BEHAVIOURAL FACTORS BASED CROWD EVACUATION MODELLING USING FUZZY-NEURAL APPROACH

WAHIDA BINTI ZAKARIA

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by

WAHIDA BINTI ZAKARIA

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"In the name of Allah, most Gracious, most Compassionate"

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TABLE OF CONTENTS

CHAPTER 3 RESEARCH METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANFIS	Adaptive Neural Fuzzy Inference System
ANN	Artificial Neural Network
CA	Cellular Automata
CEM	Crowd Evacuation Modelling
DEF-FCEM	Dynamic Emotion Forces Fuzzy Evacuation Modelling
eDEF-FCEM	Enhanced DEF-FCEM
FCEM	Fuzzy Evacuation Modelling
FCM	fuzzy Cognitive Map
FIS	Fuzzy Inference System
FL	Fuzzy Logic
FLS	Fuzzy Logic System
GAS	General Adaptation Syndrome
MF	Membership Function
NF	Non-Fuzzy
NF-CEM	Non Fuzzy Crowd Evacuation Modelling
SF	Social Force
SFM	Social Force Model
SVM	Support Vector Machine
T	Time Step

PEMODELAN PEMINDAHAN ORANG RAMAI BERDASARKAN FAKTOR PERLAKUAN MENGGUNAKAN PENDEKATAN NEURAL-KABUR

ABSTRAK

Kajian mengenai pemindahan orang ramai telah menarik minat para penyelidik dari pelbagai bidang untuk mensimulasikan fenomena panik sebenar dalam melarikan diri semasa pemindahan. Faktor utama yang dianalisis dalam bidang-bidang tersebut adalah tingkah laku orang ramai. Kajian awal tentang tingkah laku orang ramai telah mula menyerupai pola tingkah laku pemindahan sebenar seperti mengekori, berbaris dan berkelompok. Kajian-kajian ini mempunyai pemahaman yang minimum mengenai corak tingkah laku orang ramai dari perspektif psikologi yang boleh mempengaruhi emosi dalam keadaan yang tertekan serta mengakibatkan perubahan dalam tindakan perilaku. Di samping itu, keputusan simulasi dalam kajian terdahulu ditunjukkan dalam satu skrin yang kemudiannya disahkan secara kualitatif melalui pemerhatian melalui respon temubual atau tinjauan. Sebab utama penilaian tersebut ialah untuk memeriksa kesamaan corak tingkah laku. Dalam perkembangan teknologi terkini seperti kamera pengawasan, simulasi corak tingkah laku yang dihasilkan dapat dibandingkan dengan video sebenar. Walau bagaimanapun, kaedah penilaian secara kualitatif masih kekal disebabkan cabaran dalam mengesan pergerakan orang ramai untuk dibezakan ketepatannya dengan pemindahan sebenar. Oleh itu, matlamat utama kajian ini adalah untuk mencadangkan pemodelan pemindahan orang ramai (CEM) yang berasaskan teori emosi yang menerapkan faktor-faktor perilaku manusia iaitu faktor fizikal, persekitaran, psikologi dan persepsi. Emosi yang dipertimbangkan adalah panik dan keliru yang bertindak balas terhadap keadaan yang terancam dengan menggunakan pendekatan logik fuzzy. Pendekatan logik fuzzy terkenal dalam menangani ketidakpastian dan masalah kompleks yang sesuai dengan pemodelan tingkah laku manusia. Terdapat tiga varian kerja yang dicadangkan, iaitu CEM fuzzy (FCEM) dengan nilai emosi dan kelajuan yang berubah secara berkala. Seterusnya, model FCEM ditambahbaik supaya menyerupai pemindahan sebenar dengan memasukkan tingkah laku dinamik yang bertindak balas secara berterusan sepanjang simulasi melalui tindakan daya emosi ke atas fizikal orang ramai iaitu daya emosi dinamik FCEM (DEF-FCEM). Akhir sekali, *adaptive neural fuzzy inference system* (ANFIS) dengan DEF-FCEM yang dikenali sebagai eDEF-FCEM digunakan untuk mengoptimumkan parameter fuzzy dari data sebenar. Ketiga-tiga pendekatan ini dibandingkan dengan set data kesusasteraan dengan larasan yang sama. eDEF-FCEM memperoleh ketepatan tertinggi yang berguna untuk memberi gambaran corak tingkah laku orang ramai semasa pemindahan. Set data telah diekstrak daripada video pemindahan sebenar di mana pergerakan setiap ejen dapat dikesan. Keputusan eksperimen menunjukkan bahawa ketepatan cadangan FCEM, DEF-FCEM dan eDEF-FCEM telah masing-masing mencapai 63.14%, 69.51% dan 74.33% berbanding dengan ketepatan terbaik dari kesusasteraan (45.84%).

