A Machine Learning based path guidance system for safe evacuation of a hospital building in case of fire

A PROJECT REPORT

Submitted by

SARANSH GUPTA

UDAYADITYA PRATAP SINGH

Under the guidance of

Dr. JHARESWAR MAITI

Industrial and Systems Engineering Department

Indian Institute of Technology,

Kharagpur-721302

[2019]

1

Acknowledgement

We wholeheartedly thank our project guide, Prof. Jhareswar Maiti for his guidance and constant supervision during the tenure of partial fulfillment of our project. We thank him for making us realize the importance of learning while doing project and encouraging us to drive ahead. Finally we would like to thank the department for providing us this opportunity.

2

Contents

3

Introduction

Innovations are happening at a tremendous rate. The job of engineers around the world is to

make the lives of everyone around them and beyond, easier, more accessible, faster and

safer.

This constant pursuit of making things better in one domain often compromise with another

domain.

The world is becoming safer day after day. Although it is becoming safer, it is also becoming

more complex. In such a complex world, people don't necessarily make the most optimal
decisions or which have the most utility. Mathematicians from time immemorial have been
improving upon methods and more formally - algorithms, to find the best possible solution to
everyday problems. Finally, in the current times, more often than not, we possess both the
algorithms and the computational power to find solutions to problems unperceivable by most.
But the major problem remains in bridging this wide gap between Man and Machine. Even if
we know the solution to a problem using the most recent algorithms and the most powerful
computers, that solution needs to be shipped to the customer for him to use it.
This may seem not very difficult do. Communications have never before been better than
right now. But here arises a major problem - accidents.
By the definition given in the Oxford Dictionary, an accident is an unfortunate incident that
happens unexpectedly and unintentionally, typically resulting in damage or injury.
In such cases, two major problems arise out of which only one can be resolved. First, due to
the nature of the accident, in most cases, systems to find the optimal solutions are not
present beforehand. This can be resolved by analysing the possible shortcomings and
potential hazards of the environment, products and technologies that are being used.
Second, shipping the solution from the system to the victims of the accidents takes time and
in such situations, more often than not, victims are terrified and hence not able to think
rationally.
4

Problem Statement

"A Study on Hospital Fires and Patient Reaction"

Objectives

The objectives of the report will be to:
● To Suggest additional possible exits.
○ Based on the dead ends and bottlenecks faced by the people during data collection.
● To suggest the best places for entry of "Fire Department Team" for optimum evacuation to minimise casualty.
○ Based on most encountered windows and balcony during data collection.
● To train the Nurses to direct and collect those people who get lost or stuck in dead
ends and then move them along the most probable, humanly intuitive and safe path.

○ This path will be tailored according to the position of the fire and previous patient data collected using an RL inspired algorithmic model.

5

Literature Review

(De-Ching et al., 2011) explains that the evacuation procedure should proceed in three
stages:

1. Patients who are able to self evacuate in the first stage.
2. Next, patients who need assistance from staff to evacuate in the second stage.
3. And finally, patients who have no mobility and are ambulatory.

But there are some limitations in this research, it presumes some facts such as pre-evacuation time is around 1300 seconds, which is not experimentally proven, no real
experiment was done on people to prove their facts. The research is focussed more on the
fire extinguishing rather than safe evacuation by the people themselves until the fire-brigade
appears for their help.

G. R. F. Murphy and C. Foot did a study on ICU fire evacuation preparedness in London,
they took a survey of 50 adults of an ICU, and handled them a 90 questions questionnaire
asking about patient characteristics, design, equipment, training, and their evacuation plan.
Thirty-five of 50 (70%) responded within 2 months of the study. Significant weaknesses were
reported in unit design, equipment, and planning. Unit design was compromised by inadequate fire doors (20%), ventilation cut-outs (17%), and escape routes (up to 60%).

But the method is limits itself to just a survey questionnaire rather than putting patients in a
virtual fire condition. The research more emphasises on the fault of the hospital safety
conditions, it fails to generate any methodology to escape without any casualty.

