View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Universiti Teknologi Malaysia Institutional Repository

AGENT-BASED PATHFINDING ALGORITHM IN PARTIALLY OBSERVABLE ENVIRONMENT USING RAYCASTING AND NAVIGATION MESH

MOHAMAD NURFALIHIN BIN MOHD OTHMAN

UNIVERSITI TEKNOLOGI MALAYSIA

AGENT-BASED PATHFINDING ALGORITHM IN PARTIALLY OBSERVABLE ENVIRONMENT USING RAYCASTING AND NAVIGATION MESH

MOHAMAD NURFALIHIN BIN MOHD OTHMAN

A thesis submitted in fulfillment of the
requirements for the award of the degree of
Master of Science (Computer Science)

Faculty of Computing
Universiti Teknologi Malaysia

MARCH 2017

This thesis is special dedicated to my lovely family for their endless love, support and encouragement.

ACKNOWLEDGEMENT

Alhamdulillah, all praise to ALLAH S.W.T, the Almighty, most Gracious and most Merciful for the blessing and guidance.

Here, I would like to express a heartfelt gratitude to my supervisors, Prof. Dr. Habibollah Haron for his guidance, generous support, endless advice and enormous patience throughout my research work.

My sincere appreciation goes to Universiti Teknologi Malaysia for providing me financial support through Research Grant during the period of this research work.

Finally, I would like thank to all those who have contributed directly and indirectly in process to finish my research work. My sincere appreciation also extends to all my colleagues for their help and support.

ABSTRACT

Pathfinding is a navigation component of the agent in an Evacuation Model. Most models apply pathfinding approach to provide global information to the agent from the start due to the assumption that evacuees would always head towards the nearest exit and all exits are used equally. Realistically, evacuees may only perceive its immediate surroundings, and be oblivious of other exits if the evacuee is unfamiliar with the environment. In evacuation, people tend to move towards familiar direction, which is the way they came in, and current solution of applying shortest path or least cost search approach does not demonstrate this emergent behaviour. In this study, as the counterpart of human, agents emulating human physical capabilities and limitations were developed in Unity3D Game Engine. The perception component of agent imitated human conic vision using Raycasting technique while its movement speed was limited to average movement speed of median population. Using input from Raycasting, a pathfinding algorithm based on the random mouse algorithm with localization feature using Navigation Mesh was developed. The environment for testing was built in the form of a maze in Unity3D and recordings were made to detect the agent arriving at the exit or not, and the time taken to navigate the environment in each iteration. Navigation Mesh was generated to represent walkable areas, and static obstacles that confined the spaces were labeled as walls. Unrendered cubes were placed at every intersection and exit, and were labeled accordingly. Result of the simulation showed that the pathfinding algorithm allowed the agent to successfully traverse the partially observable environment without prior knowledge, and the agent had demonstrated emergent behaviour with the integration of limited perception distance and realistic movement speed. The findings have shown that the algorithm can be used to simulate emergent behaviour in an Evacuation Model.

