people. This is called crowd control, which can involve obtaining public safety. Moreover, crowd management could also be defined as a set of measures and preparations taken in the facilitation, employment, and movement of crowds. According to paper [60], crowd management practice involves accessing and interpreting information sources, predicting crowd behavior, and deciding on the use of a range of possible interventions depending on the context. These practices are done by the collaboration of different actors—e.g., event planners and managers, emergency services, local authorities, transport authorities, stewards, and the crowd itself [19].

In this paper, we consider crowd management as the intermediate stage between the monitoring stage and the decision support system (DSS) stage. Recently, crowd management

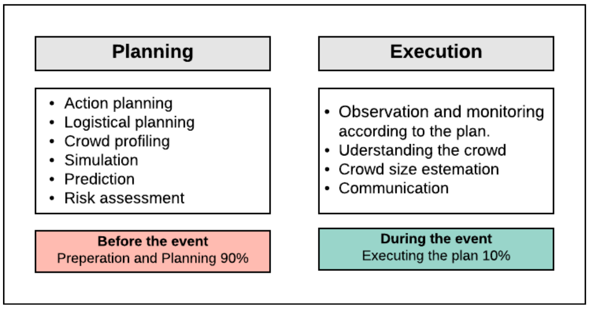

FIGURE 3. Crowd management is divided into two parts based on the event.

practices have been implemented in event-based phases, including the pre-event phase and the phase during the event [19], [60], [65]. However, crowd management is useful for more than just events. It is also employed in situations such as safety at plazas, airports, and shopping centers.

Figure 3 shows how the crowd management process is divided [19]. It shows the planning of the event, which takes up to around 90% of the management team's efforts, as well as the execution of the plan during the event, which takes the remaining 10% of their efforts.

Before the event, "Crowd management involves planning and directing the manner in which the public gathers at an event and moves at and around the event terrain." Planning typically involves anticipating what might happen regarding a crowd in a given context and preparing for it. As such, preparation includes designing for the crowd's desired behavior, foreseeing potential issues, and devising contingency plans to deal with them [60]. Therefore, simulations and risk assessments are typical tasks in the planning phase.

Simulations are used to assist experts in the planning phase. Diaz *et al.* [56] developed a system that can handle interactions with pedestrians involving the visualization of environments. The system computes a mesh for any given zone in the urban environment, doing calculations using shaders in the GPU. The calculated mesh is transformed into an instance of the scene, and elements are placed in the simulation. In more extended simulation work, a method for guiding crowd evacuation called the buffer zone was suggested by Wang *et al.* [47]. Different placements and settings of buffer zones are conducted to study this method in detail to help in planning. It is found that when the desired velocity is high, the buffer zone can be used for emergency control through accelerating the evacuation speed, decreasing the crowd density, and speeding up individual wait times during evacuation.

Risk Assessment is another important part of crowd event planning used to handle emergency situations [60]. A common risk assessment tool, the DIM ICE model, has been discussed for use during crowd management [75]. Event organizers evaluate various factors that influence crowd behavior. First, the design, which is not only the physical layout of the place or the position of exits and seating but also concerns features like a table or booth placement, should not negatively affect traffic flow or safety. Second, the information regarding how the event organizer communicates with the audience—including the use of signage, social media channels, and staffers—should be reviewed. Finally, the management inputs the findings from staffing levels and personnel such as guest services, security and law enforcement, harm reduction and medical services, CCTV monitoring, insurance stipulations, and regulatory requirements. The authors have provided a systematic review of optimization methods for evacuations [64].

During the event, a crowd's condition must be monitored, and actions must be selected and implemented according to the plan. The following are typical tasks in the execution phase:

Observation and monitoring aid the assessment and detection of any potential emergency situation at an early stage. These can be achieved by assigning security officers and stewards to the event and by using CCTV cameras for surveillance, as well as employing helicopters, drones, and aerial vehicles to monitor the area.

Understanding the crowd is essential to distinguish different crowd types in order to successfully prepare for and manage a particular crowd at a particular event. There are different types of crowds, including escaping crowds and violent crowds. There should be a crowd expert to interpret crowd behavior in real-time. This may be accomplished through either using a personnel expert or using technology to perform an automated crowd behavior analysis. The authors discussed the factors that help in understanding crowd behavior and explained how an adequate understanding of crowd action could not be merely psychological [3]. The micro-sociological dynamics also can shape and reshape the social context and its associated meanings and emotions.

Crowd size estimation eliminates the uncertainty in the number of attendees, which is a key element in large-scale crowd management [67]. A system was developed utilizing a network of basic image sensors to count people in a crowded environment [54]. This method measured the shapes by each sensor through background subtraction. The authors proposed a crowd counting approach using an adaptive capacity multi-scale convolutional neural network (ACM-CNN), which consists of three types of modules [38]. This method focused on important areas of the input image and optimized its capacity allocation conditioning on the crowd intensive degree. The authors proposed a relevant region prediction (RRP) for crowd counting, consisting of a count map and the region relation-aware module (RRAM) [55]. Each pixel in the map is a representation of the number of heads in the corresponding local area in the input image, discarding the detailed spatial information and paying more attention to counting rather than localizing individuals.

