An Alert System: Using Fuzzy Logic for Controlling Crowd Movement by Detecting Critical Density Spots

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***Abstract*—When people form crowds without an orderly arrangement, we need to consider how to best control their movement to provide safety and maximize their experience. Controlling a large crowd is a complicated and costly operation, but it is important to prevent risky situations that can lead to trampling and crushing, and to provide general public safety. Crowd control forces must be able to organize people to provide successful crowd management. In this paper we examine two types of crowds: structured crowds, where people are heading towards the same goal and in generally the same direction, as happens in religious gatherings like the Islamic Hajj or the Hindu Kumbh Mela; and unstructured crowds, where people walk in different directions, as occurs in train stations and in the centers of towns and cities. By identifying the locations of each individual in a crowd, many potential problems of controlling crowds can be detected and avoided, since we will able to identify the direction and speed of each individual and compare it to the surrounding crowd. We propose an alert system as a way of keeping crowds safe in risky situations. The alert system focuses on scrutinizing the status of individuals in order to inform the authorities in case of risk behavior. Fuzzy logic is proposed as the basis for the alert system for deciding if the locations of individuals are considered critical spots causing obstruction of crowd motion. The aim of this paper is to establish a system that is able to process and analyze the individuals' locations according to their current locations status. The system is using the fuzzy logic, as the machine starts to learn the critical density spots by pointing these locations.**

1. Introduction

In large gatherings, crowds, which can reach up to thousands or millions of people, there is a risk of unexpected dynamic movement that can cause injuries and/or death. There are two major types of crowds that are well known: **structured crowds**, where people move in deliberate specific directions, such as in the Islamic Hajj or the Hindu Kumbh Mela; and **unstructured crowds**, where people move randomly, as in town squares, shopping malls, and train stations, as shown in Figure 1(b) and Figure 1(a). There are some common difficulties that authorities controlling crowds face, such as the delay of momentum, perhaps caused by one person's medical incident, or disorderly behavior, perhaps caused by someone running through a crowd. These behaviors change the local behavior and density of the crowd. We refer to these as "critical density spots" (CDS). These spots are going to be defined by alert system that scrutinizes some crowd motion factors such as speed, direction, and opposite directed people. When this occurs, the alert system reports each individual's current location and defines creates its location status wither this spot is critical or not.

Our objective here is to determine how an alert system can identify these CDS so that organizers can deal with dangerous situations. In order to manage the mobility of crowds in a controlled manner, we propose an alert system that detects the average speed of the crowd, detects individuals' direction of movement, and detects the directions of those who move in the opposite direction. This alert system is proposed in order to prevent unexpected crowd dynamics that lead to stampedes with lethal consequences such as

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(a) An unstructured crowd motion. Image from Ozturk et al. [13].

(b) A structured crowd motion. Image is a screen capture from videos in 2019 from Ministry of Hajj, Kingdom of Saudi Arabia, https://www.haj.gov.sa/en

Figure 1. Examples of two major regimes of nominal crowd flow.

Islamic Hajj [8] and Hindu India [14] .

The data was generated from the NetLogo simulation model that was used by the paper [1], which showed promising results by collecting individuals' locations; therefore, the system scrutinizes the locations status for every individual to let the system decide if the location status is a CDS or not. Our suggested model is to use the fuzzy logic, since successful accomplishments have been reported in various problem areas, such as modeling simulation, control system, and image processing [6, 10, 15, 5]. We propose a system in which different inputs, such as finding the directions of individuals, average speed, and the detection of the directions of those individuals moving in the opposite direction; are inputs for a Fuzzy logic system. The fuzzy logic system will then indicate which individuals are in CDS and inform the authorities.

This paper proposes a novel alert system for a control crowd framework for the detection of critical density spots (CDS) and consists of different phases that show various levels of detection.

The remainder of the paper consists of four sections, background, Framework Overview and the conclusion.