ABSTRAK

Pencarian laluan merupakan komponen pengemudian ejen dalam sebuah Model Pemindahan. Kebanyakan model menggunakan pendekatan pencari laluan untuk memberi maklumat global kepada ejen dari awal kerana andaian bahawa pemindah akan sentiasa menuju ke arah pintu keluar yang terdekat dan semua pintu keluar yang digunakan secara sama rata. Secara realistiknya, pemindah hanya boleh melihat persekitaran disekelilingnya sahaja, dan tidak menyedari akan tempat keluar yang lain jika pemindah tidak biasa dengan persekitaran tersebut. Dalam pemindahan, manusia cenderung untuk bergerak ke arah yang biasa yang merupakan cara mereka datang, dan penyelesaian semasa menggunakan jalan tersingkat atau carian kos terendah tidak menunjukkan tingkah laku yang baru ini. Dalam kajian ini, sebagai perwakilan manusia, ejen mencontohi keupayaan dan had fizikal manusia telah dibangunkan dengan Enjin Permainan *Unity3D*. Komponen persepsi ejen ditiru penglihatan kon manusia menggunakan teknik *Raycasting* manakala kelajuan pergerakannya terhad kepada purata kelajuan pergerakan populasi median. Menggunakan input dari *Raycasting*, algoritma pencari laluan berdasarkan algoritma tetikus rawak dengan ciri lokalisasi menggunakan Jaringan Pengemudian telah dibangunkan. Persekitaran untuk ujian telah dibina dalam bentuk pagar sesat dalam *Unity3D* dan rakaman telah dibuat untuk mengesan ejen yang tiba di pintu keluar atau tidak, dan masa yang diambil untuk mengemudi persekitaran tersebut dalam setiap iterasi. Jaringan Pengemudian telah dijana untuk mewakili kawasan boleh lalu dan halangan statik yang menghadkan ruang ini dilabel sebagai dinding. Kiub yang tidak dilukis ditempatkan di setiap persimpangan dan pintu keluar dan telah dilabelkan dengan sewajarnya. Keputusan simulasi menunjukkan bahawa algoritma pencari laluan membenarkan ejen untuk merentasi persekitaran yang sebahagiannya boleh diperhati tanpa pengetahuan, dan ejen telah menunjukkan tingkah laku baru dengan integrasi jarak persepsi yang terhad dan kelajuan pergerakan yang realistik. Hasil kajian telah menunjukkan bahawa algoritma boleh digunakan untuk simulasi tingkah laku baru dalam Model Pemindahan.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BOCA	Building Officials of Code Administrators
EVD	Externally Verifiable Decomposition
FOV	Field of View
ICBO	International Conference of Building Officials
ICC	International Code Council
LOS	Level of Service
MAS	Multi-Agent System
MS	Malaysia Standards
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
OSHA	Occupational Safety and Health Administration
POI	Point of Interest
POMDP	Partially Observable Markov Decision Process
PPR	Predictive Policy Representation
RTS	Real Time Strategy
SBCCI	Southern Building Code Congress International

CHAPTER 1

INTRODUCTION

This chapter discusses an overview of the research conducted in this study. The topic includes background of the study, problem statement, aim of the research, objectives and scopes of the study, research significant and also contributions of the study.

1.1 Background of the Study

The general public is becoming more concerned of their safety in performing daily routines whether being indoor or outdoor. However, disaster or accidents are bound to happen no matter how much precautions were taken. Therefore, as a sign of preparedness, a contingency plan must considered and constructed. Hence, more resources and funds are pooled into developing evacuation models that may give valuable insight to help in developing or further improve an evacuation process that can minimize loss and maximize the safety of individuals.

Egress is literally defined as the act or an instance of going, especially from an enclosed place. Emergency egress or evacuation is the movement of people away from a threat or hazard to ensure the safety of the public and minimize the loss in terms of lives and property. Evacuation plans are action plans that are derived beforehand and will be executed if deemed necessary. Two approaches in deriving these plans are traditional approach and computational approach.

Traditional approach which is full-scale evacuation demonstration and adherence to building or safety codes is still widely used; however with the rapid advancement in the architecture field, its limitations identified from the ethical, practical as well as financial perspective have thus prompts the development of computational evacuation modelling. In the recent years, Computational Evacuation Modelling is gaining an increasing popularity within the research community.

In 2010, Kuligowski *et al.* produces a review of Building Evacuation Models, which reviews 26 computer models that focused on simulating evacuations in a building. These models can be categorized by their main features; availability to the public, modeling method, type of grid used, validation methods etc. In categorizing by modeling methods, three types of models are available which are Flow-based modeling, Cellular Automata and Agent-Based.

Flow-based modelling adopts the principle of fluid and particle motions, where the physical environment is represented as a network of nodes. An example of this type of modelling is EVACNET4 (Kisko *et al.*, 1998). In Cellular Automata, the space of the environment is divided into an array of grids or cells with uniform size, where the movement of an evacuee is from one grid to another neighboring grid. EGRESS (Ketchell *et al.*, 2006) is an example of Evacuation Model that uses this method. In Agent-based modeling, an agent is autonomous, whether physical or virtual, can act, perceive its environment and communicate with others, with the capability to achieve its goals. SIMULEX (Thompson and Marchant, 1995) is the first model that uses Agent-based modeling.

The advantage of implementing an Agent-based modelling in Evacuation Model when compared to Flow-based and Cellular Automata, is the ability to simulate interactions of autonomous objects, or agents to be precise, to exhibit emergent behaviours (Agent-Based Simulation Tutorial). Each agent can be use to digitally represent an individual or an evacuee within the egress simulation. Agents are divided into five categories, which are based on their degree of perceived intelligence and capability, namely simple reflex agents, model-based reflex agents, goal-based agents, utility-based agents, and learning agents. The type of agent to be used and its development process should conform to the requirement of the system

An environment can be defined as a space where agents interact with domain objects and resources, and also with other agents which shares the same space. There are several terminologies that can define the environment in which an agent is placed and as such it affects the approach in developing an agent. Particular to this study, the agent only has knowledge of its immediate and previous surrounding, have the knowledge of the existence of one or more exit in the environment, but have no knowledge on the exact position of the exit from the get go. Thus the environment could be categorized as a partially observable environment.