Communication is a very important process during the event. This includes both communication among crowd organizers and management team members and communication between the team and the crowd itself [60]. It is a way of alerting the crowd to danger through alarms, warning announcements, environmental factors, movement of other people, or visual clues. Also, it is used to brief the agents/stewards and to keep them informed about the monitored area, including if there are any plan changes or if actions need to be taken. The quality of communication will influence the time taken by the crowd to begin to move [48]. Signs, LED boards, and social media are some commonly used communication channels.

Crowd management proceed to a higher level that includes further activities like crowd expectation and crowd decision support systems.

Crowd expectation is recommended to ensure an early response to any emergency or to predict an emergency and implement early warning system for crowd safety. Various experiments are used, and monitoring data is input into a mathematical model formulated to compute crowd risk index (CRI) [53]. The CRI values can then be used by event managers to increase crowd safety.

The authors introduced a crowd risk identification system that counted individuals according to cell sensors and adjusted the numbers through face recognition [45]. Next, the mean of the two methods is measured. Then the system analyzes the risks of the crowd gathering to prevent events like stampedes as much as possible. Experiments were conducted to measure contact force under different degrees of crowding by using pressure sensors [46]. In order to measure and evaluate the cluster risk of pedestrians, each pedestrian's upper body was covered in two pressure sensors to measure the total contact force on the upper body.

According to the data, in the static state, the contact force increases as the space occupancy rate (SOR) increases. In the moving state, the contact force increases as the velocity increase under different SORs. SOR is defined as in (4)

$$\delta = \frac{\sum_{i=1}^{N} S_i}{A_i} \tag{4}$$

In this equation, δ is the SOR, Si represents the body area of pedestrian i, N represents the number of pedestrians walking inside a cylindrical control volume, and A_j corresponds to the area of the cylindrical control volume. The results assess the risk levels of local crowds and help to prevent fatalities and injuries.

Crowd decision support system (DSS) is an information system that supports crowd management or organizational decision-making activities, which includes a knowledge-based system. Given the crowd management data interpretation, analysis, rules, and expectations, the DSS will suggest a range of possible interventions to management executers to select the appropriate decision.

The authors proposed a decision–support framework named InCrowd to select an effective intervention based on a high-level description of a crowd based on the prediction model [60]. In addition, the CRI model is paired with a decision-making subsystem for large crowd management risk support [45]. The intelligent decision support system is integrated with operations research modules to analyze the captured thermographic video sequences in real-time [58]. Meanwhile, a DSS was proposed that analyzed normal video images in real-time to reach the optimal solution [54].

IV. DISCUSSION

Some of the papers examined in the background discussed crowd aspects but were vaguely structured. Some of the reviews were focused on a particular aspect of crowd studies, whereas others were dated and lacked a sufficient number of references. We advocate for other researchers to approach the crowd topic from more diverse viewpoints and with more defined features.

In general, there are two approaches to study the crowd. The first one is the direct approach which attempts to treat every single person in the crowd as an individual. In contrast, the second indirect/holistic approach treats a group of persons as a unified element. The indirect approach is widely used to detect independent motion in a crowd, such as in video surveillance, by tracking people's interest point clusters over time. On the other hand, the direct monitoring approach is the most appropriate for recognizing, monitoring, and counting individuals in lower density crowds. However, this becomes more difficult and complicated in denser crowd scenarios, especially in surveillance with occlusions present. Thus, detecting and monitoring individuals is more challenging and requires more processing, which explains why the indirect approach is often used [5], [18].

A. CROWD DETECTION STAGE

Many new techniques have been developed to improve crowd detection, monitoring, and management. Even so, the results of combining two or more techniques have proven that hybrid methods increase accuracy, enhance performance, and counteract many drawbacks. This has been displayed using the Gaussian Mixture-Hidden Markov Model (GM-HMM), the Spatiotemporal Convolutional Neural Network (ST-CNN), and the Temporal Aware with Convolutional Network (TAN) for crowd detection [10], [40].

B. CROWD MONITORING STAGE

Many researches have attempted to find the most appropriate solution for such an important topic to discover the most convenient, efficient, and accurate module at the lowest expense.

Al-Shaery and Khozium [22] proposed an approach for tackling real-time crowd monitoring using a combination of two or more methods, which can help in avoiding the system's disadvantages and can procure the benefits of its advantages to create a stronger, more accurate system. Figure 4 shows that the proposed collaboration was between satellite images, thermography, and wearable devices.

