Crowd Models for Emergency Evacuation: A Review Targeting Human-Centered Sensing

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Abstract

Emergency evacuation of crowds is a fascinating phenomenon that has attracted researchers from various fields. Better understanding of this class of crowd behavior opens up for improving evacuation policies and smarter design of buildings, increasing safety. Recently, a new class of disruptive technology has appeared: Human-centered sensing which allows crowd behavior to be monitored in real-time, and provides the basis for real-time crowd control. The question then becomes: to what degree can previous crowd models incorporate this development, and what areas need further research? In this paper, we provide a survey that describes some widely used crowd models and discuss their advantages and shortages from the angle of human-centered sensing. Our review reveals important research opportunities that may contribute to an improved and more robust emergency management.

1. Introduction

Lack of information may aggravate a disaster situation. The location and severity of hazards could for instance be uncertain, and even dynamically changing. This, of course, renders the task of evacuating the disaster area more challenging. When people in addition behave in unanticipated or irrational ways, particularly as a *crowd*, safety may further deteriorate. One example would be crowd trampling caused by panic. When facing such uncertainty, it is crucial to have robust rescue management and evacuation strategies that are able to cope with these and other kinds of complications, to avoid severe losses of human lives.

In recent years, there have been increasing efforts devoted to investigate emergency evacuation of crowds. A wide range of approaches are employed to understand how humans behave in a disaster, as individuals in crowds. This involves studying how certain situations trigger specific responses, and how decisions are made when individuals or groups of individuals face different kinds of decision scenarios. The actual physics of movement and actions during a disaster is also an area of focus. In all these studies the goal is to lay a foundation for improved emergency management [1-6].

Even though advancements of mobile device technologies unfold many fascinating possibilities of crowd research for emergency evacuation, how can one gather information about the crowds' context (location, movement, condition in a disaster) [7], and use the collected information as a decision support [8] for navigation in emergency evacuation, have not been fully explored. The use of mobile sensors and mobile sensing techniques will be an opportunity that allows people to embrace a visual surveillance component for tracking single individuals in a disaster.

The purpose of this paper is to transmit the flavor of several crowd analyses as an overview of the field while discussing their strengths and weaknesses. The review serves a basis for seeking the opportunities of crowd modeling research which consider human-centered sensing for emergency evacuation—a type of study that examines the user's context and characterizes a user's activity or status in an emergency condition.

This paper is organized as follows: Section 2 classifies different crowd models used in literature while section 3 describes each model classification in more detail. Section 4 compares the effectiveness of each model classification using the human-centric sensing and emergency evacuation criteria. Section 5 contains concluding remarks.

2. Classification of Crowd Studies

The interest of researchers in crowd dynamics dates back to the year 1895 when LeBon introduces *La Psychologie des foules* [9]. Since then, crowd dynamics has been investigated from various fields, particularly when pedestrian dynamics was introduced [10], self-organization phenomena, clogging effect, and intermittent flow were identified [11]. Numerous crowd studies are inspired by this pedestrian model [10-15].

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To review the crowd literature we classify them into five threads, as depicted in Fig. 1. These threads represent the field of studies that affect the focus and the purpose of the crowd models.

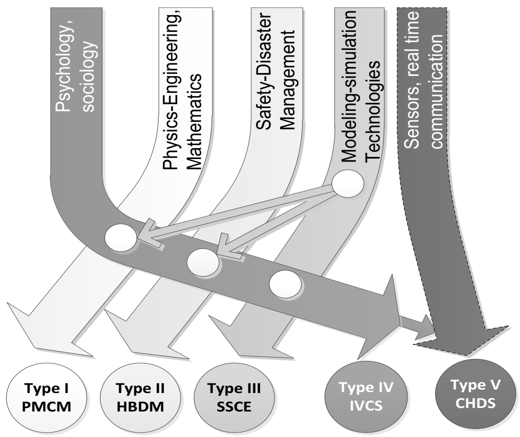

Figure 1. Five threads and five types of crowd literature

The first thread is called "psychology and sociology" as two main subjects that have laid a basis for the crowd studies and influenced the development of the four other threads. The most prominent theory of the first thread is the *collective mind*. Psychologists propose two theories as explanations for the formation of collective mind: *Contagion* [9] and *Predisposition* [16] theories. The former suggests that individual in a crowd tends to lose their cognitive abilities and are easily infected by collective irrational behavior, *a contagion effect*. The latter argues that collective behavior is actually a result of pre-existing individual tendencies (e.g. antisocial personalities) which blends in a crowd (e.g. a violent behavior in a riot).