For the agent to move freely within the environment, the traversable space needs to be specified beforehand. How the space would be represented would be depending on the environment’s topology and the required efficiency. Although regular grid representation is more popular, the complexity of modern day architectures and the need for such environment to be represented seamlessly suggests that irregular grid representation would be more proper. Navigation mesh is an irregular grid representation that is made up of triangles and polygons meshes that covers the areas in which the agent may traverse.

Pathfinding, or wayfinding, is a component used to help direct the agent from its initial position towards the destination. A popular topic in pathfinding is computing the shortest route or least costly route to be travelled. But in a partially observable environment, without the knowledge of its destination, the agent may not be capable to do so. In order to find the exit, the agent would need to explore the environment. Thus rather than implementing algorithm intended to find shortest route, it is more apt to implement algorithm that is designed for exploration instead.

In Unity 3D Game Engine, Raycasting is a technique used for collision detection. This is achieved by shooting an invisible ray from a designated point towards a specified direction, detecting any objects that lay in its path. The human eyes functions by gathering light rays from the surrounding. In concept, both raycasting and the human eyes are similarly used for gathering information from the surroundings. The difference would be that the human eyes absorb rays, whereas raycasting emits rays. Therefore in theory, it is possible that raycasting can function as the “eye” of an agent.

1.2 Problem Statement

To develop an Evacuation Model is quite a challenging task as every element that made up the model compliments each other and need to be given equal amount of attention and resources to develop, to say the least. Therefore, in this study, the simulation model will only be concerned with a portion of an Evacuation Model which is the development of the pathfinding algorithm. Most evacuation models provide the agent with global information, i.e. the knowledge of where the end-point is, from the beginning. Some exceptions such as MASSEgress (Pan, 2006), relies on visual perception for path-finding instead. Criteria, in which routes are calculated, are fastest route towards exit, shortest route towards exit and route defined by user (Kuligowski *et al.*, 2010).

Realistically the environment of an evacuation can be categorized as a partially observable environment, where the location of the exit is not initially provided, or the agent is unfamiliar with the layout of the world. Popular directed algorithm, such as Dijkstra and A*, requires such parameters to be defined beforehand, therefore should not be applicable as is, in such circumstances. We should instead consider undirected pathfinding algorithm, which encourages the agent to explore the environment. Still, a design based completely on this concept would not be useful in creating a believable behaviour for an agent. The proposed algorithm needs an additional feature to complement the search, a localization component to keep track of its progress internally, in order to increase the efficiency while at the same time providing the agent with the possibility to demonstrate human-like behaviour. The reason stated above thus, became the motivation of this study.

1.3 Aims of the Research

This research aims to develop a dynamic pathfinding algorithm with the use of raycasting and navigation mesh which is competent to navigate in a partially observable environment, whilst also capable to demonstrate emergent social behaviours such as competitive, queuing, herding behaviours and bi-directional crowd flow.

1.4 Research Questions

Listed below are the questions that drive this study:

i. Can an agent that has a believable behaviour be developed by applying human-like capacity and limitation?

ii. Can a dynamic pathfinding algorithm, with raycasting and navigation mesh, traverse a partially observable environment and with the knowledge that it gathers, move towards the end goal?

1.5 Objectives of the Study

The objectives are as listed below:

i. To propose an agent with human-like capacity and limitation that can demonstrate simple believable human behaviour.
ii. To develop a dynamic pathfinding algorithm with raycasting and navigation mesh that is capable to traverse a partially observable environment.
iii. To create a new 3D environment for testing and evaluation of the proposed algorithm.

1.6 Scopes of the Study

Below lists the scopes of which this study is conducted:

i. The proposed pathfinding algorithm is developed specifically for use in an evacuation model.
ii. The project is developed with the use of Unity3D Game Engine and the scripts are written in C# language.
iii. The environment is self-created based from general maze image.
iv. The number of agent and its placement in the environment are decided randomly.