Satellite images have the advantage of being fast and are able to cover a wide area. However, it cannot recognize each person in sharp detail since their resolution is not high enough, although thermography does reveal temperature variations. As a result, warm objects such as humans or warm-blooded animals can be seen clearly against

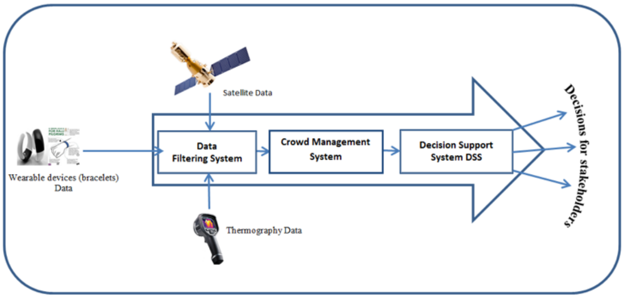

FIGURE 4. The use of the three methods in crowd monitoring.

cooler backgrounds (e.g., the outdoors day or night), but the main disadvantage of thermography is the presence of shadows in the image. This can be handled, though, by using a shadow removal technique to create an accurate depiction of the crowd.

Another drawback concerning this method is that the infrared camera used for thermography can only capture a very limited area. In addition, calibration must be done every 30 minutes due to temperature differences. Another option is using wearable devices, which have also been proposed instruments for crowd monitoring. For instance, smart bracelets with an internet connection can send data to the server on demand. The problem comes when this connection fails. However, in this situation, the data is locally stored, and it will be resent to the server whenever the connection is restored.

Adding to this body of work, Liu and Xie [53] proposed the use of a holistic monitoring approach like a CCTV camera paired with a direct tracking method like cell sensors or face recognition. A cell sensor can count the number of individuals by counting the number of mobile phones in the area, whether they are working or not. Mobile phones are widely used; statistics show that 85% of the world's citizens are mobile users.

The advantages of the cell sensor are numerous: It is user-friendly, has an easy computing process, it is cheap to install, and it is portable. Of course, this instrument also possesses some drawbacks. For example, it is affected by signal interference, and mobile phone numbers may not be accurate. Also, these numbers are imprecise; they may be affected by age, material condition, etc.

Another method of monitoring is face recognition, a biological identification technology. The images reflecting the actions and state of a crowd are captured with a high definition camera and evaluated based on facial features. However, this method also has some disadvantages.

First, obstacles and occlusions might appear in the vision. Second, a person with a larger build may be counted as one, whereas a smaller person carrying a child will be counted as two people, even though that person requires less space than the larger person. Finally, facial recognition technology raises some individual privacy concerns.

C. CROWD MANAGEMENT STAGE

1) CROWD MANAGEMENT VS. CROWD CONTROL

There is a misconception between crowd control and crowd management. The two terms are often used interchangeably, but it is vital to acknowledge their differences to function more appropriately during an event. Crowd management includes facilitating crowd activities, movement, and enjoyment, as well as ensuring crowd safety. On the other hand, crowd control mainly addresses the concerns that develop once a crowd begins to behave in a disorderly manner or begins to get out of control [5].

Crowd management is proactive; crowd control is reactive. Therefore, crowd events should be organized and managed to prevent any emergencies from arising. Therefore, the crowd control process should be implemented as a last resort when a crowd is out of control, and the event is not going according to the management plan. Also, implementing this system too soon can cause negative consequences.

2) MANAGEMENT AND SAFETY GUIDE STEPS FOR CROWDED EVENTS

Several key steps are involved in the planning of any sizeable, crowded event [76].

- Plan, organize and consult with the key figures both inside and outside of the organization, including management team leaders, event contractors, venue owners, local authorities, and emergency services personnel. When a large crowd is expected, hire staff as needed and have a trained security detail on set.
- Know the audience. Expected attendees may depend on the nature of the event. Certain behaviors can be predicted, like emotional pilgrimages during Hajj rituals or music fans surging near the stage at a concert or sports fans getting emotional over a game's final score.
- Assess the potential health and safety risks of the event. Prepare an emergency plan that addresses issues like overcrowding, crowd crushing, violent acts, and fire. Share this plan with public safety agencies.
- Set up barriers or rope lines in advance and ensure that there are legible signs describing the entrance and exit locations.
- Have a clear line of communication with both the management team members and the crowd.
- Finally, review the execution plan with the management team following the event. Assess which approaches worked well and which could have been improved. This review is crucial in planning the next event.

V. CONCLUSION

This paper presents a comprehensive review of crowd studies, from crowd detection to crowd monitoring to crowd management. Crowd safety is the ultimate goal of crowd-related research. Therefore, eliminating the risk of injuries and fatalities in mass gatherings is based on the efficiency of systems developed at each stage of crowd management. A well-designed system equipped with a solid execution plan will achieve the ultimate goal in this process. Crowd management systems cannot be treated as separate processes but instead must be seen as one system of different integrated stages. A fully integrated system is missing from the existing literature. Therefore, the need for such a system is an important goal to achieve in order to manage a crowd efficiently.

