Faculty of Computer Science and Information Technology

An Emotion-based Belief-Desire-Intention Methodology for Fire Evacuation Simulation

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature

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ABSTRACT

This research aims to extend the Belief-Desire-Intention (BDI) methodology by incorporating emotions to provide a more authentic simulation of complex human behaviour in fire evacuation scenarios. Emotions play a vital role in decision-making processes, making their accurate representation necessary for realistic simulations. Building upon these findings, two experiments were conducted: Experiment 1 compares the effectiveness of the emotion-based BDI methodology against the extended BDI methodology in modelling agent behaviour during fire evacuations. Experiment 2 employs the System Usability Scale (SUS) score to assess the usability of the emotion-based BDI methodology. The outcomes of both experiments demonstrate the potential of the proposed approach to create more accurate and insightful simulations. This study expands the understanding of the relationship between emotions and behaviour and contributes to the refinement of the emotion-based BDI methodology, making the way for improved simulations across diverse scenarios. Through this research, the potential of enhancing computer simulations with emotions, offering a more authentic representation of human behaviour and decision-making in critical situations, can be observed. This research contributes to extending the BDI methodology by incorporating emotional factors to improve decision-making during fire evacuations. By designing an emotion-oriented BDI framework and evaluating key emotional properties, the study enhances the realism and reliability of evacuation simulations. The integration of emotions leads to more accurate decision-making patterns, resulting in better safety outcomes and more realistic simulations that closely mirror real-world human behaviour in emergencies. Hence, from the results of the analysis, the emotion-based BDI methodology can be used to present human responses, providing a valuable framework for future advancements in simulation technology and applications.

Keywords: Emotion, emotion-based BDI methodology, BDI methodology, fire-evacuation simulations, emotion modelling

Metodologi BDI Berasaskan Emosi untuk Simulasi Pemindahan Kebakaran

ABSTRAK

Penyelidikan ini bertujuan untuk memperluas metodologi 'Belief-Desire-Intention (BDI)' dengan menggabungkan emosi, bertujuan untuk menyediakan simulasi yang lebih tulen bagi tingkah laku manusia yang kompleks dalam senario pemindahan kebakaran. Emosi memainkan peranan penting dalam proses membuat keputusan, menjadikan perwakilan tepatnya penting untuk simulasi realistik. Berdasarkan penemuan ini, dua eksperimen telah dijalankan: Eksperimen 1 membandingkan keberkesanan metodologi BDI berasaskan emosi terhadap metodologi BDI lanjutan dalam memodelkan tingkah laku ejen semasa pemindahan kebakaran. Eksperimen 2 menggunakan skor 'System Usability Scale' (SUS) untuk menilai kebolehgunaan metodologi BDI berasaskan emosi. Hasil kedua-dua eksperimen menunjukkan potensi pendekatan yang dicadangkan untuk mencipta simulasi yang lebih tepat dan berwawasan. Kajian ini memajukan pemahaman kita tentang interaksi antara emosi dan tingkah laku dan menyumbang kepada penghalusan metodologi BDI berasaskan emosi, membuka jalan untuk simulasi yang lebih baik merentas pelbagai senario. Melalui penyelidikan ini kita dapat melihat potensi mempertingkatkan simulasi komputer dengan emosi, menawarkan gambaran yang lebih tulen tentang tingkah laku manusia dan membuat keputusan dalam situasi kritikal. Penyelidikan ini menyumbang penyelidikan yang meluaskan metodologi BDI dengan memasukkan faktor emosi untuk menambah baik pembuatan keputusan semasa pemindahan kebakaran. Dengan mereka bentuk rangka kerja BDI berorientasikan emosi dan menilai sifat emosi utama, kajian ini meningkatkan realisme dan kebolehpercayaan simulasi pemindahan. Penyepaduan emosi membawa kepada corak membuat keputusan yang lebih tulen, menghasilkan hasil keselamatan yang lebih baik dan simulasi yang lebih realistik yang mencerminkan tingkah

laku manusia dunia sebenar semasa kecemasan. Oleh itu, daripada hasil analisis, metodologi BDI berasaskan emosi boleh digunakan untuk membentangkan respons manusia, menyediakan rangka kerja yang berharga untuk kemajuan masa depan dalam teknologi simulasi dan aplikasi.

Kata kunci: *Emosi, metodologi BDI berasaskan emosi, metodologi BDI, simulasi pemindahan kebakaran, permodelan emosi*

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LIST OF ABBREVIATIONS

BDI	Belief, Desire and Intention
OCC	Ortony, Clore & Collins
EBDI	Emotion, Belief, Desire, Intention
AOM	Agent-Oriented Modelling
CA-SIRS	Cellular Automata- Susceptible, Infected, Recovered, Susceptible

CHAPTER 1

INTRODUCTION

1.1 Study Background

A fire evacuation drill is essential to disseminate and practice a fire evacuation procedure to the public. The fire evacuation procedure is required to ensure people understand how to behave in an emergency when an unpredictable fire incident occurs. (Tomar, 2019). The fire evacuation is a set of procedures which is taken to transfer people from a place affected by the fire to another safer place (Abdul Aziz et al., 2019).