Sociologists promote the *Emergent norm* and *Identity* theories as explanation for the collective mind. The former assumes that collective behavior takes place under the governance of emergent norms developing through the social interaction in a gathering. Once the norms are established and spread through rumors or movement, the crowd members follow them [17]. The latter stresses the intersection of distinct individual identities that plays a role to form shared group identity and provide the norms, values and beliefs governing the group's behavior. Several attributes have been linked to crowd such as: emotionality, suggestibility, destructiveness in antisocial or violent manners, spontaneity, anonymity and unanimity [18].

The second thread of crowd studies is "physics, engineering and mathematics". Physics concepts such as motion, force, and velocity have been added as a part of the crowd's attributes and expressed in mathematical modeling.

The third thread is called "safety engineering and disaster management". Under this thread, researchers examine the best way to manage crowd related disasters and ensure public safety. Thus, the social-psychological characteristics are studied to recognize the human behaviors in a disaster.

The fourth thread is related to application and development of enhanced modeling and simulation technologies on the crowd studies. Researchers develop simulation software that is used to imitate real emergency situations and to develop scenarios of the crowd disasters. Note that this development also has some impact on the two previous threads, as more recent studies related to physics, engineering and safety management include sophisticated numerical and graphical simulations.

The fifth thread is the incorporation of a sensing paradigm into crowd research. Collecting large scale of data using static, mobile (camera, video, microphone, GPS) and wireless sensors are the main approach in this thread. To a certain degree, the models are used for decision support and smart evacuation management.

Based on the aforementioned threads, we divide crowd literature into five types (Fig. 1): 1) Physics-mathematics-based crowd models (PMCM); 2) Human behavior and decision making (HBDM); 3) Software simulations for crowd evacuation (SSCE); 4) Integrated virtual crowd simulations (IVCS); 5) Crowd for human-centric sensing and decision support (CHDS). The next section describes further each type of the crowd research.

3. Overview of Existing Literature

3.1. Physics-mathematics Crowd Models (PMCM)

Physics and mathematics inspire the crowd models. In the *microscopic approach*, which is called the pedestrian model, every individual in the crowd is treated separately (as a "particle"). There are several variants of the micro-pedestrian model, as described below:

The *Social Force Model (SFM)* encodes the human desires in the form of social forces. The SFM contains a set of differential equations of motion, where positions and velocities of pedestrians are time-dependent variables. The SFM has addressed several problems such as lane and strip formation, turbulent waves, herding, bottlenecks [10, 11], and a clogged phase of a crowd showing persons being stuck [19]. The psychological aspect is represented, e.g. through the tendency of a person to keep distance from a neighboring person. The force is captured through the physical interaction between their bodies: radial force and slide friction [19].

Cellular Automata (CA), each entity of pedestrian is represented as a node that occupies a cell [20, 21]. In a

CA model, time is also divided into many intervals, and the current state of a specific cell is determined by the states of its neighboring cells at the last time step. Zhao et al., [21] use a CA model for crowd emergency evacuation that includes physical attributes such as visibility of exit signs, doors, windows and "flow with stream" psychological phenomenon where people tend to follow other. *Lattice gas models* (LGM) are variants of cellular automata [4] where each pedestrian is considered as an active particle on the grid that has a certain velocity. LGM has also been presented slightly differently, i.e., as mobile lattice gas model [22] for simulating pedestrian evacuation processes.

In *macroscopic approach,* pedestrians are described by means of their average density. There are several types of macro models. *Fluid Dynamic Model (FDM)* [12] assumes that pedestrian flow will move smoothly according to flow-density relationship $Q(\rho) = \rho V(\rho)$, where Q represents the flow, ρ is pedestrian density and V is average velocity. The average velocity V is believed to go to zero at some maximum density. Variations to the model are often added, such as intention and interaction. *The Flow Tiles (FT)* [23] represents crowd in a flow tile. Each flow tile defines a small, stationary region of velocity field. They can be pieced together to form large stationary fields and drive fluids, crowds or other effects.