A common misconception of crowd control and management was clarified, and it was evident that the crowd management model is preferable, whereas crowd control is a reactive process that should be used only as a last resort. Another vital aspect discussed was crowd monitoring, and some approaches were mentioned, including the indirect monitoring approach, which is widely used for high-density crowds. Conversely, the direct approach is generally avoided because of its considerable processing time and effort requirements. Moreover, the integration of two or more techniques is greatly recommended, and it is proven that hybrid techniques increase accuracy, enhance performance, and counteract drawbacks. The efficient crowd management system is based on the efficiency of crowd detection and crowd monitoring. Crowd management is a proactive process aiming to improve crowd safety.

This paper highlights that crowd management systems require well-designed DSS with early warning capabilities in order to achieve this ultimate goal of crowd safety. A sufficiently responsive crowd management system is not yet documented in the existing literature. A highly efficient crowd management system must incorporate different disciplines, including psychology, sociology, engineering, applied mathematics, computer science, and artificial intelligence.

REFERENCES

[1] (2015). *Health Services for Hajj and Umrah General Department: 'Strenuous Efforts and Important Roles Reflecting the MOH's Readiness'*, Ministry of Health, Saudi Arabia. Accessed: Jan. 20, 2020. [Online]. Available: https://www.moh.gov.sa/en/Ministry/MediaCenter/News/Pages/News-2015-09-24-002.aspx

[2] K. M. Zeitz, H. M. Tan, M. Grief, P. Couns, and C. J. Zeitz, "Crowd behavior at mass gatherings: A literature review," *Prehospital Disaster Med.*, vol. 24, no. 1, pp. 32–38, Feb. 2009, doi: 10.1017/S1049023X00006518.

[3] C. Stott and M. Radburn, "Understanding crowd conflict: Social context, psychology and policing," *Current Opinion Psychol.*, vol. 35, pp. 76–80, Oct. 2020, doi: 10.1016/j.copsyc.2020.03.001.

[4] V. X. Gong, W. Daamen, A. Bozzon, and S. P. Hoogendoorn, "Crowd characterization for crowd management using social media data in city events," *Travel Behav. Soc.*, vol. 20, pp. 192–212, Jul. 2020, doi: 10.1016/j.tbs.2020.03.011.

[5] S. A. M. Saleh, S. A. Suandi, and H. Ibrahim, "Recent survey on crowd density estimation and counting for visual surveillance," *Eng. Appl. Artif. Intell.*, vol. 41, pp. 103–114, May 2015, doi: 10.1016/j.engappai.2015.01.007.

[6] S. Lamba and N. Nain, "A literature review on crowd scene analysis and monitoring," *Int. J. Urban Des. Ubiquitous Comput.*, vol. 4, no. 2, pp. 9–20, Sep. 2016, doi: 10.21742/ijuduc.2016.4.2.02.

[7] L. F. Borja-Borja, M. Saval-Calvo, and J. Azorin-Lopez, "A short review of deep learning methods for understanding group and crowd activities," in *Proc. Int. Joint Conf. Neural Netw. (IJCNN)*, Jul. 2018, pp. 1–8, doi: 10.1109/IJCNN.2018.8489692.

[8] K. R. Ahuja and N. N. Charniya, "A survey of recent advances in crowd density estimation using image processing," in *Proc. Int. Conf. Commun. Electron. Syst. (ICCES)*, Jul. 2019, pp. 1207–1213, doi: 10.1109/ICCES45898.2019.9002291.

[9] G. Sreenu and M. A. Saleem Durai, "Intelligent video surveillance: A review through deep learning techniques for crowd analysis," *J. Big Data*, vol. 6, no. 1, pp. 1–27, Dec. 2019, doi: 10.1186/s40537-019-0212-5.

[10] A. A. Afiq, M. A. Zakariya, M. N. Saad, A. A. Nurfarzana, M. H. M. Khir, A. F. Fadzil, A. Jale, W. Gunawan, Z. A. A. Izuddin, and M. Faizari, "A review on classifying abnormal behavior in crowd scene," *J. Vis. Commun. Image Represent.*, vol. 58, pp. 285–303, Jan. 2019, doi: 10.1016/j.jvcir.2018.11.035.

[11] V. Nguyen and T. D. Ngo, "Single-image crowd counting: A comparative survey on deep learning-based approaches," *Int. J. Multimedia Inf. Retr.*, vol. 9, no. 2, pp. 63–80, Jun. 2020, doi: 10.1007/s13735-019-00181-y.

[12] A. Capponi, C. Fiandrino, B. Kantarci, L. Foschini, D. Kliazovich, and P. Bouvry, "A survey on mobile crowdsensing systems: Challenges, solutions, and opportunities," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 3, pp. 2419–2465, 3rd Quart., 2019.

[13] Q. Chen and L. Shi, "Mobile crowd sensing technologies: A survey and new perspectives," *Int. J. Sci.*, vol. 7, no. 6, pp. 329–336, 2020.

[14] N. N. A. Sjarif, S. M. Shamsuddin, and S. Z. Hashim, "Detection of abnormal behaviors in crowd scene: A review," *Int. J. Adv. Soft Comput. Appl.*, vol. 4, no. 1, pp. 1–33, 2012.