To simulate a fire evacuation process, a real drill is implemented. However, evacuation drill results are limited or inaccurate due to the lack of the element of fear emotion; the number of participants may be inaccurate and unrealistic experiment (Zinke et al., 2014). To overcome the real fire drill practice, fire evacuation simulation is introduced.

Fire evacuation simulation is a valuable tool for determining the safety of a building or premises and the efficiency of the evacuation process in the event of a fire. Besides, fire evacuation simulation is used to determine the evacuation behaviour such as the time needed to evacuate an affected area. On the other hand, fire evacuation simulation is an effective approach to reproducing evacuation behaviours of people during fire accidents (Ding et al., 2024).

Several simulation techniques have been introduced for fire evacuation simulation. They are mathematical model which uses mathematical representation to develop the fire behaviour to run the simulation (Mutthulakshmi et al., 2020). An agent-based simulation is introduced to study how people react during fire evacuation. The modelling is used to give

a clearer insight into the complex evacuation process. To support agent-based fire evacuation simulation, an extended BDI methodology is introduced (Wai et al., 2021). When modelling human evacuation during a fire, the main goal is to ensure that everyone has evacuated the affected areas in time and there will be fewer casualties are expected when the evacuation is done.

Although an agent is modelled with human cognitive architecture (Wai et al., 2021), it is still missing the notion of emotion when simulating the fire drill evacuation. Emotion is a mental response such as fear or anger, which can be affected by surrounding events. Emotion can also be the cause of a person's behavioural changes and decision making. Emotion has affected human decisions during a fire evacuation (Moore-Petinak et al., 2020). For example, fear and emotion during a fire evacuation can lead to panic which will cause an undesirable decision that can bring harm to the person and the people surrounding. Hence, adding emotion into the BDI agent simulation is needed to enhance its ability to mimic human behaviour and decision-making processes more accurately.

Hence, in this research, the proposed methodology aim to improve the extended BDI methodology to be able to model the complex emotional properties of human behaviour in decision making focusing on a fire evacuation case study. The proposed methodology aim to investigate the ability to adopt the existing BDI methodology to represent the emotional properties as described throughout this research.

In this research, the proposed methodology adopt the state of the art of the (Openness, Consciousness, Extroversion, Agreeableness, Neurotism) model (Durupinar et al., 2011) by integrating OCEAN model in the BDI methodology to enhance the emotional intelligence and behavioural realism of the BDI agent simulation. The OCEAN model, also known as the Big Five personality traits model, provides a comprehensive framework for

understanding human personality based on five key dimensions: Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (Durupinar et al., 2011).

1.2 Research Problem and Questions

Simulating believable human behaviour during fire evacuation is challenging, as emotions like fear, panic, and stress significantly affect decision-making, often leading to irrational behaviours such as herding and freezing (Kinateder & Ronchi, 2019). These emotional responses complicate evacuation simulations, highlighting the need for models incorporating psychological factors to improve safety and predict crowd dynamics more accurately. Although work has been introduced to simulate agents in fire evacuation through extended BDI methodology (Wai et al., 2021), explicitly incorporating emotional elements into the BDI framework for evacuation scenarios remains largely unexplored. Emotions significantly enrich simulations by adding depth, complexity, and realism, ensuring a more accurate reflection of human behaviours in real-world situations (Ortony & Turner, 1990). Emotion is a complex and multifaceted psychological state that plays a vital role in human behaviour and decision-making (Şahin et al., 2019). Without emotion, simulations and models of human actions and choices can become detached from reality, resulting in simulations that lack authenticity and fail to represent accurately the differences in human responses and interactions.

Based on this problem, this study aims to answer the following research questions:

i. How can the BDI methodology be extended to incorporate emotional states and decision-making processes?
ii. What emotional properties and mechanisms are essential for successfully developing and implementing an emotion-based BDI methodology?

iii. How do these emotional enhancements impact the realism, effectiveness, and believability of fire evacuation simulations using the BDI methodology?

1.3 Research Aim and Objectives

This research aims to extend the BDI methodology into an emotion-oriented BDI methodology to model human emotion during a fire evacuation. The complete emotion-oriented BDI methodology will serve as a systematic guide to designing realistic and believable human behaviour in fire evacuation simulation. This is important to ensure that the evacuation simulation can guarantee the avoidance of causalities and economic damage during a fire evacuation. The objectives of this research are the following:

i. To design and implement a method to incorporate emotion-oriented human decision-making into fire evacuation simulations through an extension of the BDI methodology.

ii. To evaluate the emotional properties used in developing the emotion-based BDI methodology.