BEHAVIOURAL FACTORS BASED CROWD EVACUATION MODELLING USING FUZZY-NEURAL APPROACH

ABSTRACT

Crowd studies on evacuation have attracted researchers from many fields of study that aim to simulate reality phenomena of escape panic during the evacuation. The main factor being analyzed is the crowd behaviour. Early studies of crowd behaviour have started to imitate reality behaviour patterns of evacuation such as following, queuing and herding. This studies have a little understanding on the crowd behaviour patterns from the psychological perspective on the emotions influences under stressful situation which may result in different behavioural actions. In addition, the simulations results in earlier studies are shown in a single screen which are then validated qualitatively through observation by interview respond or survey. The main reason for such evaluation is to check on the similarity of the behavioural patterns. In later advancement of technology such as surveillance camera, the simulations of behavioural pattern produced are comparable side by side to the real videos. Nevertheless, the validation method still remain as qualitative due to the challenges in tracking peoples movement during the evacuation which is needed for accuracy validation against the reality evacuation. Therefore, the main goal of this study is to propose a crowd evacuation modelling (CEM) that derived from psychological theory of emotions which incorporated human behavioural factors namely physical, environment, psychology and perception. The emotions considered are panic and confuse which react to the threatening situation using fuzzy logic approach. Fuzzy logic approach is well-known in handling uncertainties and complex problem which suit well in modelling human behaviours. There are three variants of proposed work, namely fuzzy CEM (FCEM) with the constant value of emotions and speed. Next, it is followed by enhancing the model to be closed to realistic evacuation by adding dynamic behaviour reactions throughout the simulation with the proposed physical forces of emotions in the crowd namely dynamic emotions forces FCEM (DEF-FCEM). Lastly, Adaptive Neuro-Fuzzy Inference System (ANFIS) with the enhanced DEF-FCEM called eDEF-FCEM optimizes fuzzy parameters from the real data. These three approaches were compared with the literature data set given with the same setting. eDEF-FCEM obtained the highest accuracy which is useful to give insight on the crowd behaviour patterns during the evacuation. The data set was extracted from real evacuation video where the movement of each agent was tracked. The experimental results showed that the accuracy of proposed FCEM, DEF-FCEM and eDEF-FCEM have achieved 63.14%, 69.51% and 74.33% respectively compared to the best in literature (45.84%).

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Mass events take place almost everywhere in the world involving thousands of attendees in the gathering. The examples of mass events are football match at the stadium or concerts, national celebrations or remembrance, religious activities and festivals. Public places such as shopping malls, airports, bus stations and schools are places where many people are attracted too. All these scenarios involved many people at a time with individual behaviour representations, which can be called a crowd (Xu *et al.*, 2014). The crowd behaviours are the results of multiple individual behaviours that have contributed to the complexity in understanding crowd behaviour.

In the event with thousands of attendees, anything can go wrong. A sudden loud shout can cause the crowd to become chaos and evacuate (Langner and Kray, 2014). An example of a real-life incident which took place on May 4, 2010 in Amsterdam has triggered panic and immediate *evacuation*[1] with some injuries (Bosse *et al.*, 2013). In addition, other crowd disasters which are tracked since 1902 by Still (2014) showed that many crowd incidents during evacuation remain unresolved even with the existence of various models of crowd evacuation modelling (CEM). Hence, the crowd evacuation studies have grabbed attention from multiple domains of study such as industry, academia and government agencies to support the need in providing heads up and plan for the panic crowd to escape during the evacuation.

[1]Evacuation is the actions of the peoples to move out for a safer place from a dangerous situation.

Therefore, many studies attempted to investigate and improve crowd emergency evacuations such as Radianti *et al.* (2015), Bakar *et al.* (2018) and Qu *et al.* (2018). According to Pan *et al.* (2007), Proulx and Richardson (2002) and Cheng and Zheng (2018) in order to navigate crowd to escape directions in public assembly places, ones have to understand human and social behaviours during emergencies.

Most of the crowd evacuation studies in the past simulated the model to imitate reality of crowd evacuation. Past models of CEM highlighted on the lacking of crowd behavioural studies in the perspective of psychology and social sciences (Santos and Aguirre, 2004; Aguirre *et al.*, 2011; Abdelhak *et al.*, 2012; Seitz *et al.*, 2017; Gerakakis *et al.*, 2019). Social science is the study of human society and social relationship which referring to social behaviour or interaction in the context of CEM domain. Meanwhile, psychology is the study of the human mind, especially those affecting behaviour (Carlson, 2010). In the study of Wang *et al.* (2011a), they mentioned that human intelligence in the decision making (cognition[2]) and psychology played a major role in evacuation process but it is insufficient to consider only traditional methods with weak detailed features and efficiency. Another study conducted by Xu *et al.* (2014) still highlighted the challenges in crowd behaviour due to the complexity of human behaviour and it is remained as an open issue due to various psychological and social factors. In recent years, Seitz *et al.* (2017) agreed on the need to incorporate crowd psychological theories in elucidating the factors underpinning behaviour in crowds. This is obviously due to some gaps that need to be enriched on the existing models.

[2]Cognition is the mental action or process in understanding something which encompasses aspects such as evaluation, reasoning, problem solving and decision making.

Throughout the years, there have been increasing efforts devoted to investigating emergency evacuation of crowds, particularly on the behaviour. A wide range of approaches are employed to understand human cognitive[3] behaviour in a disaster, either as individuals or group in the crowds (Bellomo *et al.*, 2016; Namoun *et al.*, 2018). This involved studying on how certain situations trigger emotions and specific responses, and how decisions are made when individuals or groups of individuals face different kinds of decision scenarios which mostly can be found in psychology studies of emotions (Lazarus and Folkman, 1984; Cannon, 1927; Scherer, 1999).

As the complexity of the model increased to suit the realistic crowd situation, crowd dynamic behaviour appears to be in trend. According to Kim *et al.* (2012), the nature in human behaviours is the changes in the response to the situation which is called as dynamic. Crowd dynamic studies in CEM mostly focused on the agent movement which leads to the behaviour of the crowd in the simulation. In the study of crowd dynamic by Moussaid *et al.* (2011) based on the social force model (SFM), there are three simple rules set to determine crowd behaviour which resulted in lane formation from the model proposed.