1.7 Research Significance

Taking into consideration the characteristics of the environment in which an evacuation transpires, this study proposes a dynamic pathfinding algorithm for computer evacuation model. The algorithm, which is developed in Unity3D Game Engine, will be implementing Raycasting technique, to replicate the human perception. When coupled with Navigation Mesh; implemented to highlight the traversable region within the environment, the algorithm should provide the agent with the ability to traverse the environment towards the exit, without prior knowledge of the environment provided. Additionally, the study explores the possibility for a model-based reflex agent, without complex intelligence, to demonstrate emergent social behaviour such as competitive, queuing, herding behaviours and bi-directional crowd flow.

1.8 Contributions of the Study

This study proposes a new approach to pathfinding in evacuation model. Rather than presenting the agent with global knowledge from the start, providing predetermined options and solutions, the agent's capabilities were purposely limited with the intention to make it more humane. This encourages the agent to traverse the environment and collect their own knowledge, which is more realistic. This approach also explores the possibility of agents with limited capabilities to simulate believable human behaviour by exhibiting emergent social phenomenon.

REFERENCES

About ICC [online] Available at: http://www.iccsafe.org/about-icc/overview/about-international-code-council/ [Accessed 5 May 2015]

Algfoor, Z. A., Sunar, M. S. and Kolivand, H. (2015). A Comprehensive Study on Pathfinding Techniques for Robotics and Video Games, *International Journal of Computer Games Technology, vol. 2015*, Article ID 736138, 11 pages.

Almeida, J. E., Rosseti, R. J., and Coelho, A. L. (2011). Crowd Simulation Modeling Applied to Emergency and Evacuation Simulations using Multi-Agent Systems. in *DSIE' 11-6th Doctoral Symposium on Informatics Engineering, 2011*, pp. 93-104.

Bayrak, A. G., Polat, F. (2010). Formation Preserving Path Finding in 3-D Terrains. *Applied Intelligence 36(2)*. pp. 348–368

Blah, G. (2014). *Why Implementing an Evacuation Plan is Important*. [online] Available at: http://www.conceptsafety.com.au/why-implementing-an-evacuation-plan-is-important/ [Accessed 19 Jan. 2015]

Bonet, B., Geffner, H. (2011). Planning under Partial Observability by Classical Replanning: Theory and Experiments, *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI)*. page 1936-1941

Boularias, A. (2008). A Predictive Model for Imitation Learning in Partially Observable Environments, *2008 Seventh International Conference on Machine Learning and Applications*. pp. 83-90.

Boyce, K.E., Shields, T.J., Silcock, G.W.H., (1999). Toward the characterization of building occupants for fire safety engineering: capabilities of disabled people moving horizontally and on an incline. *Fire Technology 35 (1),* 51–67.

Carsten, J., Ferguson, D., Stentz, A. (October 2006). 3D field D∗: improved path planning and replanning in three dimensions, in *Proceedings of the IEEE/RSJ*

International Conference on Intelligent Robots and Systems (IROS '06), pp. 3381–3386.

Carsten, J., Rankin, A., Ferguson, D., Stentz, A. (2009). Global planning on the mars exploration rovers: software integration and surface testing, *Journal of Field Robotics, vol. 26, no. 4,* pp. 337–357.

Chong, O., Ricciarini, S. (August 2013). *APEC Building Codes, Regulations, and Standards; Minimum, Mandatory, and Green*. Nathan Associates Inc, United States.

Christensen, K. M., Collins, S. D., Holt, J. M., Phillips, C. N. (2006) The Relationship Between the Design of the Built Environment and the Ability to Egress of Individuals with Disabilities. *Review of Disability Studies, 2(3)*, pp. 24-34.

Colonna, G. (2002). *Introduction to Employee Fire and Life Safety*, National Fire Protection Association.

Cuesta, A., Abreu, O., Alvear, D. (2015). *Evacuation Modeling Trends*. Springer International Publishing, Switzerland.

Emergency Action Plan: Evacuation Elements [online] Available at: https://www.osha.gov/SLTC/etools/evacuation/evac.html [Accessed 3 Feb. 2015]

Fahy, R. F., Proulx, Guylene, (2001). Toward creating a database on delay times to start evacuation and walking speeds for use in evacuation modelling, *Human Behaviour in Fire, Proceedings of the 2nd International Symposium, MIT*, March 26–28, 2001, Interscience Communications, London.

Ferber, J. (1999). *Multi-agent systems: an introduction to distributed artificial intelligence. Vol. 1*. Reading: Addison-Wesley.

Fox, D., Burgard, W., and Thrun, S. (1999). Markov Localization for Mobile Robots in *Dynamic Environments, Volume 11*, pp. 391-427.