1.4 Research Scope

This research focuses on extending the BDI methodology towards modelling agent emotion during a fire evacuation. The extended Agent-Oriented Modelling (AOM) begins with the requirements elicitation step. From elicitation, the modeller will proceed with the modelling process, which involves a goal model, organisation model, emotion-oriented goal model, emotion-oriented role model, emotion-oriented organisation model, emotion-oriented Tropos goal model, emotion-oriented domain model, emotion-oriented knowledge model, emotion-oriented scenario model, emotion-oriented interaction model, and emotion-oriented behaviour model. Finally, the model is simulated using the BDI simulation tool to

examine and analyse the various dynamics, behaviours, and outcomes that emerge within the simulated environment. This simulation process allows us to gain insights into the intricate interactions and patterns of the modelled system, providing a deeper understanding of its functioning and potential implications in real-world scenarios.

1.5 Thesis Organizations

This thesis consists of six chapters. An overview of every chapter is described as follows:

Chapter 1 describes the introduction of the research, which includes the research background, research aim, research objective and research scope.

Chapter 2 provides an overview of human behaviour modelling, personality models, emotion models, and BDI-based agent behaviour simulations. It emphasizes the importance of BDI methodology in understanding agent decision-making and explores its architecture. The chapter also discusses various emotion theories and techniques for modelling emotions in emergencies like evacuations. It concludes by examining the integration of emotion into the BDI architecture and its connection with personality traits, offering insights into human behaviour within agent simulations.

Chapter 3 presents the research methodology. Each step has been meticulously documented and elaborated upon comprehensively.

Chapter 4 presents the extension of BDI methodology with emotion. This section introduces the extension of the BDI (Belief-Desire-Intention) methodology through the integration of emotion. Building upon the foundational principles of BDI, this extension incorporates the intricate dimensions of human emotion, enriching the modelling framework.

Chapter 5 describes the walkthrough of the Emotion-Based BDI Methodology and offers a detailed exploration of its core components and operational framework.

Chapter 6 describes the evaluation of the proposed methodology. It is a crucial aspect of this research, aimed at assessing its effectiveness, usability, and potential contributions. Through a series of well-designed experiments and analyses, the methodology's performance is rigorously examined.

Chapter 7 includes a summary of this thesis, which provides a summary of its key points, highlights the research's contributions, and suggests potential directions for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter reviews human behaviour modelling, the general human personality model, and the emotion model. Section 2.2 reviews BDI-based agent modelling and simulations. Section 2.3 elaborates on the theory of emotion. Section 2.4 presents the emotional development in the agent system. The chapter concludes in Section 2.5.

2.2 BDI-Based Agent Behaviour Modelling and Simulations

Fire evacuation simulation through Belief Desire Intention (BDI) was developed by Wai et al. (2021) to model human cognition and decision making in fire evacuation simulation. The Belief-Desire-Intention (BDI) model is known as a theory of practical reasoning which describes human reasoning with three mental attitudes: belief, desire, and intention (Velleman & Bratman, 1991). The BDI model was proposed by Bratman in the 1980s and closely follows the Practical Reasoning System (PRS) (Sterling & Taveter, 2009). In a PRS system, an agent holds five main components. The sets of facts that hold knowledge about the world are the first component of an agent in the PRS system (Sterling & Taveter, 2009). As the agent gains more experience in the world, these facts or knowledge will also be updated. Therefore, in the BDI architecture, belief represents the facts and knowledge that an agent has about the environment. According to Sterling and Traveter (2009), the facts and knowledge of an agent will be obtained during the system design layer.

The next component is the set of goals that the agent must achieve. These achievements of goals lead to the next attitude of the BDI architecture which is known as desires (Sterling & Taveter, 2009). The desires represent the purpose and motivation of

agents which are obtained from the events and rules in the system design layer. After the sets of goals are derived, the next component is the intentions. Intentions describe what the agents are currently doing to achieve the set of goals determined earlier. Besides, the structure of the intention components is the mechanism for instantiating, scheduling, executing, and monitoring plans for the agents (Sterling & Taveter, 2009).

The fourth component involved in PRS is the library of plans. This library holds the sets of concrete actions according to the sets of goals each agent holds (Sterling & Taveter, 2009). The plans will help agents to adapt to the changes happening in the environment or the world more attentively. Finally, the last component is the interpreter or the reasoner. The reasoner plays the role of combining the overall behaviour of an agent, managing sensing and acting, informing the agent on the changes in beliefs about the world and choosing which plan to take place (Sterling & Taveter, 2009).