Meanwhile, Lohner (2010) added a force in the perspective of human will as the navigational behaviour in the movement theory to create realistic behaviour which eventually called as crowd dynamics. The actual physics of movement and behaviour actions of the crowd during a disaster is also an area of focus which eventually lead to dynamic behaviours of the crowd. For instance, navigational behaviour derived from the force-based model such as Boids theory (Reynolds, 1999), social force model

[3]The cognitive perspective focuses on the way that people's thoughts influence their emotions (Whitbourne and Halgin, 2013)

(SFM) (Helbing *et al.*, 2000) applied in numerous simulation of the crowd movement. Other work discussed in the past on the navigational behaviour such as flow-based model applied in the worked of Krausz and Bauckhage (2012); Sindhuja *et al.* (2014) and geometrical-based model for collision-free by Wang *et al.* (2011b). The continuous changes in the response towards a situation in the simulation models have created dynamic behaviours in the crowd. Throughout this thesis, the mentioned dynamic behaviours focused on the crowd navigational behaviours as the result of emotional changes.

In all these studies, the goal is to simulate *reality evacuation*[4] while prioritizing the crowd to escape safely (Wirz *et al.*, 2012; Radianti *et al.*, 2013; Jo *et al.*, 2014; Fu *et al.*, 2017; Zhao *et al.*, 2018; Gerakakis *et al.*, 2019). The realistic term in the context of this thesis refers to the ability to imitate real human behaviour during emergency which can be measured quantitatively to obtain accuracy.

1.2 Challenges to Simulate the Real Crowd Evacuation Modelling through Behavioural Factors Identification

Currently, with many crowd evacuation models and simulations used by different applications and purposes as discussed in Section 1.2, crowd evacuation incidents are still unresolved. In 2005, the Society of Fire Protection Engineer in Maryland (USA), identified the lacking of behavioural data from the emergency scenes which concluded that simulation of existing models was mostly based on the assumption (O Connor, 2005). According to them, computational models seemed to have accurate evacuations simulation but due to scarcity of emergency behaviour data, prediction accuracy was

[4]Reality evacuation is the actual evacuation which is unplanned.

doubted.

In 2009, Johansson *et al.* (2009) researched clearly mentioned on the difficulty in getting the emergency video scenes for the model to be validated quantitatively. In a recent study by Moussaid *et al.* (2016), also mentioned that the experimented models simulation of the agent cannot reliably emulate real human behaviour, especially when the data from the emergency scenes are difficult to obtain. In addition, the assumption is made due to scarcity of emergency scenes video data which lab experiment video data may not be suitable for the behaviour study during the emergency (Moussaid *et al.*, 2016). Hence, there are many other studies that have tried to integrate reality human behaviour into the evacuation model by studying human factors during emergencies with a qualitative method such as side by side screens comparison (Shields and Proulx, 2000; Proulx and Richardson, 2002; Sharma and Otunba, 2011; Zhao *et al.*, 2018). Crowd behaviour during a disaster is the primary aspect studied to simulate real evacuation situation. However, the massive challenge is the unpredictable crowd behaviour during the emergency (Wirz *et al.*, 2012; Radianti *et al.*, 2013; Namoun *et al.*, 2018). Earlier studies of non-emergency have applied fuzzy logic approach in imitating realistic behaviour derived from the emotions such as FLAME model by El-Nasr *et al.* (2000) and PETEEI model El-Nasr *et al.* (1999). Those studies are meant to represent human behaviour through robot such as happy, sad, fear as the results from the emotions. However, during the emergency, the likelihood of the crowd to encounter bad feelings such as fear, sad, stress, confuse and panic are more relevant compared to the good one which is in line with Selye (1956) on the human emotional transition between normal to panic state which is due to the extreme event that is beyond control.

According to Cao *et al.* (2017), emotion is a kind of psychological activity produced by individuals along with cognition and consciousness, which not only affects the individual's behaviour but could also affect the behaviours of other individuals. Therefore, understanding human decision making based on emotional changes from the perspective of psychology towards behavioural action is crucial in producing near to realistic CEM simulation (Seitz *et al.*, 2017).

To date, many studies that integrated panic and stress into the CEM model such as (Helbing *et al.*, 2002; Abdelhak *et al.*, 2012; Sharma and Otunba, 2011; O'Connor *et al.*, 2015). However, the underlying theories applied to these models are from the simple perspective of psychology. Thus, understanding the emotions evolvement resulting in the different behaviours of the crowd remained puzzled in imitating the actual behaviour patterns. Besides, the validation of the past models was not from the real emergency scene. Hence, it is difficult to conclude the accuracy of the past models as the validation is executed qualitatively (Haghani and Sarvi, 2016; Namoun *et al.*, 2018). Accuracy in the discussion here is the measurement of simulating human position to be the same as the actual frame in the emergency scene. Thus, the simulations movement produced close to the real emergency video are considered to be with higher accuracy (Bosse *et al.*, 2013).

Meanwhile, Langner and Kray (2014) indicated that studies of CEM which focused on human perception are pathfinding, obstacle avoidance and collision detection such as Reynolds (1999); Moussaid *et al.* (2016) which integrated human navigational behaviour of crowd during evacuation. Apart from this, crowd behavioural studies focusing on behavioural actions derived from cognitive emotions are from Banarjee *et al.* (2005) which is based on ant colony optimization (ACO) with emotions fabrication in a war situation. Followed by mirroring mental states from the perspective of neuroscience by Bosse *et al.* (2013) and crowd behaviour as a whole or mob crowd introduced by Durupinar *et al.* (2016) based on the psychological theory of OCC model (Ortony *et al.*, 1990) with the consideration of twenty-two emotions dimension. All these models were built with the intention to simulate the real situation.