2. Background

In terms of controlling crowd motions, we need to understand the crowd motion or behavior. [9] distinguishes two types of crowds with regard to their formation and direction; the structured crowd where people are close to each other and have one destination and direction, and the unstructured crowd where people pass one another in seemingly random directions. Crowd motion analysis can be effective in order to control a crowd. One method is presented by Cao et al. [4] to detect abnormal crowd motion. Khan et al. [9] reported finding requirement engineering to help understand the achievement of recent research on the enhancement of crowd intelligence. Moussaïd et al. [11] studied the walking behavior of pedestrian social groups and its impact on crowd dynamics by analyzing 1500 pedestrians under normal conditions and showed the interactions socially between the group members regarding walking behavior. In Zurich, Switzerland, there is a large festival that takes place for three days; Ulf Blanke et al. [2] captured the dynamics of crowd motion and behavior using an app based on participatory gps-localization.

To monitor crowd motion for the avoidance of safety-critical crowd events, a design of a computer-based system was shown by Deshpande, N.P. et al. [6] using Fuzzy Logic and G.I.S in two studies: open air theatre and an auditorium. The purpose was to determine speed, displacement, and the usability of the overall space. Containing riots with non-lethal weapons (NLWs) is a means used by police and the military; [10] presented a sensitivity analysis for crowd motion agent-based crowd injury modeling by using the Fuzzy Logic approach. Zhou et al. [15] presented a detailed case of crowd evacuation behavior, adding assailants effects, by using Fuzzy Logic. For motion planning to shape a template, Chang et al. [5] proposed a technique for simulation that worked by using Fuzzy Logic; there were two steps: global motion planning and controlling for shape constraints. Alajlan et al. [1] have shown crowd motion by Using Neural Networks and Genetic Algorithms for predicting human movement to help of crowd control motion.

A lethal incident happened in 2015 at the Hajj (an Islamic ritual) where a structured crowd of pilgrims stampeded; Musa et al. [12] proposed a method for crowd-head calculation to prevent any future stampeding. Lakshay et al. [3] suggested strategies for better crowd motion control and for risk management to avoid stampedes at mass gatherings, such as in religious places, railway stations, or social events. Prasun et al. [14] focused on stampedes at religious events in India, such as Sri Kalubai Yatra Mandhardev at Wai, Maharashtra (in 2005) and the event Dussehra Festival Stampede at Patna, Bihar (in 2014), by analyzing the causes and flaws in crowd motion control.

3. Framework Overview

3.1. Problem statement overview

Learning the behavior of a crowd's movement can be useful to improve the control process of people at large events, such as sport events, religious gatherings, and evacuations. Structured and unstructured crowds are two ways of distinguishing crowds by presenting the motile behavior of crowd movement. The structured crowd motion can behave like wave movement, since the individuals are at high density and close to each other, one large mass of people. This wave of people comes with the risk of casualties in the event of chaos or confusion, when individuals changed their speed or direction significantly with the current speed heading and relative to the speed average for the crowd. This is unlike the unstructured crowd, where individuals are scattered in different places and are able to swiftly change paths and move in between other individuals in a problem situation. By observing crowd motion and distinguishing in terms of the aforementioned measures, we will illustrate some major factors that will be beneficial for crowd control processes to prevent accidents.

3.2. Factors of Fuzzy logic

We want to focus on an individual's location status via an alert system to scrutinize whether that status needs to be controlled in the case that the authorities are needed to intervene. The alert system will define various individuals' location status by monitoring factors, such as detecting **the average speed** of intervene, a factor that has a high impact on crowd motion. If there is a fluctuation in the average speed, affected by an individual's motile behavior, it can lead to disrupting crowd movement. People tend to walk in groups of families, friends, or couples; these groups can impact the average speed of crowds when intervene speed is inconsistent [7].