The Continuum Crowd (CC) [24] captures multiple large homogeneous groups of people who are moving to reach a specific goal. CC has been expanded into a complex environment structure with different floors, walls, windows, pillars [25]. The model mostly neglects variability of individual behavior, since the focus is on the formation and planned motion of crowds. The flow-based models are criticized for ignoring the differences between individuals, and treat everyone as having the same behavioral set. Yet, it is a popular way to capture the motion of large crowd. In CC model for example, variability try to be achieved by inserting a number of agents within the model. Agents are treated as moving obstacles and considered to be promising for future hybrid crowd modeling.

Non-Local Crowd Dynamics (NLCD) [26-28] with a discrete element method (DEM) is a variant of macroscopic models. In the NLCD, each individual moves toward a fixed target, deviating from the best path according to the crowd distribution to avoid entering regions with higher densities. The model is claimed to be coherent to the feature of lane formation in pedestrian dynamics study. NLDC is also successfully show the effects of discontinuities in the crowd flow such as obstructions, traffic jams, stop-and-go phenomena on a moving platform (lively footbridges) [29].

Smith et al. [30] describe the growing need for a realistic crowd simulation in the design of large venues such as concert halls and stadia. Singh et al. [31] embrace the social aspect by introducing realistic subgroup behavior, representing people in the crowd desiring to stay together (e.g. families, friends) and show its tendency to avoid a division in crowd, in a case of contra-flow.

Several crowd studies combine macro and micro approaches [32, 33]. The "self-organization" [32, 34-36] is proposed as a key concept to understand the relationship between local inter-individual interactions (micro) and collective patterns (macro). Repeated interactions among individuals, random fluctuations, information exchange and the knowledge processing at the collective level are the basis of self-organization.

Burger et al. [37] investigate the macroscopic limit of a cell based microscopic CA crowd model and discover the trapping effect of crowd behind non-convex obstacles. Epstein, et al. [38] use hybrid method, computational fluid dynamics (CFD) and agent-based modeling (ABM) for the evacuation planning. The aim is to simulate how large spatially-distributed populations of agents might respond in the face of a physically realistic contaminant plume.

The crowd modeling has been applied in engineering fields, particularly building, transport and urban design. For example, to design entrance and exit widths, the dimensions of ingress and egress routes, the stability of structures which may have to take the weight of a crowd, pressures on barriers, the location of emergency sensors, exit signs, the improvement of means for crowd to locate emergency routes when exit signs become obscured by smoke [30, 31, 39-43].

3.2. Human Behavior and Decision Making (HBDM)

Behaviors, response, decision making under stress [5, 44-46], panic [47, 48] and crowd management in emergency evacuation are the main focuses of the HBDM literature. [1, 2, 4]. The human response studies look at the actions that people take based upon their perception of the situation, their intentions to act and the considerations involved before these actions are carried out. Thus, the cognitive process and collective behavior are often a part of the discussion.

The typical research questions are: What factors affect human behavior under emergency? Why are decisions difficult to make in disaster situations? Are people competing or cooperating under emergency? How does the human cognitive process affect their behavior and option in disasters? What makes emergency management effective?

Kobes et al. [5] specify the critical factors determining the performance of human response under fire: the human features cover personality, knowledge and experience, powers of observation, judgment and movement. The social features include affiliation (e.g. family), task fixation and role and responsibility. The building features include materials, compartments, size of building. The situational factors include focus point, occupant density, easy of wayfinding, building evacuation team and maintenance. The danger factor is about the perceptual features (e.g. visual, smelling, audible and tangible) where people will notice the fire growth rate, smoke yield, toxicity and heat.

In the HBDM literature, there are disagreements whether or not crowd tends to be irrational and panic [5, 49, 50], and consider panic as a myth [51]. Kobes [5] uses "an increased stress level" instead of panic since it is often defined as irrational, illogical and uncontrolled behavior, which is not the same as stress. In contrast to panic, Mawson [52] and Aguirre [47] introduce *social-attachment* as an important factor affecting collective response toward dangers. They will not flee but seek the proximity to the familiar persons and place. Drury et al. [50] advocate this opinion, and argue that in emergency, crowd is far from being selfish, shows crowd solidarity instead. Despite of this objection, panic and irrational behaviors are often adopted into crowd models that combining emotions and cognition within computational science as reviewed by Nissan [53].

A part of the HBDM literature is for the improvement of the emergency evacuation management, such as facilitation of evacuee actions, development of emergency plans, and avoidance of severe evacuee injuries, disorganization, confusion and structural damage [54, 55].