Most of the past studies build models and run the simulations with the intention to imitate realistic behaviour using a qualitative technique such as video observation which has limited understanding of human decision making and more towards making assumption (Seitz *et al.*, 2017). The qualitative method can be made through observation and questionnaires but mostly it relies on the human to judge the realistic of the behaviour (Moussaid *et al.*, 2016). A recent study conducted by Zafar *et al.* (2017) has mentioned about a complex model which involved individual emotions such as fear, hope and belief but limited in understanding the complexity of crowd behaviour in terms of discrete quantitative measure. Nevertheless, there was also studies of CEM with the combination of devices such as radio frequency identification detection (RFID) with fuzzy logic approach (Sharma *et al.*, 2008), used of mobile phone (Radianti *et al.*, 2014) and global positioning system (GPS) as the infrastructure to study on the crowd behaviour (Namoun *et al.*, 2018). While all the studies have been highlighted as the most active topics in CEM, modelling crowd behaviour from the aspects of cognitive by understanding human decision making in terms of psychology appears to be essential for better realism in tailoring towards behavioural actions and patterns (Lemercier and Auberlet, 2016).

Indeed, crowd evacuation is a challenging issue because emergency events may propagate in uncertain ways due to the effect of the perceived environment, the speed of crowd movement, space capacity constraining, and shifting in crowd behaviour due to the psychological aspects which contributed to the behavioural factors (Wang *et al.*, 2008; Mitchell, 2016). However, the situation can be worsened when it is surrounded by many panic people (Durupinar *et al.*, 2016). The negative emotions are triggered by the surrounding stimuli such as environment or stressor and perception of individual behaviour where the assessment is made. Human emotions play a major role in decision making (cognitive) which are tailored to the behavioural actions (Durupinar *et al.*, 2016). This is explained in psychological theories of emotions under stressful condition by Lazarus and Folkman (1984) where emergency often creates emotions and appraisals which resulted in behavioural actions. Therefore, the incorporation of psychological theories in understanding human behavioural actions as the result of the emotions and cognitive responses is very significant in achieving realistic crowd behavioural patterns.

1.3 Problem Statement

The challenges discussed in Section 1.2 revealed the factors impacting crowd evacuation during the emergency which mainly focused on the behaviour of the crowd such as individual psychology, perception, environment, physical and personality effect (Pan *et al.*, 2007; Chu *et al.*, 2014).

The deficiencies in incorporating human and social behaviours into modelling human behaviour during an egress evacuation have been highlighted numerous times by authorities in fire engineering and social sciences (Aguirre *et al.*, 2011; Pan *et al.*, 2007). In a recent study of Seitz *et al.* (2017), mentioned that the increasing numbers of computer simulation in predicting human behaviours from video observations without the understanding of human behaviours in term of psychology. Crowd panic and emerging[5] behaviours have resulted in behaviour patterns such as queuing, herding, competitive and following which are the most prevalent behavioural factors discussed in past studies (Sharma, 2009; Helbing *et al.*, 2002; Wang *et al.*, 2011a). However, there are no detail studies on the emerging of human emotions under a stressful situation which impact on human cognitive behaviour in making the decision and coping with stress under the evacuation scenario.

Next, the problem faced in producing a realistic crowd behaviour modelling is due to limited extraction of qualitative data (O'Connor *et al.*, 2015; Liu *et al.*, 2009a; Flagg and Rehg, 2013) into quantitative from the observation study. This is mainly because of the restricted amount of emergency video scenes that lead to a panic situation which is also known as real panic data (Helbing *et al.*, 2000; O Connor, 2005; Pan *et al.*, 2007; Sharma *et al.*, 2008; Chu *et al.*, 2014; Moussaid *et al.*, 2016). Hence, many studies are done qualitatively. However, the problem could not be eliminated if we rely on qualitative insight only without measuring the validity of the model. The performance and accuracy of the proposed model shall be validated quantitatively so that the model can be improved significantly. Real behaviour data extraction through position tracking is needed to simulate the realistic behaviour of the crowd during the emergency.

Besides, another trending aspect on crowd evacuation which has drawn attention

[5]emerging is the evolution of the behaviours such as many peoples run at once towards the same door will produce herding, following or queuing effect

in recent advances is to understand dynamics behaviour of the crowd during the movements in a stressful situation (Moussaid *et al.*, 2016). In recent progress of modelling and simulation techniques, with the advancement of live monitoring such as surveillance camera, videos have provided to more empirical insights on the crowd movements. Thus, the crowd movement or trajectories can be easily evaluated for accuracy if a clear emergency video scenes can be obtained. However, this is not the usual case as the limitation in extracting appropriate data from a video (Haghani and Sarvi, 2016; Zainuddin and Aik, 2012; Namoun *et al.*, 2018) has caused many models not to be validated. Thus, the need for the emergency evacuation video as the benchmark is crucial to determine the accuracy measure of the proposed CEM which consists of behaviours and patterns.

Most of the studies have also discussed on achieving realistic behaviour of the crowd through dynamic changes of the individuals which is either by external environment or with the adjustment of their movements. According to Jiang *et al.* (2018), the emerging of emotions affected the movements of the individuals such as the changes in position, orientation and speed ranging from the self-organization phenomena such as unidirectional (Moussaid *et al.*, 2011), turning and merging flows (Dias *et al.*, 2012; Shi *et al.*, 2015), egress and ingress from a door (Daamen and Hoogendoorn, 2010). Therefore, this thesis highlights the dynamic behaviour approach through physics force model introduced by Reynolds (1999) to simulate behaviour reactions under the influenced of the emerging emotions from the real scenario.

According to Smith *et al.* (2009), it is vital to understand crowd dynamic behaviour when designing any public places as good venue design (Still, 2014) can significantly reduce fatalities or eliminate them. Smith *et al.* (2009) stated that with a good setup gathering place, it will smooth up the crowd flowing out from the venue which at first need the behaviour data from the actual emergency scene. Moreover, Xu *et al.* (2014) agreed that with such model, it helps the authorities to assess risk and optimize the escape design space. According to Gerakakis *et al.* (2019), all modelling approaches have the same concern which is to improve the evacuation flow by understanding crowd escaping behaviour pattern during panic situation. Therefore, this thesis attempts to model crowd escapee behaviour from emergency evacuation scene and to provide insight to the authorities on the crowd behaviour patterns during the evacuation to smooth up the evacuation process.