By monitoring the direction of individuals, a way to control crowd motion will be possible. People pay attention to the area of vision in front of themselves in order to make a decision about a desired direction or to avoid collisions with others; this has been demonstrated in different techniques by simulating the direction of individuals. Therefore, we have chosen to detect **the direction of individuals** as a major factor for our alert system. The direction of people has become an important subject for many researchers; they have presented different approaches and methods to crowd control based on [4, 1, 2, 5] for the cases of abnormal behavior, or behavior near emergency exits.

The last factor to be monitored by the alert system is the forewarning of most dangerous case, namely the**the opposite directed individuals** who are head or starting to head in the wrong direction; most crushing and stampeding happens by the collision of two crowds. In 2015 this scenario took place in Mina, Saudi Arabia during the Hajj and caused more than two thousand deaths among pilgrims. Due to people who were misdirected and going against the correct direction, a collision occurred between these highly dense crowds [8].

These factors are going to be the essential variables for the alert system as shown on Table 1 . In the case when the CDS alert goes off, it will point to the spots of every affected individual and will save time and effort for the authorities resolving any problem.

3.3. Alert System framework overview

The alert system is going to report the location status of every individual continuously to determine if the location status is a CDS or not. In other words, the system will ask about the location status of every individual by monitoring the factors of the average of crowd speed, individuals' directions, and the detection opposite-directed individuals in order for the alert system based on Fuzzy Logic to report to the authorities.

Table 1. VARIABLES AND MEMBERSHIP FUNCTIONS

Variables	Membership Functions
The average speed	CDS, need attention, safe
The direction of individuals	CDS, need attention, safe
The number of opposite directed individuals	CDS, need attention, safe

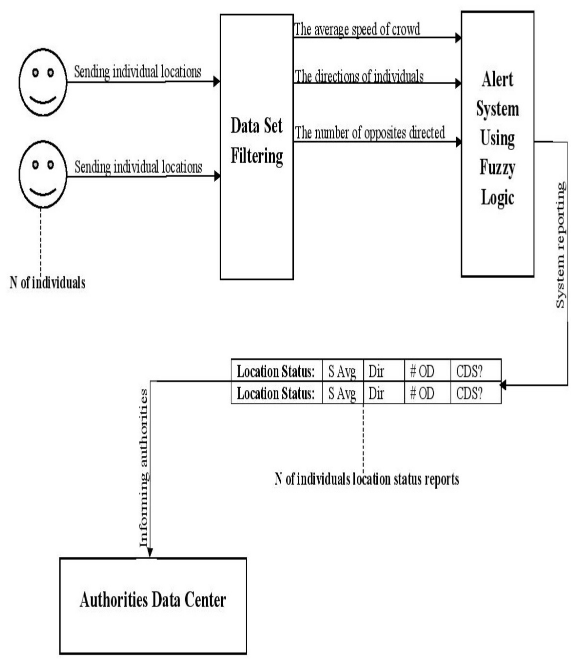

Figure 2. This shows the workflow for alert system. Collecting the individuals locations as an inputs for alert system to produce reports status about each individuals.

Our system will be able to monitor the high-density structured crowd motion to identify the potential areas of threat, based on the CDS location status for every individual, and inform the authorities ahead of actual danger. However, we believe our model will be dependent on the features of the unstructured crowd because these determinations are based on some reliable factors of crowd motion and behavior. Figure 2 explains the workflow of alert system by collecting the individuals current location due to extracting the speed average of crowd, the direction of individuals, and the opposite directed individuals. Therefore, these information will be feed to alert system that uses fuzzy logic for informing authorities about the critical density spots.

4. Conclusion

In this paper, we have presented the basic model of an alert system for controlling crowds by detecting the critical density spots in order to inform the authorities who make decisions about crowd control. Two types of crowds, structured and unstructured, are going to be studied by collecting every individual's location. The identification of these potential critical density spots can lead to greater safety in large crowd conditions. In the future, the framework will be implemented and tested by simulated crowds motion.

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