Qiao et al. did a remarkable work in binding human interaction with safety evacuation, they
propose a methodology with the help of human interaction which may be used to train
people for safe evacuation. But they failed to propose that how will it be possible. They
proposed that human interaction can make safe evacuation much better.

Rita F. Fahy et al. have done a significant work in binding safety evacuation with the help of
human interactions. They studied Human Behavior in the World Trade Center Evacuation.
This paper includes analyses of the behavior of the tower occupants only, that is, those who

were on Floors 11 and above at the time of the incident. There were 225 such respondents
from Tower 1 and 157 from Tower 2. The bomb was placed closer to Tower 1 than Tower 2
and responses to many of the questions differed significantly between occupants of the two
towers.
Sheeba Angel A.*, Jayaparvathy R. did worked on Performance modeling of an intelligent
emergency evacuation system in buildings on accidental fire occurrence. They introduced an
intelligent method to study the evacuation dynamics of high rise buildings under fire
emergencies. The system performance is evaluated in terms of pre evacuation delay,
normalized system throughput and evacuation time by varying the number of evacuees. By
these results they were able to explain where emergency exits should be placed, but they
failed to develop a system which will guide people inside the building to escape without any
causality until fire brigade comes.
6
Kelly Rendon Rozo et. al. worked on Building evacuation plans using agent based
simulations considering pedestrians behaviour. Results of the work were able to identify the
weakness in the buildings with multiple exiting routes using some score techniques. But
when it comes to the pedestrians behaviour, they didn't use the real time data of random
people using any virtual reality technique which can make significant differences in the
original result and the theoretical result.
(Jiang et al., 2014) tries to analyze the main factors that affect the fire safety evacuation
performance of hospital buildings by observing large amounts of pedestrians' walk velocity in
a hospital, by cameras and videos.
A correlation analysis between the special behavioral characteristics of populations in
hospitals and pedestrian walk velocity and other features show that the speed of walking of
hospital patients is approximately 10%~20% less than that of the healthy population.
The same paper shows that approximately 33% of the patients have no clue about what to
do after the fire-alarm is sounded.
Sujata Pathak from K.J. Somaiya College of Engineering in 2019 published a work on

Automated Fire Evacuation System with Congestion Control. They used modified Dijkstra
algorithm for the path planning system. But the algorithm itself is limited only to the 2D paths,
The algorithm may fail for a multistoried building. Moreover they did not work upon the
human behaviour in case of fire. The modified Dijkstra algorithm itself is quite complicated to
be applied for 2D maps, the algorithm only ensures the optimality of the path, it may or may
not be feasible for a human being to pass through that path. Adding to the above, It just
shows one optimal path, as the fire is dynamic so it may be possible that fire encloses that
optimal path, and in that case the algorithm fails to guide the optimal path.
Huang De-Chinga et. al. did a Study for the evacuation of Hospital on Fire during
Construction, his focus was on evacuation time of patients and staff that often draws major
attention because of the hospital's diverse population, mix of patient conditions, and having
multiple units on one floor. They worked on the different factors such as temperature which
affects the fire spread in the hospital.
Adam Stančík et. al. used building information modelling. They used visual programming to
model an evacuation plan, but it fails to bind it with human behaviour, moreover the plan fails
to suggest some new emergency exits in the building in order to avoid any chaos.
7

Method

In the previous researches done by some great scientists in this field we saw that some
important points were missing in them, their studies lacked human reaction in case of fire.
We have done that study and have discovered a way to build a path guidance system based
on human reaction with the help of Virtual Reality environment and Reinforcement Learning.
With a Reinforcement Learning based approach we have successfully been able to predict
the safest path in case of fire to evacuate the hospital building.
While performing experiments, we noted the time taken to bail out of the building by the
volunteers. The paths taken by the volunteers to escape were noted, the paths were
recorded as integer nodes, each node was coded as a unique integer as shown here:
Based on the time noted, and corresponding path recorded, we defined some scores

- $_3$ Time Score
- Azimuthal Score

These scores are directly proportional to the instantaneous optimality of path, the better the
score, more will be the **instantaneous optimality** of the path.