Besides, the efficiency of the proposed model should be able to demonstrate individual behaviour which contributes to the behaviour patterns of crowds towards the escape direction. Thus, the research questions of this study are:

- How to develop and evaluate the behavioural factors in crowd evacuation modelling based on psychological theory and measure the accuracy?
- How to enhance the proposed crowd evacuation modelling to change the behaviours dynamically and measure the accuracy?
- How to optimize the proposed crowd evacuation modelling using the emergency video data as the benchmark and maximize the accuracy measure?

1.4 Objectives of the Study

This research aims to develop and evaluate a novel model of crowd evacuation which can simulate the real scenario during emergency event and predict crowd behaviour pattern in emergency by considering the identified behavioural factors. Specifically, the aim of the study is supported by the following objectives:

1. To propose and evaluate crowd evacuation modelling using fuzzy logic that integrates human behavioural factors based on emotions theory and measures the accuracy with the benchmark video data.
2. To incorporate the physics force of emotions in the movement of crowd evacuation modelling which changes the behaviours dynamically and measures the accuracy with benchmark video data.
3. To improve the crowd evacuation modelling by optimizing the fuzzy logic parameters and neural network to achieve higher accuracy.

1.5 Study Scope and Significance

Modelling crowd behaviour during emergency event involved numbers of various factors. Therefore, various parameters, constraints and behavioural properties which may pose as challenges in solving the underlying problem are considered. Thus, the scopes and limitations have to be made transparent to ensure the study to be manageable. The scopes of this research are given as follows:

- The focus type of crowd discussed in this research is limited to the pedestrian crowd only, not involving the crowd in a vehicle.

- Crowd evacuation properties - In this work, crowd densities targeted are ranging from a medium which is about 10000 (Mohammad *et al.*, 2014; Harris *et al.*, 2017) to a large crowd which is approximately 20000 (Narain *et al.*, 2009; Still, 2014; Chooramun *et al.*, 2019). Ignoring handicap, occlusions and wheelchair individual. The agent is plotted in 2D with a tiny circle shape. Meanwhile, the speed of the agent will be differentiated by colours coding according to their speed range.

- Video Analysis - The analysis of the real event is only on the part where the incident happens that leads to crowd evacuation (from a static position to evacuation). There were 35 individual data extracted from different densities of 10000 people and the location of the emergency. The video data analysis is about 5 seconds which is from 11-17 seconds of the video recorded. The pattern of evacuation is captured and analyzed.

- Data set - The only data set available that matched to the proposed work is from Bosse *et al.* (2013) which consists of emergency video scene and the tracking of individuals position. The video scene from this data is an open space gathering within buildings which may have more than three escape directions. However, in this study, the escape directions are labelled as ED_1, ED_2 and ED_3 to indicate the attraction of the crowd during the evacuation in the rectangle screen (the screen somehow is the mixture of wall and open space) which have been identified according to the data set.

- Automation - This research does not mean for automation as the objective is to capture emergency offline on a rectangle layout. The more data set added, the more robust the model would be.

This research is considered crucial as it attempts to bridge the gaps in understanding human behavioural actions from a psychological perspective which is then validated with the data extraction from the emergency video scene. The outcome of the proposed model which contain the high similarities to the emergency crowd behaviour will be useful for the simulation by other parties such as those who involved in setting up big events where the patterns of human behaviour under emergency is needed in testing the evacuation flow.

1.6 Outline of the Thesis

This thesis is organized into six chapters. Brief descriptions of the content of each chapter is given as follows:

(I) Chapter 1 of the thesis begins with a discussion of the problem background, challenges, objectives, scopes and significance of the research topic in general.

(II) Chapter 2 outlines the important aspects and challenges posed in the domain problems. This chapter also provides some insight into the theoretical background of the focused domain problems as well as prior works.

(III) Chapter 3 describes the research methodology that is employed in this research including the research framework, data sources, instrumentation, problem description, performance measures and experimentation conducted in the study.

(IV) Chapter 4 outlines the existing crowd evacuation modelling (CEM) using fuzzy logic approach on the human behavioural factors. The human behavioural factors considered are from the perspective of psychology, environment, physical and perception. The proposed fuzzy CEM (FCEM) model has three input parameters namely distance, panic and confuse with an output of speed that creates behavioural changes on each agent. The multiple movements of an agent will create trajectories that can be measured the accuracy of the proposed model with the literature data.

(V) Chapter 5 integrates dynamic emotion forces (DEF) into the proposed FCEM to get more realistic interaction and influence of agents in a specific radius. The newly proposed model is called DEF-FCEM. The effect of adding a new force of dynamic emotions on this model towards the heading directions is analyzed.

(VI) Chapter 6 enhances DEF-FCEM with adaptive neural fuzzy inference system (ANFIS) to optimize the input range of fuzzy parameters with the training data from the real emergency video. The proposed model is called eDEF-FCEM which will apply the new range of the three input parameters as in Chapter 4 to maximise the accuracy measured.

(VII) Chapter 7 discusses the overall contribution of the thesis, limitation and future work.

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

This chapter reviews the past studies of various aspects, problems and approaches in the field of crowd evacuation modelling. Throughout this chapter, the gap in the crowd evacuation modelling as well as the approaches that are needed towards simulating realistic crowd are emphasized. Finally, the potential trends and directions derived from the scope of the study are discussed. To obtain a clearer view of this chapter, it is structured as in Figure 2.1.