3.3. Software Simulations for Crowd Evacuation (SSCE)

Researches have provided several simulation software for evacuation and emergency management. They are available publicly as commercial and free software, or accessible only through particular project, or consultation service. The produced software mostly focuses on two main features: highlights *the movement* (e.g. Simulex, Evacnet4, and PathFinder) or highlights *the behavior* (e.g. Exit89, Egress and Exodus).

Simulex [56, 57] is a coordinate-based model which calculates the evacuation movement of individual people, through a multi-story building. Users can create a 3-D model of a building with floor plans and staircases, placing the evacuee, defining exits. It can models the physical shape and motion of each individual person such as side-stepping and overtaking patterns, speed fluctuations, queuing, body-twisting, and a choice of different exits using the automatic route-assessment functions.

Pathfinder is an agent-based simulator where each occupant uses a set of individual parameters and makes decisions independently throughout the course of the simulation. Pathfinder includes an integrated user interface and 3D results visualization. It provides the tools to design building layout and fire protection system.

The *Evacnet4* [58] is designed to determine optimal building evacuation plan. It provides option for destination allocation, arc movement summaries, floor clearing times, evacuation profiles, snap shots and bottleneck identification.

The *Exit89* [59] is designed to simulate the evacuation of large, high occupancy buildings. Users can track the movement of individuals while they travel through the building. The model embraces evacuees with a range of mobilities (disabled occupants, children), and delay times. It also comprises a choice of routing options (shortest routes or likelihood where occupants follow familiar exits and ignore available emergency exits), walking speeds, contra-flows and travel up-down stairways.

Egress [60] is developed by Ketchell The simulation technique applied is based on the use of CA. People are modeled as individuals on a grid. User can simulate evacuation from buildings where no evacuation drill data is available, or evacuation trials are not practical due to the nature of the operations or large numbers of people involved.

Exodus [61], is one of the most advanced crowd simulation models that has been applied for different contexts, such as ships, planes, and buildings. As a primarily agent-based model, the movement of individuals is established by a fixed set of motion rules and interacting sub models: movement, behavior, passenger (agent), hazard, and toxicity. The software possesses a set of social psychological attributes and characteristics for each agent. This set comprises age, name, sex, breathing rate, running speed, dead/alive, among others. The agents also possess a fixed degree of familiarity with the building, agility, and patience. The model simulates the egress of large numbers of persons, delay of movement due to extreme heat or effect of toxic gases.

Although we do not discuss further, we notice that plenty of software for crowd simulations are available [1, 6, 62]. Kuligowski and Gwyne [63] underline essential points that user should consider when selecting an evacuation model, such as age and generation of model, refinement of representation, approach and the output. The scope of the representation such as people, structure, phases of evacuation, emergency situation and application area, are additional factors to take into account. In short, user should know if the model is able to cope with the requirements of the specific application area.

3.4. Integrated Virtual Crowd Simulations (IVCS)

Machine vision, virtual and intelligence environments and integration of several crowd modeling methods are among the research focus.

Realistic visualization is important, as well as the integration with realistic physics and social-psychological factors. Software development is not necessarily intended for mass-market, but rather to tackle specific research challenges. Common crowd simulation software is often used to support this type of work.

Agent-based Model (ABM) is a popular approach that often developed with the help of existing software [64-68], for instance to examine the formative evacuation plan of fire in the metro system [64], staged strategy for urban evacuation [65], the evacuees with disabilities [66], the evacuation of crowd from large public building under fire [67], and from underground station [68]. Physics models still influence the way researchers define motion, collision and interaction in IVCS type of studies [69-72]. Oguz et al. [73] use a model-based rendering approach where a polygonal mesh is rendered for each agent according to the agent's skeletal motion and an offline occlusion culling technique.

Further efforts are directed to furnish the crowd with artificial intelligence (AI) [71, 74]. The more advanced approach furnishes the entities with set of functions such as sight, hearing, basic emotion, energy level, aggressiveness level, goals that interacting with other member' goals. This approach can result in realistic simulations, but it is considered to be very expensive to program and implement. Decision making capability of individuals in crowd is particularly considered in ABMs. Individual is treated as an autonomous agent equipped with human-like functional modules such as perception, cognition, decision making and action.