₃ Time Score

Time score will be used to calculate how well a particular agent does as compared to the
worst case time (or the maximum time). It will be a value between 0 and 1.

Azimuthal Score

Azimuthal score will be used to calculate how well a particular agent does in finding a path
on the same floor. A rational human will prefer to exit from the same floor rather than from a
different one.
To do this, we will define the three angles (α, β and γ) from the start position to the exit point.
It will be between 0 and 1.

8

Underlying Assumptions

● Path cannot be retraced.
● Loops are unacceptable.

Calculation and Post Calculation of Scores

The calculated scores will be added to the dataset. Following this, the revised dataset will
then be used by another algorithm to suggest all the possible paths on which people tend to
go, and rank them based on how optimum they are for escaping.
Here we found the number of possible paths, in the testing time (real scenario), based on the
Human Behaviour Model. We then used the scores to determine the best possible path out
of the possible paths.
We arrange the possible paths in the most likely order (based on human behaviour)

Note : *We show multiple paths in decreasing order of priority because in a realistic situation, multiple people using the same path might lead to the situation of bottleneck and hence will reduce the score (which is an indicator of the optimum path).*

9

Data Description

So far we have collected data nearly from 25 different people with the help of **virtual reality**
simulations done in **UNITY3D** with the help of **oculus-rift and controllers** for the real-time
experience of the situation.
The data consists of some major columns such as " Initial_position", "final_exit",
"path"," azimuthal_angle", "t_r(in_sec)", "fire_position", "fire_in_path".
During the experiment, the
rooms, compartments of the hospital building were being divided into some integer labeled

nodes.
"Initial_position" shows the initial node position of the test subject from where it has to escape,
"final_exit" is the exit node from which the test subjects successfully escapes, "path" is the comma
separated series of nodes through which the test subject passes during the test. "azimuthal_angle"
angle is the acute angle made by the vector "initial_position" → "final_exit" with x, y, z axes
respectively. "t_r(in_sec)" is the time taken by the test subject to escape from the building through a
chosen path. "fire_position" is the instantaneous node position of fire in the building, "fire_in_path" is
the one hot encoded column for the condition if fire is encountered in path or not.
Apart from these major columns, there are some minor columns as well for the further
analysis of the situation was handled by different kinds of people. These further analysis
were done on the basis of video gaming experience of people, on the basis of age, gender
etc.

Model

Since the data was dynamic and partially unsupervised so traditional machine learning
models for supervised or unsupervised data were discarded and a new model inspired by
Reinforcement learning was being introduced for the training purpose in which it takes
suitable action to maximize reward in a particular situation.
Reinforcement learning differs from the supervised learning. In **supervised learning** , the *training*
data has the **answer key** with it so the model is trained with the correct answer itself whereas in
reinforcement learning , there is no answer but the reinforcement *agent* decides what to do to
perform the given task.
Application of Reinforcement learning encounters the problem of dynamic fire, and is
intelligent enough to introduce new emergency exit gates to avoid any chaos.
10

Solution approach

From the data collected, t_r, azimuthal angles and their corresponding fire position, initial
position, final exit were being processed. For each combination of path, initial position, fire
position, final exit, a time score was being calculated:
Time_score = (1−1 / (1 +exp(−x/10)))
[0< Time_score <1]
Similarly azimuthal score was calculated as:
a_score = {2cos(a) + 2cos(b) + cos(c)}/5 {where a , b , c are acute angles from x , y , z
axes}

[0 <a_score <1]
Then a final score was calculated using formula:
Final_score = (Time_score * a_score)^½
If there was fire encountered during the escape in experiment then immediately the final
score of that path, position combination was awarded 0.
Based on the Final score, best paths were sorted out with the help of algorithm. The best
path is considered as the path with maximum final calculated score, and the score is unique
for every path, position combination.