2.2 The Crowd

In the modern society nowadays, large gathering is becoming a phenomenon which involved hundreds or thousands of crowd (Krausz and Bauckhage, 2012). Crowd can be defined as a group of people which have the same purpose in the gathering (Kugu *et al.*, 2014). The crowded place can be in the concerts, live game in stadium, and even in the shopping malls, airport or any public places especially during peak hours. Mostly, these crowds are pedestrians.

Pedestrians crowd studies have been in placed since 1990 which involved many parties such as engineering, physics, education and training. There are studies on the movement of the crowd either as a whole or individual, understanding behaviour pattern, decision making of individual crowd and many more. In all these studies, the main concern was on the crowd behaviour during emergency evacuation (Gerakakis

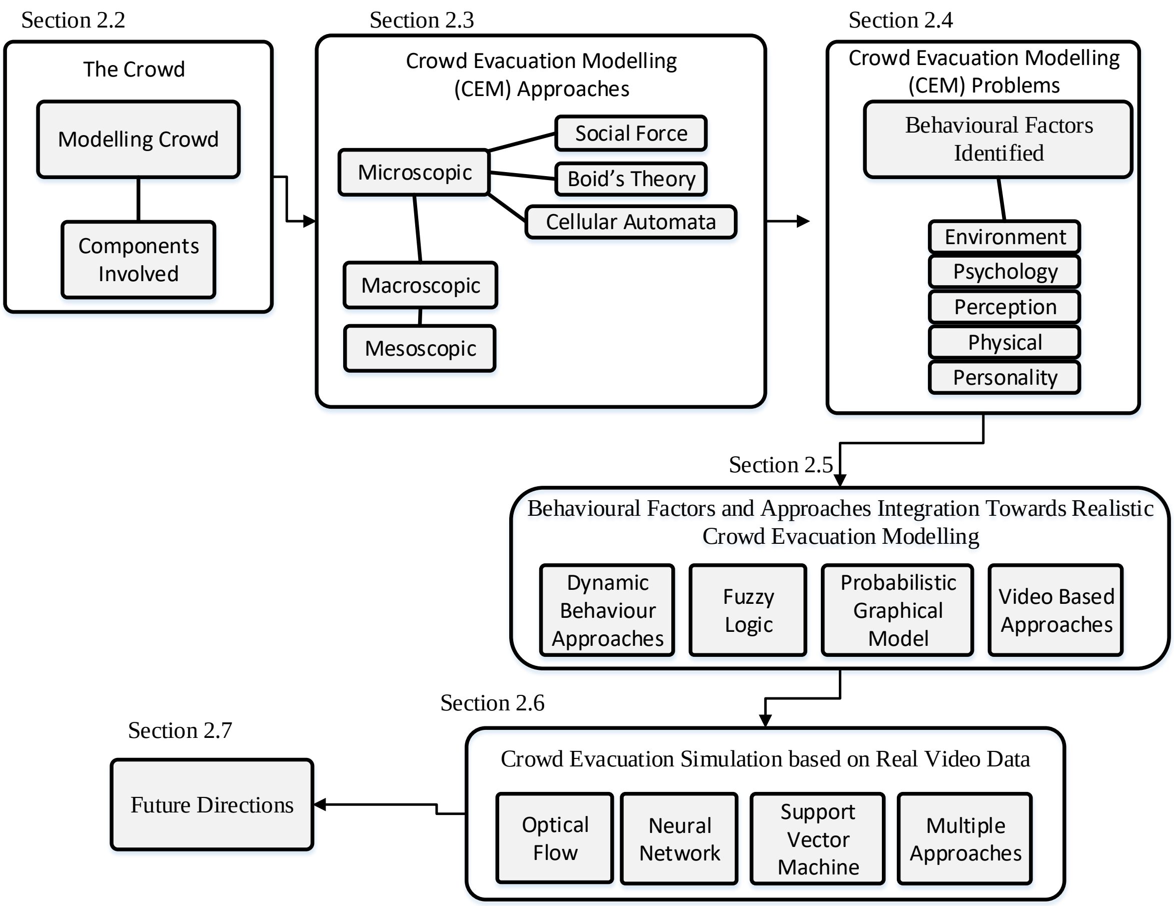

Figure 2.1: The Structure of Literature Review

et al., 2019).

Looking at the historical data trend on the crowd disaster reported by expert Prof. Dr G. Keith Still (2014); Krausz and Bauckhage (2012), there are still many tragedies that involved pedestrian crowds such as injuries and life loss. These kind of tragedies happened due to sudden changes in the environment, resulting the crowd to evacuate. Table 2.1 provides a detail of the disasters mentioned with the categories of the emergency identified based on the reason given. Most of the incidents that happened were due to escape panic. Basically, there are two types of environment changes being identified in Table 2.1, namely escape panic (EP) and goal oriented (GO). Table 2.1 showed that escape panic evacuation was the most frequent category that happened and resulted in higher injuries and death. This category is explained in Section 3.3.2(a) (Chapter 3). Though, the death and injured tragedies reported in Table 2.1 could be due to the deficiency in crowd management (Radianti *et al.*, 2013; Fruin, 1971) or inadequate facilities or design problems (Fruin, 1971; Chu *et al.*, 2014; Pan *et al.*, 2007; Smith *et al.*, 2009), the bottom line of all this is to understand the complexity in the human behaviour in modelling realistic crowd evacuation.