A multi-agent model is an ABM variant that introduces the leader agents and their function and the functions they serve during evacuation to improve the validity of the simulation models [75]. On the other hand, ABMs have been criticized for having too many details in the agent model may not necessarily give more realistic results. They are lacking of proper social relations among individuals [6].

Other stream under IVCS category is about models emphasizing *real-time navigation and virtual reality*. Lamarche and Donikian [76] model virtual humans for real time navigation. Their model replicates the real environment, furnish with a spatial subdivision. The model also contains algorithm that detects bottlenecks inside the environment, a hierarchical path planning, and an additional structure that computes neighborhood relations between entities. An algorithm for handling reactive navigation, visual optimization of the trajectory and collision avoidance is further embraced to the model. Jin et al. [77] scrutinize interactive navigation control of a large crowd in a hybrid architecture. Each individual is modeled as a particle with its own personality. The simulation of multiple groups of crowds is implemented by specifying one vector field for each crowd. Hence, different crowd will have different governing vector field to guide its crowd behavior. The autonomous movement is added into each agent, enforced by minimum distance to avoid collision between agents. Virtual reality approach is also used by Narain et al. to simulate the dense hajj crowd [78]. A crowd is represented as a set of agents, and treated as a continuum fluid that has density and flow velocity. The model includes local collision avoidance in the simulation.

Apparently, hybrid approach by combining global path planning and assigning behavior and motion of each agent seems to be common in this stream. However, most studies attempt to capture very large number of crowd, often have to scarify the social and psychological characteristics of individual.

There are few studies that are less machine vision oriented, but integrate several approaches into a crowd model, yielding a distinctive crowd analysis. For example, Lee and Son [79] propose integrated BDI (Belief-Desire-Intention) model for evacuation of crowd under the terrorist bomb. It is a mixture of Bayesian network, decision field theory, probabilistic depth first search technique, with experiment in a virtual environment. Agent-based simulations, real time planning and decision execution functions are further embedded in this research. The aim is to allow responsible agencies executing the most efficient emergency evacuation. Combining BDI on immersive virtual reality environment for emergency evacuation, decision making, decision support and real time planner has been proposed by Shendarkar et al. [80], although the implementation is slightly different. The challenge with the integration of different approaches into a crowd model is to keep focus on the main modeling goals.

3.5. Crowd for Human-centric Sensing and Decision Support (CHDS).

Newer crowd themes have been explored such as human-centered sensing, visual surveillance for a decision support, and smart emergency management [81]. Static conventional sensors and wireless sensor are also used. Mobile phones are exploited as sensors due to the facts that the cameras can be used as video and image sensors, the microphone can serve as an acoustic sensor, and the embedded GPS receivers can provide location information.

An example of the study is "mobile on-body sensing" for machine recognition of crowd behavior and acquiring large-scale dataset [82], which basically processing signals from on-body sensor to reveal information about individual behavior and activities. This approach no longer preoccupied with a problem of synthesizing realistic pedestrian behaviors with suitable model. Recognizing crowd behavior cover the selection of competing models that are likely to explain the observed sensor data, interpretation data, and to devise methods for map sensor signals into several kinds of crowd behaviors. Roggen et al. [82] combine machine learning techniques, with information spreading, distributed data fusion, graph visualization and graph clustering (network analysis) into crowd analysis.

Video tracking method has been applied to automatically evaluate pedestrian trajectories [15]. The shortages of video tracking have been identified. Some method needs the manual clicking for specifying the starting point of pedestrians. The oblique camera positions can cause pedestrians be hidden behind each other at high densities or even "lost". There are restrictions of most tracking algorithms to manage only several dozens of pedestrian.

Johansson and Helbing [15] employ Artificial Neural Network (ANN) software to automatically detect heads by searching head-like patterns, extrapolating the location of head detections, and finding pedestrian movements, for the crowd turbulence of pilgrim in Mina, that leads into crowd disaster. The use of image enhancement and pattern recognition method is intended to overcome weaknesses in the video-tracking method.

Emergency response simulation using wireless sensor network, and distributed building evacuation simulator for smart emergency management (DBES) has been examined by Dimakis et al. [81]. DBES is combined with the multi-agent paradigm that models all simulated entities as dedicated agents. These entities are able to interact with, search for and subscribe to one another. The system contains a number of Decision Nodes (DN) in the building and a network of sensors. Their role is to provide directions to the evacuees regarding the best available exit, based on real-time information coming from the sensors. The recommendations of the DNs are computed in a distributed manner, and are communicated to the evacuees or emergency personnel [81].