The Pseudocode of the method goes like this:
Read the dataset
Read the column fire_in_path:
If yes:
Skip and assign total_score as 0:
else:
Read α, β, γ, and time_taken
Feed α, β and γ to a function to automatically convert them to
corresponding acute angles
If 0<= α, β, γ <=90:
It is ok;
Else if α, β &γ >90 and <180:
Do 180 - (α, β, γ):
Pass:
Continue till α, β, γ <=90:
11
Calculate :

$a\_score_{(i)} = \sum_{i=0}^{i<n} \{2\cos(\alpha_i) + 2\cos(\beta_i) + \cos(\gamma_i)\}/5$; n = number of rows in the dataset
Now read the time_taken:
For i less than n :
$x_i = time\_taken_i$
$time\_score_{(i)} = 1 - 1/(1 + \exp(-x_{(i)}/10))$
Define total_score:
$total\_score_{(i)} = \{time\_score_{(i)} * a\_score_{(i)}\}½$
Add total_score column to the main data set as a separate column
---------------Training part till here--
Now for the testing part:
Take initial_position, fire_position as input:
For a given initial_position, fire_position:
find the best route based on the scores calculated from the dataset:
Sort the shortlisted instantaneously optimal paths based on the scores:
if no route available for current initial_position and fire_position
Display "can-not find any path"
If current initial_position in an intermediate position of a path:
Display "N.A. (score not calculated for intermediate paths but the path shown is safe
from fire)"
Display safe paths:

This is how best routes will be displayed by the algorithm.

Results:

We wrote the above pseudocode in python, processed the data into csv format, and applied
the algorithm, following results were obtained when tested on sample test set:

Rank of path	Initial Position	Fire position	predicted safe paths	score of path
1	202	131	202 , 203 , 201 , 801 , 101 , 991	0.341760
2	202	131	202 , 203 , 212 , 216 , 802 , 132 , 133 , 102 , 101 , 991	0.327951

12

1	202	203	N.A. (No way out possible because fire is there in the adjacent node)	0.0
1	220	203	220 , 219 , 218 , 216 , 802 , 132 , 131 , 992	0.26429
2	220	203	220 , 219 , 218 , 216 , 802 , 132 , 133 , 102 , 101 , 991	0.065461
1	117	802	117 , 115 , 114 , 111 , 103 , 102 , 101 , 991	0.355885
1	111*	216	117 , 115 , 114 , 111* , 103 , 102 , 101 , 991	N.A. (score not calculated for intermediate paths but the path shown is safe from fire)
1	111*	216	113 , 111* , 114 , 118 , 120 , 123 , 124 , 993	N.A. (score not calculated for intermediate paths but the path shown is safe from fire)

* intermediate position of a path

| 1 | 207 | 102 | 207 , 204 , 203 , 212 , 216 , 802 , 132 , 131 , 992 | 0.13049553139977288 |

Training Methodology:

As our methodology was based on Reinforcement learning related technique which definitely
required some training data to test. Our model included human interaction in a virtual
environment which definitely itself was a challenge. As working with oculus rift needs some
gaming experience. According to the survey of the people who were with us for the
experiment, nearly 27% of them had no gaming experience, a questionnaire was prepared
for the survey, and the results can be seen here:

13

The volunteers were being provided some training in a fake environment to acclimate them
in the hospital VR environment.
Fig: udayaditya singh giving training to use oculus controllers
As per the survey, it was not difficult for most of the volunteers to get acquainted in the VR
environment:
However some sort of headache/nausea/ Motion-sickness was experienced by some of them as revealed by the survey:
14
According to the survey, 54.5% volunteers think that the system is very easy to understand:
Here are some snapshots of the training process:
15
Some glimpses of the VR hospital environment as seen by the oculus rift:
Fig: VR view of first floor of building. Fig: satellite view of the hospital building.
Fig: VR view of the main entrance of the hospital building.