[15] V. J. Kok, M. K. Lim, and C. S. Chan, "Crowd behavior analysis: A review where physics meets biology," *Neurocomputing*, vol. 177, pp. 342–362, Feb. 2016, doi: 10.1016/j.neucom.2015.11.021.

[16] S. Lamba and N. Nain, *Crowd Monitoring and Classification: A Survey*. Lviv, Ukraine: Springer, 2017, pp. 21–23.

[17] H. Gayathri, P. M. Aparna, and A. Verma, "A review of studies on understanding crowd dynamics in the context of crowd safety in mass religious gatherings," *Int. J. Disaster Risk Reduction*, vol. 25, pp. 82–91, Oct. 2017, doi: 10.1016/j.ijdrr.2017.07.017.

[18] K. Rohit, K. Mistree, and J. Lavji, "A review on abnormal crowd behavior detection," in *Proc. Int. Conf. Innov. Inf., Embedded Commun. Syst. (ICIIECS)*, Mar. 2017, pp. 1–3, doi: 10.1109/ICIIECS.2017.8275999.

[19] C. Martella, J. Li, C. Conrado, and A. Vermeeren, "On current crowd management practices and the need for increased situation awareness, prediction, and intervention," *Saf. Sci.*, vol. 91, pp. 381–393, Jan. 2017, doi: 10.1016/j.ssci.2016.09.006.

[20] J. Fourati, B. Issaoui, and K. Zidi, "Literature review of crowd management: A hajj case study," in *Proc. 14th Int. Conf. Informat. Control, Autom. Robot.*, 2017, pp. 346–351, doi: 10.5220/0006472103460351.

[21] D. Sharma, A. P. Bhondekar, A. K. Shukla, and C. Ghanshyam, "A review on technological advancements in crowd management," *J. Ambient Intell. Humanized Comput.*, vol. 9, no. 3, pp. 485–495, Jun. 2018, doi: 10.1007/s12652-016-0432-x.

[22] A. M. Al-Shaery and M. O. Khozium, "Crowd management challenges: Tackling approach for real time crowd monitoring," *Int. J. Sci. Eng. Res.*, 2019.

[23] J. Cui, H. Zha, H. Zhao, and R. Shibasaki, "Laser-based detection and tracking of multiple people in crowds," *Comput. Vis. Image Understand.*, vol. 106, nos. 2–3, pp. 300–312, May 2007, doi: 10.1016/j.cviu.2006.07.015.

[24] M. Yamin, M. Mohammadian, X. Huang, and D. Sharma, "RFID technology and crowded event management," in *Proc. Int. Conf. Comput. Intell. Modeling Control Autom.*, Dec. 2008, pp. 1293–1297, doi: 10.1109/CIMCA.2008.233.

[25] M. Yamin and Y. Ades, "Crowd management with RFID and wireless technologies," in *Proc. 1st Int. Conf. Netw. Commun.*, Dec. 2009, pp. 439–442, doi: 10.1109/NetCoM.2009.14.

[26] 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 *Proc. Int. Conf. Comput. Appl. Technol. (ICCAT)*, Jan. 2013, pp. 1–7, doi: 10.1109/ICCAT.2013.6522008.

[27] A. Sharma, A. Raut, P. Donde, and A. K. Manekar, "Radio frequency based navigation and management system for KUMBH," in *Proc. IEEE Int. Conf. Comput. Intell. Commun. Technol.*, Feb. 2015, pp. 422–426, doi: 10.1109/CICT.2015.51.