We consider the fifth type of crowd research offer further research opportunities, since the human-centric sensing for emergency evacuation, in fact, is very rare. The case of video tracking of crowd disaster is an example of the opportunities to make use of tracking information as a decision support for an improved surveillance and identification of the critical crowd.

4. Discussion

Now, let us highlight what similarities and differences are apparent in all types of crowd studies (see also Table 1). All five literature categories can be roughly categorized into macroscopic or microscopic models. Macroscopic models deal with coarse parameters such as the average speed of crowd flow whereas at the microscopic level, parameters such as the current flow of pedestrians at each simulation step are refined. The simulation of large crowd remains a challenging task for each crowd model as it deals with its scalability. This step requires identifying the model that best represents the core entity of the problem (individual), the vital parameters of each individual combined with an efficient computation and communication strategy in order to tackle the huge workload within a crowd. All studies discuss the role of panic in emergency evacuation (both agreements and disagreements). All include safe escape, path finding, escape routing, and to a certain degree, try to split the agents in the model into different roles (e.g. leader-followers). None explicitly deals with human-centric sensing for emergency evacuation.

Differences in approaches can be interpreted in terms of how each main thread identified in Section 2, affects the focus of crowd analysis, the type of phenomenon observed, main goals, and the reference disciplines. Besides, the differences are evidence when come to the use of models as decision support, real-time interactivity, simulation presentation, role of visualization, the use of sensors, and large scale of data collection. Certainly, differences also exist in the degree of complexities and context of the emergency situation, but they are not discussed here, since our interest is to see the features that can support the human-centric sensing-based crowd model for human tracking in emergency evacuation.

PMCM studies are still the most influential models that inspire most crowd researches. The invention of clogging effects, jamming, herding, flock, for instance, are sources of inspiration of how to improve exit doors, signs, egress routes design in tall buildings and large stadium as well as the traffic and transport design. Various simulations either numerical or graphical have been developed based on the understanding of physical motion as proposed by Helbing.

Behavioral aspects and social dynamics which are missing from PMCM models are covered by assigning psychology and social parameters in the individual "particle" of the crowd, or by developing hybrid models. Yet, the latter models also contain disadvantages. Among them is the difficulty to develop behavioral rules that consistently produce realistic crowd motion, and global path planning for each individual quickly becomes computationally expensive.

No approaches are proposed on how to monitor people's activities in the disaster. Visualization is mostly intended to show the density or motion of the crowd and test some hypothesized crowd effects. PMCM models are used neither for navigation nor for crowd surveillance.

HBDM studies significantly contribute to understanding of human response in emergency situations. Collective behavior, panic, anxiety, stress, social dynamics, social attachment, norms, contagious effects, and cognitive processes have been scrutinized elsewhere, in the crowd literature. Aforementioned concepts have been adopted in other threads particularly to refine computational-based crowd models.

Despite of these improvements, so far, sociologists are still unsatisfied with the methods used by modelers in order to capture the crowd behaviors. ABM models often overlook the importance of group-level dimensions such as norms, values, the intimacy of human relations, commitments to lines of action, leadership and a sense of identification and membership in meaningful groups. Even if social factors are included, they lack of plausible explanation of social practices.

The panic-based view that is often used by computer scientists in their crowd models is another source of criticism. Sociological studies have documented that panic in a disaster are actually rare. Most models have no adequate validation. Sociologists suggest scholars to improve the crowd modeling by grounding the model on what people do in the situations that are being simulated [83]. Crowd models should incorporate group interaction and inter-group dynamics. In addition the panic perspective on people's behavior during fire should be replaced, to be more in line with today's social scientific understanding of what happening during the disaster, particularly fire crises. A critic refers to a good point that recording devices provide unique-authentic data that can be exploited as a mean for validating evacuation models. Although the main goal of human-centered sensing is individual tracking, there will be potential to improve the validation issues of the crowd models [83].

STCE type of work gives huge advantages for researchers that have limited programming skills with excellent knowledge of crowd emergency management. The products help them to further test and simulate different evacuation scenarios. To a certain degree, the software is also useful for the decision support systems, since some of the software can be understood by wider users and audiences with more limited technical background. However, social scientists believe that existing software is still limited and cannot capture the effect of extreme crowding and take group effects into consideration.