2.2.1 The Main Components in Modelling Crowd

Modelling crowd is getting attention from many parties due to its importance in prioritizing people to escape during emergency evacuation especially in today's world where there are a lot of events that involved many people at once. Modelling crowd in the state of emergency and normal circumstances are also two different aspects because human may behave differently in these different situations. Thus, in modelling crowd

Table 2.1: Historical Crowd Disaster Table 2010-2019

Year	Place	Death	GO / EP	Reason
2010	Loveparade, Duisburg	21,>500i	EP	Crowd turbulences
2010	Water Festival, Phnom Phen	>380	EP	Stampede
2010	Remembrance of the Dead on Dam Square, Amsterdam	63i	EP	Panic due to 1 person start shouting
2011	Haridwar, India	16	GO	Religious ceremony on the banks of Ganges river
2011	Lava Ignite Northampton	2	EP	Nightclub exit crush at Lava Ignite Northampton
2011	Budapest, Hungary.	3,14i	EP	Severely overcrowded
2012	Cathedral Square, Cairo, Egypt,	3,137i	EP	To view the body of Coptic Pope Shenouda III of Alexandria
2012	Madrid, spain	5	EP	Halloween party
2013	Abidjan, Ivory Coast.	60,>200i	EP	New Year's celebration
2013	Luanda, Angola	10,120i	EP	New Year's eve
2013	Santa Maria, Brazil	242, >168i	EP	Nightclub
2013	a stampede broke out at the train station in Allahabad, India,	36,>39i	GO	Hindu festival Kumbh Mela
2014	Nigeria several stadiums	24,>118i	EP	Attend for job tests
2014	stampede at the Gandhi Maidan, India	32,>26i	GO	Dasehra celebrations
2014	stampede at Qasim Bagh Stadium in Multan, Pakistan	7,>40i	EP	After the speech of Pakistan, Imran Khan
2014	Kwekwe, Zimbabwe	11,40i	EP	Stampede at stadium
2014	Shanghai, China	36,42i	EP	New Year's celebration
2015	Cairo, Egypt	28	EP	Football game
2015	The Shrove Tuesday festival in Port-au-Prince, Haiti	16	EP	A man was shocked by high-voltage
2015	Bangladeshi city of Mymensingh	23,50i	EP	Stampede at a free clothing drive
2015	Stampede on the banks of the Godavari River, India	27	GO	Hindu pilgrims
2015	Stampede at Mina, Saudi Arabia	2262,934i	GO	Overcrowding incident during the Hajj pilgrimage.
2015	Taloqan, Afghanistan	12,42i		Major earthquake
2015	Pacevilla, Malta	74i	EP	A glass stairwell railing collapsed during a stampede Club
2016	Ethiopia	52 to 300	GO	Oromo people protestion
2016	Lucknow, India	24	GO	Hindu religious ceremony
2017	de Janerio	17, 61i	EP	Opening footbal match
2017	Lusaka, Zambia	8,28i	GO	Church Prayer Event
2017	Turin, Italy	1,1500i	EP	UEFA Champions League
2017	Mumbai, India	22,100+i	EP	stampede during peak hours
2018	Chennai, India	2,33i	EP	stampede at Rajaji Hall
2018	Caracas, Venezuela	17,5i	EP	club stampede after tear gas canister explosion
2019	Cookstown, Ireland	3	EP	hotel disco rush
2019	Port Harcourt, Nigeria	15	EP	crowd surged towards a gate after President speech
2019	Caracas, Venezuela	3,30+i	EP	stampede during a concert in Caracas

EP = Escape panic, GO = Goal oriented, i = injured evacuation, both internal and external factors of individual and group in the crowd become relevant (Zafar *et al.*, 2017). In 2017, Seitz *et al.* (2017) highlighted on the lacking in understanding human behaviour. Meanwhile, in a recent study of Alginahi *et al.* (2019) still highlighted the importance of understanding crowd behaviour in order to achieve efficiency in monitoring and managing crowd. Consequently, modelling crowd in terms of the real behaviour still remained as an open issue in overcoming the disaster in crowd (Aguirre *et al.*, 2011; Seitz *et al.*, 2017). In addition, the complexity of human behaviour itself is the main culprit for the crowd model to be the same as the actual crowd behaviour.

Modelling crowd requires understanding of the components involved in crowd which is visualized in Figure 2.2. The main components identified are an individual, a group which is formed by many individuals and many groups and individuals which are formed into a crowd. Each of the individual in the crowd is imposed with the external and internal factors (Zafar *et al.*, 2017). Communication between the internal and external factors have resulted in the behavioural actions and pattern of the individual and crowd. Hence, the internal factors can be the perception of the individual agents towards the situation which lead to the psychological and physical reactions depending on the personality that the individual possessed. Meanwhile, external factors can be anything that invoke the changes in the environment which cause an individual to assess its surrounding visually (perception). All these components are discussed in the past studies with the combination of multiple aspects to serve the purpose of the study. The general understanding of the crowd is depicted in Figure 2.2 that serves most of the crowd models in the past.