[28] L. Schauer, M. Werner, and P. Marcus, "Estimating crowd densities and pedestrian flows using Wi-Fi and Bluetooth," in *Proc. 11th Int. Conf. Mobile Ubiquitous Syst., Comput., Netw. Services*, 2014, pp. 171–177, doi: 10.4108/icst.mobiquitous.2014.257870.
[29] J. R. Santana, L. Sanchez, P. Sotres, J. Lanza, T. Llorente, and L. Munoz, "A privacy-aware crowd management system for smart cities and smart buildings," *IEEE Access*, vol. 8, pp. 135394–135405, 2020, doi: 10.1109/ACCESS.2020.3010609.
[30] A. Basalamah, "Sensing the crowds using Bluetooth low energy tags," *IEEE Access*, vol. 4, pp. 4225–4233, 2016, doi: 10.1109/ACCESS.2016.2594210.
[31] T. You, M. Umair, and Y.-G. Hong, "Mobile crowd sensing based on CICN," in *Proc. Int. Conf. Inf. Commun. Technol. Converg. (ICTC)*, Oct. 2017, pp. 1272–1275, doi: 10.1109/ICTC.2017.8190919.
[32] A. G. Abuarafah and M. O. Khozium, "Integration of background removal and thermography techniques for crowd density scrutinizing," *Int. J. Comput. Academic Res.*, vol. 2, no. 1, pp. 14–25, 2013.
[33] A. Pennisi, D. D. Bloisi, and L. Iocchi, "Online real-time crowd behavior detection in video sequences," *Comput. Vis. Image Understand.*, vol. 144, pp. 166–176, Mar. 2016, doi: 10.1016/j.cviu.2015.09.010.
[34] A. De Freitas, L. Mihaylova, A. Gning, D. Angelova, and V. Kadirkamanathan, "Autonomous crowds tracking with box particle filtering and convolution particle filtering," *Automatica*, vol. 69, pp. 380–394, Jul. 2016, doi: 10.1016/j.automatica.2016.03.009.
[35] V. A. Sindagi and V. M. Patel, "A survey of recent advances in CNN-based single image crowd counting and density estimation," *Pattern Recognit. Lett.*, vol. 107, pp. 3–16, May 2018, doi: 10.1016/j.patrec.2017.07.007.
[36] M. D. Chaudhari and A. S. Ghotkar, "A study on crowd detection and density analysis for safety control," *Int. J. Comput. Sci. Eng.*, vol. 6, no. 4, pp. 424–428, Apr. 2018, doi: 10.26438/ijcse/v6i4.424428.
[37] S. D. Khan, "Congestion detection in pedestrian crowds using oscillation in motion trajectories," *Eng. Appl. Artif. Intell.*, vol. 85, pp. 429–443, Oct. 2019, doi: 10.1016/j.engappai.2019.07.009.
[38] Z. Zou, Y. Cheng, X. Qu, S. Ji, X. Guo, and P. Zhou, "Attend to count: Crowd counting with adaptive capacity multi-scale CNNs," *Neurocomputing*, vol. 367, pp. 75–83, Nov. 2019, doi: 10.1016/j.neucom.2019.08.009.
[39] S. Basalamah, S. D. Khan, and H. Ullah, "Scale driven convolutional neural network model for people counting and localization in crowd scenes," *IEEE Access*, vol. 7, pp. 71576–71584, 2019, doi: 10.1109/ACCESS.2019.2918650.
[40] X. Wu, B. Xu, Y. Zheng, H. Ye, J. Yang, and L. He, "Fast video crowd counting with a temporal aware network," *Neurocomputing*, vol. 403, pp. 13–20, Aug. 2020, doi: 10.1016/j.neucom.2020.04.071.
[41] A. Seyfried, B. Steffen, W. Klingsch, and M. Boltes, "The fundamental diagram of pedestrian movement revisited," *J. Stat. Mech., Theory Exp.*, vol. 10, no. 10, pp. 41–53, 2005, doi: 10.1088/1742-5468/2005/10/P10002.
[42] A. Johansson, M. Batty, K. Hayashi, O. Al Bar, D. Marcozzi, and Z. A. Memish, "Crowd and environmental management during mass gatherings," *Lancet Infectious Diseases*, vol. 12, no. 2, pp. 150–156, 2012, doi: 10.1016/S1473-3099(11)70287-0.
[43] A. G. Abuarafah, M. O. Khozium, and E. AbdRabou, "Real-time crowd monitoring using infrared thermal video sequences," *J. Amer. Sci.*, vol. 8, no. 3, pp. 133–140, 2012.
[44] Z. Huang, P. Wang, F. Zhang, J. Gao, and M. Schich, "A mobility network approach to identify and anticipate large crowd gatherings," *Transp. Res. B, Methodol.*, vol. 114, pp. 147–170, Aug. 2018, doi: 10.1016/j.trb.2018.05.016.
[45] P. S. Karthika, P. M. Aparna, and A. Verma, "Understanding crowd dynamics at ghat regions during world's largest mass religious gathering, kumbh mela," *Int. J. Disaster Risk Reduction*, vol. 31, pp. 918–925, Oct. 2018, doi: 10.1016/j.ijdrr.2018.08.005.
[46] X. Li, W. Song, X. Xu, J. Zhang, L. Xia, and C. Shi, "Experimental study on pedestrian contact force under different degrees of crowding," *Saf. Sci.*, vol. 127, Jul. 2020, Art. no. 104713, doi: 10.1016/j.ssci.2020.104713.
[47] J. Wang, B. Jin, J. Li, F. Chen, Z. Wang, and J. Sun, "Method for guiding crowd evacuation at exit: The buffer zone," *Saf. Sci.*, vol. 118, pp. 88–95, Oct. 2019, doi: 10.1016/j.ssci.2019.05.014.
[48] G. B. C. Office, R. Challenger, C. W. Clegg, M. Robinson, G.-B. C. Office, and G.-B. H. M. S. Office, *Understanding Crowd Behaviours: Supporting Theory and Evidence*, vol. 2. London, U.K.: TSO, 2010.
[49] G. Xiong, J. Cheng, X. Wu, Y.-L. Chen, Y. Ou, and Y. Xu, "An energy model approach to people counting for abnormal crowd behavior detection," *Neurocomputing*, vol. 83, pp. 121–135, Apr. 2012, doi: 10.1016/j.neucom.2011.12.007.