Fruin, J. J., (1987). *Pedestrian Planning and Design*, Revised ed. ElevatorWorld, Inc., Mobile, AL.

Graham, R., McCabe, H., and Sheridan, S. (2003). Pathfinding in computer games. *The ITB Journal: Vol. 4: Iss. 2,* Article no. 6

Grosshandler, W.L., Bryner, N., and Madrzykowski, D. (June 2005). *Report of the Technical Investigation of the Station Nightclub Fire, NIST NCSTAR 2*, National Institute of Standards and Technology, Gaithersburg, MD.

Gwynne, S., Galea, E. R., Owen, M., Lawrence, P. J., and Filippidis, L. (1999). A review of the methodologies used in the computer simulation of evacuation from the built environment. *Building and Environment, 34(6),* pp. 741-749.

Harper, R. F. (2000). *The Code of Hammurabi King of Babylon, about 2250 B.C. : autographed text, transliteration, translation, glossary, index of subjects, lists of proper names, signs, numerals, corrections and erasures; 2nd ed*. Chicago: The University of Chicago Press.

Hart, P., Nilsson, N., & Raphael, B. (1968). A formal basis for the heuristic determination of minimum cost paths. *IEEE Transactions on Systems, Science, and Cybernetics, 4,* pp. 100–107.

ICC, *Building Codes; How They Help You* [online] Available at: https://www.iccsafe.org/safety/Documents/BSW-BldgCodes-How.pdf [Accessed 9 July 2015]

Jackson, S. (2015). *Unity 3D UI Essentials*. Packt Publishing.

Jaklin, N., Geraerts, R. (2016). Navigating Through Virtual Worlds: From Single Characters to Large Crowds. In D. Russell, & J. Laffey (Eds.) *Handbook of Research on Gaming Trends in P-12 Education.* pp. 527-554. Hershey, PA: Information Science Reference.

Jones, J., Ashok, G. (2005). *Knowledge Organization and Structural Credit Assignment*.

Ketchell, N., Morgan, C., and Ramskill, P. (2006). *A Technical Summary Of The EGRESS Code*. ESR Technology, ESRT/NOIL/27812001/002(R) Issue 1a.

Khairuddin, A. R., Talib, M. S., and Haron, H. (2015). Review on simultaneous localization and mapping (SLAM), *2015 IEEE International Conference on Control System, Computing and Engineering (ICCSCE), Penang*, pp. 85-90.

Kisko, T.M., Francis, R.L., and Nobel C.R.(1998). *EVACNET4 User's Guide*. University of Florida.

Kobes, M., Helsloot, I, de Vries, B., Post, J. G., Oberijé, N., Groenewegen, K. (March 2010) Way finding during fire evacuation; an analysis of unannounced fire drills in a hotel at night, *Building and Environment, Volume 45, Issue 3*. pp. 537-548.

Korhonen, T., Hostikka, S. (2009). *Fire dynamics simulator with evacuation: FDS+Evac technical reference and user‘s guide* (Working paper No. 119). Espoo: VTT Technical Research Center of Finland

Kuligowski, E. D., and Gwynne, S. M. (2010). The Need for Behavioral Theory in Evacuation Modeling. *Pedestrian and Evacuation Dynamics 2008*, Springer, Berlin, pp 721–732.

Kuligowski; Erica D., Peacock; Richard D., Hoskins, Bryan L. (2010). *A Review of Building Evacuation Models (2nd edition)* National Institute of Standards and Technology, Gaithersburg, MD (NIST TN-1680)

Ley, A. J. (2000). A History of Building Control in England and Wales 1840-1990. *RICS Books*.

Lozano-P´erez, T., Wesley, M. A. (1979) An algorithm for planning collision-free paths among polyhedral obstacles, *Communications of the ACM, vol. 22, no. 10*, pp. 560–570.

Ma J, Song WG, Tian W, Lo SM, Liao GX (2012) Experimental study on an ultra high-rise building evacuation in China. *Saf Sci 50(8)*. pp. 1665–1674

Mehaffey, J. R., Bert, J. L. (May 1997). *Fire Protection; NIOSH Instruction Module*. Project SHAPE, National Institute for Occupational Safety and Health.

Misa, T. J. (2010). An interview with Edsger W. Dijkstra. *Communications of the ACM 53(8)*, pp. 41–47.

Mott MacDonald Simulation Group. (2012). Simulation of transient evacuation and pedestrian movements. *STEPS user manual*. Croydon, England.