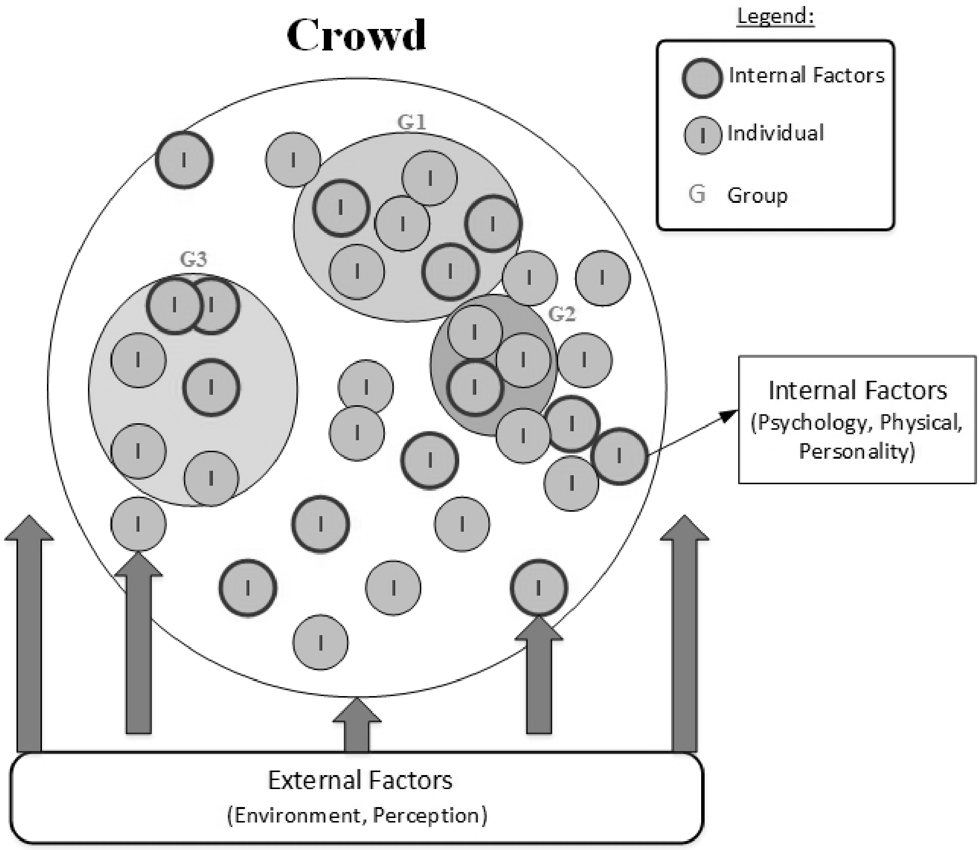

Figure 2.2: The Crowd Evacuation Modelling (CEM) Components

Figure 2.2 demonstrates the relationship between external and internal factors that contribute to the different behavioural actions of an individual in a crowd. According to Wijermans (2011), at a glance, the social environment role may look like important. However, at his second thought, the mental states and physiology may be more important. Thus, he believed that understanding the underlying theory of crowd behaviour in detail is crucial as the first step of modelling crowd (Wijermans, 2011).

Modelling crowd requires ones to understand and imitate the behaviour of crowd either as a whole or as individual. In the past, physics science has modelled crowd in the aspect of crowd movement by internal and external forces (Helbing and Molnar, 1995; Reynolds, 1987), psychological science and robotic studies which was introduced by El-Nasr *et al.* (2000) and model human emotion through facial expression in 1999 (smile, sad, angry face) to imitate real human behaviour. Meanwhile, a study of crowd movement based on games by Reynolds (1999) modelled crowd through flocking behaviours of birds with certain rules employed. Apart from this, studies which explored on the game strategies to imitate crowd behaviour also in growing trend such as Zheng and Cheng (2011) and Zafar *et al.* (2017).

Crowd modelling is getting attention from many fields even though it is built up with only five components[1] but the uniqueness of human and the interaction between them have added the complexity. Each individual is unique and complex. According to Almeida *et al.* (2015), crowd behaved differently in normal and emergency situation. Thus, behaviour studies of crowd evacuation in imitating realistic scenario

[1] The five components are, individual, group, crowd, internal and external factors

have to be learned from the real emergency scene. It is also supported by Zafar *et al.* (2017), where in modelling crowd evacuation, both internal and external factors of individual and group in the crowd became relevant. Detailed discussion on the past studies method in imitating the real evacuation behaviour of crowd is explained in Section 2.4 and Section 2.5.

2.3 Crowd Evacuation Modelling Approaches

One of the most trending aspect in crowd modellings that are currently being researched is to imitate realistic scenario of crowds as accurate as possible by using artificial intelligent algorithms to dictate intricacies of the agent behaviour (Nygren, 2007; Fu *et al.*, 2017). Agent based approached is widely used due to its reasoning capabilities that allow it to sense its surroundings, assess current situation and has a certain level of cognitive. Whilst this gives key behaviour, the base algorithms of crowd movement can be extended to give more advanced behavioural features with human emotions or psychology embedded into it.

The algorithms chosen depends on the purpose of simulation and desirability to achieve certain type of behaviour. In modelling realistic crowds, two approaches can be used. The first one is mathematical models where the rules and behaviours of crowd are predefined by the variables and equations. The second approach is treating the crowd as individual using an agent based approach where the behaviour of the agents is defined in more algorithmic way (Nygren, 2007). The overall simulation mechanism that controls how the simulated individual or group in crowd performs is reflected by these approaches. These approaches treat crowds as a collection of heterogeneous or homogeneous entities which interact with each other. There are three major modelling approaches with different modelling granularity that discussed here in brief.

The three approaches of crowd models which are mainly discussed on the agent movement are the microscopic, macroscopic and mesoscopic models. Based on a study conducted by Radianti *et al.* (2013), microscopic models look at a crowd as an individual and a separate entity, meanwhile for macroscopic models, crowds are described through their density and average flow. Mesoscopic models describe the relationship between macro (collective patterns) and micro (inter-individual interactions) (Wang *et al.*, 2008). Normally, for a small to medium scale crowd, researchers are able to model the behaviour of the individuals in the crowd and such approaches usually integrate more details into the crowd model and support investigation of crowd dynamism at the individual level (Zhou *et al.*, 2010).

Referring to Table 2.2, most of the studies focused on microscopic models but the discussion in their studies leaned more towards group (macro) instead of individuals (micro). Thus, a further study on individual behaviour has to be in place to understand how much it is able to influence towards a realistic crowd evacuation result.

2.3.1 Microscopic Approaches

The first approach is known as a pedestrian model, namely microscopic (Radianti *et al.*, 2013). Microscopic approach is an agent-based approach where each individual is treated as an independent agent with certain capabilities to behave in the simulated world. There are rules set for each agent to follow and the agent can make his own decision independently based on some local information that are relevant to the agent