[50] X. Gu, J. Cui, and Q. Zhu, "Abnormal crowd behavior detection by using the particle entropy," *Optik*, vol. 125, no. 14, pp. 3428–3433, Jul. 2014, doi: 10.1016/j.ijleo.2014.01.041.
[51] R. Chaker, Z. A. Aghbari, and I. N. Junejo, "Social network model for crowd anomaly detection and localization," *Pattern Recognit.*, vol. 61, pp. 266–281, Jan. 2017, doi: 10.1016/j.patcog.2016.06.016.
[52] C. Direkoglu, "Abnormal crowd behavior detection using motion information images and convolutional neural networks," *IEEE Access*, vol. 8, pp. 80408–80416, 2020, doi: 10.1109/ACCESS.2020.2990355.
[53] S. Liu and K. Xie, "Research on crowd gathering risk identification based on cell sensor and face recognition," in *Proc. Int. Conf. Ind. Informat.-Comput. Technol., Intell. Technol., Ind. Inf. Integr.*, Dec. 2015, pp. 201–204, doi: 10.1109/ICIICII.2015.132.
[54] T. Alam and M. Aljohani, "Decision support system for real-time people counting in a crowded environment," *SSRN Electron. J.*, vol. 12, no. 1, pp. 34–41, 2020, doi: 10.2139/ssrn.3639076.
[55] X. Chen, Y. Bin, C. Gao, N. Sang, and H. Tang, "Relevant region prediction for crowd counting," *Neurocomputing*, vol. 407, pp. 399–408, Sep. 2020, doi: 10.1016/j.neucom.2020.04.117.
[56] L. A. Toledo Diaz, I. R. Rivas, K. Rodriguez, and I. Rudomin, "Crowd data visualization and simulation," *Procedia Comput. Sci.*, vol. 139, pp. 622–629, 2018, doi: 10.1016/j.procs.2018.10.201.
[57] M. O. Khozium, A. G. Abuarafah, and E. AbdRabou, "A proposed computer-based system architecture for crowd management of pilgrims using thermography," *Life Sci. J.*, vol. 9, no. 2, pp. 277–282, 2012.
[58] M. O. Khozium, "A hybrid intelligent information system for the administration of massive mass of Hajjis," *Life Sci. J.*, vol. 9, no. 4, pp. 171–180, 2012.
[59] M. F. Ali, A. Bashar, and A. Shah, "Smartcrowd: Novel approach to big crowd management using mobile cloud computing," in *Proc. Int. Conf. Cloud Comput. (ICCC)*, Apr. 2015, pp. 1–4, doi: 10.1109/CLOUDCOMP.2015.7149656.
[60] N. Wijermans, C. Conrado, M. van Steen, C. Martella, and J. Li, "A landscape of crowd-management support: An integrative approach," *Saf. Sci.*, vol. 86, pp. 142–164, Jul. 2016, doi: 10.1016/j.ssci.2016.02.027.
[61] S. Hashish and M. Ahmed, "Efficient wireless sensor network rings overlay for crowd management in arafat area of makkah," in *Proc. IEEE Int. Conf. Signal Process., Informat., Commun. Energy Syst. (SPICES)*, Feb. 2015, pp. 1–6, doi: 10.1109/SPICES.2015.7091437.
[62] O. J. Akinwande, H. Bi, and E. Gelenbe, "Managing crowds in hazards with dynamic grouping," *IEEE Access*, vol. 3, pp. 1060–1070, 2015, doi: 10.1109/ACCESS.2015.2453341.
[63] J. Yin, Y. Bi, X.-M. Zheng, and R.-C. Tsaur, "Safety forecasting and early warning of highly aggregated tourist crowds in China," *IEEE Access*, vol. 7, pp. 119026–119040, 2019, doi: 10.1109/access.2019.2936245.
[64] M. Haghani, "Optimising crowd evacuations: Mathematical, architectural and behavioural approaches," *Saf. Sci.*, vol. 128, Aug. 2020, Art. no. 104745, doi: 10.1016/j.ssci.2020.104745.
[65] P. C. Bishop, T. M. Gibbs, and J. Lantz, *Crowd Management and Special Event Planning*, 2nd ed. Amsterdam, The Netherlands: Elsevier, 2020.
[66] S. Kumar, D. Datta, S. K. Singh, and A. K. Sangaiah, "An intelligent decision computing paradigm for crowd monitoring in the smart city," *J. Parallel Distrib. Comput.*, vol. 118, pp. 344–358, Aug. 2018, doi: 10.1016/j.jpdc.2017.03.002.
[67] F. Aros-Vera, A. Sadeghi, R. Younes Sinaki, and D. Sormaz, "A simulation-based framework for checkpoint design in large-scale crowd management: Case study of the papal mass in philadelphia," *Saf. Sci.*, vol. 127, Jul. 2020, Art. no. 104701, doi: 10.1016/j.ssci.2020.104701.
[68] (2020). *List of Human Stampedes*. Wikipedia. Accessed: Jul. 30, 2020. [Online]. Available: https://en.wikipedia.org/wiki/List_of_human_stampedes
[69] FPJ Web Desk. (2016). *What is Simhastha Mahaparv Kumbh All About?*. The free press J. Accessed: Jul. 30, 2020. [Online]. Available: https://www.freepressjournal.in/latest-news/what-is-simhastha-mahaparv-kumbh-all-about
[70] P. N. E. Neufert B. Baiche, and N. Walliman, *Architects' Data*, 3rd ed. Oxford, U.K.: Blackwell Publishing Limited, 2002.
[71] Z. Ji, Y. Huang, Y. Xia, and Y. Zheng, "A robust modified Gaussian mixture model with rough set for image segmentation," *Neurocomputing*, vol. 266, pp. 550–565, Nov. 2017, doi: 10.1016/j.neucom.2017.05.069.
[72] D. Fortun, P. Bouthemy, and C. Kervrann, "Optical flow modeling and computation: A survey," *Comput. Vis. Image Understand.*, vol. 134, pp. 1–21, May 2015, doi: 10.1016/j.cviu.2015.02.008.