Naveed, M., Kitchin, D., Crampton, A., Chrpa, L., and Gregory, P. (2012). A monte-carlo path planner for dynamic and partially observable environments, in *Computational Intelligence and Games*. IEEE, pp. 211-218.

Occupational Safety and Health Standards, 29 C.F.R. (2002).

Olson, S. H. (1997). *Baltimore: The Building of an American City*. Johns Hopkins University Press, Baltimore (Md.), p. 248.

Pan, X. (2006). *Computational modeling of human and social behaviors for emergency egress analysis*. Dissertation Stanford University.

Peacock, R. D., Hoskins, B. L., Kuligowski, E. D. (2012). Overall and local movement speeds during fire drill evacuations in buildings up to 31 stories. *Safety Science, 2012. 50(8)*. pp. 1655-1664.

Predtechenskii, V.M., Milinskii, A.I., (1978). *Planning for Foot Traffic Flow in Buildings*. Amerind Publishing Company, Inc., New Delhi.

Proulx, G., Latour, J.C., MacLaurin, J.W., Pineau, J., Hoffman, L.E., Laroche, C., (1995). *Internal Report 706*, Institute for Research in Construction, National Research Council Canada, Ottawa ON.

Proulx, Guylène, (1999). Occupant response during a residential high-rise fire. *Fire and Materials, 23*.

Raithby, J. (1819). Charles II, 1666: An Act for rebuilding the City of London. *Statutes of the Realm: Volume 5, 1628-80*. Great Britain Record Commission. pp. 603-612. British History Online. [online] http://www.british-history.ac.uk/statutes-realm/vol5/pp603-612. [Accessed 30 Oct. 2015].

Ronald, W. P., Greene, M. (1983). *Citizen Response to Volcanic Eruptions: The Case of Mt. St. Helens*. Ardent Media.

Ronchi, E., Kinsey, M. (2011). Evacuation models of the future: Insights from an online survey on user's experiences and needs. In J. Capote et al. (Ed.), *Advanced research workshop evacuation and human behaviour in emergency situations EVAC11*. pp. 145–155. University of Cantabria (Spain).

Russell, S. and Norvig, P. (2010). *Artificial intelligence : A Modern Approach 3rd Edition*. Prentice Hall.

Shapiro, L. G., Haralick, R. M. (1979). Decomposition of two-dimensional shapes by graph-theoretic clustering, *IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 1, no. 1,* pp. 10–20.

Simmons, R., Koenig, S. (1995). Probabilistic robot navigation in partially observable environments, *Proc. International Joint Conference on Artificial Intelligence*.

Spearpoint, M., MacLennan, H. A: (2012). The effect of an ageing and less fit population on the ability of people to egress buildings. *Safety Science 2012, 50*. pp. 1675–1684.

Thompson P. A., Marchant E.W. (1995). Testing and Application of the Computer Model 'SIMULEX'. *Fire Safety Journal (Vol. 24, No. 2)*. pp 149-166.

Thompson, P. A., Marchant, E. W. (1995). A computer model for the evacuation of large building populations. *Fire Safety Journal, 24*, pp. 131–148.

Thompson, P., Lindstrom, H., Ohlsson, P., Thompson, S. (2003). Simulex: Analysis and Changes for IMO Compliance. *Proceedings of 2nd International Conference: Pedestrian and Evacuation Dynamics*. pp. 173-184.

Ulam, P., Goel, A., Jones, J., Murdock, J.W. (2005). Using Model-Based Reflection to Guide Reinforcement Learning, *Proceedings of the Nineteenth International JointConference on Articial Intelligence (IJCAI 2005) Workshop on Reasoning, Representation and Learning in Computer Games. pp. 1-6.*

Wikipedia, The Free Encyclopedia; *Sensory System* [online] Available at:, http://en.wikipedia.org/wiki/Sensory_system [Accessed 12 Nov 2014]

Wright, M.S., Cook, G.K., Webber, G.M.B., (March 26–28, 2001). The effects of smoke on people's walking speeds using overhead lighting and wayguidance provision. In: *Human Behaviour in Fire, Proceedings of the 2nd International Symposium, MIT*. Interscience Communications, London.

Zhang, Y., Kim, K., Fainekos, G. (2016). DisCoF: Cooperative Pathfinding in Distributed Systems with Limited Sensing and Communication Range, *The 12th International Symposium on Distributed Autonomous Robotic Systems*. pp. 325-340