IVCS studies seem to embrace as much good elements as possible from other three types of work into the crowd models, and have a desire to present the virtual crowd and environment as realistic as possible. Integration of several approaches with visual graphics is obvious. Real-time interactions are often used in some studies [76, 77]. It can be for navigations and user control of the model. Threat mapping and evacuation path are also discussed, but is not grounded on real time threat information or real position of people who are in danger, since the sensing factors are not a focus here.

CHDS has laid down a basis for possible development toward human-centered sensing for emergency evacuation. As mentioned in section 3, static sensors such as videos have been used to analyze the crowd motion. The on-body mobile sensing is also employed to monitor the pedestrian movement in a crowd. Human-centric sensing uses the sensor devices integrated in mobile phones to collect data has been used for monitoring health, sport experiences, social media, price auditing.

Table 1. Comparison of the features and focus of crowd studies

	PMCM	HBDM	STCE	IVCS	CHDS
Focus	motion; force; velocity; mass; density, particle; fluid models	cognitive; behavioral decision making; hazard; evacuation; social process	motion; force; mass; velocity; density, hazard sources; agents; layout	agent-based; intelligent agents graphic vision	human-sensing mobile-sensing participatory-sensing
Type of phenomenon observed	clogging; herding; flock; self-organization; stuck, continuum crowd, flow tiles	cognitive process; timely evacuation; decision making; management; social attributes, group dynamics	movement; behavioral; path finder; spread of hazard; agent roles and characteristics	agent roles, social-psychological attributes; evacuation path; safe escape	smart management; human tracking; environmental condition-tracking
Primary goals	show motion and particles; effects of force; velocity; mass; density on crowd	experimentation with disaster; recognizing human behaviors in disaster; efficient evacuation	software development; user-friendly crowd simulation software; hazard visualization	show motion and particles; effects of force; velocity; mass; density on crowd	human- environmental condition; decision supports
Real time	no	no	interactivity	interactivity	interactivity
Decision support	no	no	yes	yes	yes
Simulations	numerical, graph, visual	numerical, graph	numerical, graph, visual	numerical, graph, visual	numerical, graph, visual
Sensing	no	no	no	no	yes
Surveillance	no	no	no	no	yes
Visualization	simple to 3D animated graphics	no	layout of environments; animated human motion & characteristics	realistic environment; virtual human/crowd; tracking map	tracking map, individual location escape path
Data collection	no	no	no	no	yes
Reference discipline	physics, mathematics; engineering	psychology; sociology; disasters management	computer science, safety engineering	computer science; computer graphics	computer science

Spatio-temporal data is the most common information to be collected. Lately, people expand the method for collecting pictures, sound, acceleration, pollution, biometric, and barometric data, which may be useful for detecting threats in a disaster.

In term of emergency evacuation, human-centered sensing literature is still very limited or poor. Thus research opportunities in this type of crowd studies seem to be widely open. The sensor data can be collected through manual, automatic, and context-aware. In the manual mode, the participants trigger the collection of sensor readings themselves when they detect relevant events. In the automatic mode the sensor readings are collected at a constant sampling frequency, while their collection depends on the surrounding environment. In the context-aware mode, the embedded sensors monitor their environment and activate the sensing function when previously set thresholds are exceeded [1]. For application in emergency evacuation, further examination is needed, which mode can serve best as a decision support in emergency evacuations.

5. Concluding Remarks

The purpose of the current survey is to highlight various crowd models that can support a study focusing on how one can conduct crowd surveillance in a disastrous situation and collect information about their location, movement and condition. The ultimate goal is to obtain real-time updates of immediate threats, recognize threat patterns, detect crowd location relative to the hazard sources, and use the information as decision support for navigation in an emergency evacuation. The CHDS approach seems promising for these purposes.

Conversely, one can notice that particle-motion approach as often used in PMCM models is very useful when the objective covers recognition of the crowd movement, as shown by Johansson and Helbing's [15] study. It is not yet fully explored how sensors in mobile devices can be a medium for human tracking in a disaster. There may even be more opportunities that are yet unfolded such as: how can one use a mobile sensor for identifying a person's psychological condition (e.g., stress or not), their movement (e.g. moving slow or fast), their location (e.g. distance to the nearest exit and hazard), and obviously to help rescue teams to get continuous support and navigation during the evacuation.

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