[73] O. Arandjelovic, "Crowd detection from still images," in *Proc. Brit. Mach. Vis. Conf.*, 2008, pp. 1–10, doi: 10.5244/C.22.53.
[74] I. Ali and M. N. Dailey, "Multiple human tracking in high-density crowds," *Image Vis. Comput.*, vol. 30, no. 12, pp. 966–977, Dec. 2012, doi: 10.1016/j.imavis.2012.08.013.
[75] S. A. Adelman and P. Tempkins. (2019). *When Planning Crowd Management, Consider the Crowd's Expectations*. [Online]. Available: https://www.hubinternational.com/blog/2019/02/planning-crowd-management/
[76] D. Murphey. (2018). *6 Steps for a Safe and Effective Crowd Management Strategy*. Eventinterface. Accessed: Jun. 21, 2020. [Online]. Available: https://www.eventinterface.com/en/blog/6-steps-for-a-safe-and-effective-crowd-management-strategy/

ALI M. AL-SHAERY (Member, IEEE) received the B.Sc. degree in civil engineering from Umm Al-Qura University, Makkah, Saudi Arabia, in 2003, the M.Sc. degree in surveying from University College London, U.K., in 2006, and the Ph.D. degree in geospatial engineering from the University of New South Wales, Australia, in 2013. He was the Deputy Director of the Transportation and Crowd Management Center of Research Excellence (TCMCORE) from 2013 to 2014. He has been the Dean of the Institute of Consulting Research and Studies (ICRS) since 2015. He is currently an Associate Professor with the Department of Civil Engineering and the Dean of the Institute of Consulting Research and Studies. He is also the Chair of Governing Board of Center of Safety, Risk and Crisis Management. His research interests include global navigation satellite systems (GNSS) real-time kinematic positioning RTK, geographic information systems, location-based applications, smart and sustainable cities, and crowd management.

SHROUG S. ALSHEHRI (Member, IEEE) was born in 1996. She received the B.Sc. degree (Hons.) in computer science, in 2019. She is currently pursuing the M.Sc. degree in computer science with the College of Computer and Information Systems, Umm Al-Qura University, Makkah, Saudi Arabia. She also has a nanodegree in deep learning, data analysis, and iOS development. Her research interests include data analysis, the IoT, machine learning, deep learning, information systems, and crowd management.

NORAH S. FAROOQI (Member, IEEE) received the B.Sc. degree (Hons.) in computer science from Umm Al-Qura University, Saudi Arabia, in 2007, and the M.Sc. degree (Hons.) in information systems and the Ph.D. degree in computer science from The University of Sheffield, U.K., in 2010 and 2013, respectively. She is currently an Associate Professor of computer science with the Department of Information Science, College of Computer and Information Systems, Umm Al-Qura University. She is also the Vice Dean of the Institute of Consulting Research and Studies. She had many publications related to databases and security. Her research interests include systems development, information systems, crowd management, and the IoT. She is a reviewer in a number of academic journals related to computer topics. She developed a number of electronic systems and presented several courses in the development of scientific research skills.

MOHAMED O. KHOZIUM (Member, IEEE) received the first M.S. degree in aviation science (laser applications) from the Air War Studies Institute, in 1994, the high diploma, and the second M.S. degree in computer science and IS from Cairo UN. Many studies in electronic warfare from USA and France, Ph.D. degree in computer Science and information system from Cairo University, in 2005. Since 2015, he has been a Professor. He is currently with the Department of HITM, Faculty of Public Health and Health Informatics, ICRS Consultant, UQU. His research interests include electronic warfare, AI, ES, BI, and crowd management, machine learning, and other aspects of simulation. He is also a Member of the Institute of Consulting (MIC). He had been awarded "doing duties honestly and faithfully award" and "excellent duty medal from the first level" from president of Egypt, in 1996 and 2006, respectfully.