Limitations:

Although a lot of cases have been considered, but there are still some challenges for the
proposed model.
Lift was not considered while experiments assuming the fact that lifts are disabled during fire
situation.
It requires the whole Virtual-Reality simulation model of a Real Building in order to collect
experimental data which can be very costly as it requires a lot of graphics in it.
Node-labeling of each room and compartment of a hospital building and then testing can be
a rigorously long and time consuming process for large hospital buildings.
The proposed model requires fire and smoke sensors, blue guide lights and a server in
which we can feed the learnt model in order to process further, which again is a costly
process.
The experiments were done with static fire, although the algorithm can process the dynamic
fire as well.
All the experiments were done without programming any chaos happening inside the building, which is different from the real scenario.
Although large efforts have been done to make the conditions realistic but still we lag in
some areas such as the propagation of fire and smoke, they depends upon the direction of
wind, and the type of material, which can not be defined inside UNITY3D as far as we have
come to know.
16

Future Scopes:

Apart from the above limitations, the proposed model can be used efficiently for the safety
purpose.
This model has the capability to guide someone from one position to final exit via the safest
and the easiest path without being affected by the fire.
Apart from the path guidance, the algorithm can also help to introduce new emergency exits
from the building in order to avoid any chaos during fire emergency.
This model is not limited to a hospital building only, it can be applied in any type of building,
especially the large buildings where fire risks are more probable.
Special care has been taken while programming the model and it has been made enough
efficient to process large data fast at minimum system requirements.
The algorithm will also work as a normal path guidance system even if there is no fire in a
building, just like an automated path guide.
This reward based Reinforcement Learning model can also be used for traffic signals in a
city which can efficiently minimize the jamm condition on roads of a big city.
This reward based approach has application in Artificial Intelligence as well, such as
automated barriers, automated traffic cameras etc.

References

Bibliography
1. De-Ching, Huang, Chien Shen-Wen, Lin Chien-Hung, Huang Po-Ta, Song Yi-Ting, and Sie Huei-Ru. "A Study for the Evacuation of Hospital on Fire during Construction." *Procedia Engineering* 11 (2011): 139-46. doi:10.1016/j.proeng.2011.04.639.
2. Jiang, Ze-Min, Pei-Hong Zhang, Rong-Xue Shang, and Xiang-Liang Tian. "Investigation and Simulation on Human Evacuation Behaviour in Large Hospital Building in Shenyang." *Procedia Engineering* 71 (2014): 101-06. doi:10.1016/j.proeng.2014.04.014.
3. Modelling building emergency evacuation plans considering the dynamic behaviour of Pedestrians using agent-based simulation. (Kelly Rendon Rozo, Julian Arellana*, 17 alcides Santander-Mercado, Maria Jubiz-Diaz) universidad del norte
4. Sujata Pathak, Shreya Parikh, Advait Bhat. "Automated Fire Evacuation System with Congestion Control" 2nd International Conference on Advances in Science & Technology (ICAST-2019) K. J. Somaiya Institute of Engineering & Information Technology, University of Mumbai, Maharashtra, India
5. G. R. F. Murphy* and C. Foot. "ICU fire evacuation preparedness in London: a cross-sectional study" Critical Care Unit, Royal Marsden Hospital, Fulham Road, London SW3 6JJ, UK, British Journal of Anaesthesia 106 (5): 695-8 (2011) Advance Access publication 16 March 2011 . doi:10.1093/bja/aer033

6. Lifeng Qiao, Beijing (CN); Hui Zhang, Beijing (CN); Rui Yang, Beijing (CN); Yanyan
Chu, Guangzhou (CN); Shaodong Guo, Beijing (CN); Hengtao Wang, Beijing (CN);
Qingshan Jia, Beijing (CN); Qianchuan Zhao, Beijing (CN); Yi Jiang, Beijing (CN);
Satish Narayanan, Ellington, CT (US) ," FIRE SITUATION AWARENESS AND
EVACUATION SUPPORT "
7. RITA F. FAHY National Fire Protection Association 1 Batterymarch Park Quincy,
Massachusetts 02269-9101 USA GUYLENE PROULX National Fire Laboratory
Institute for Research in Construction National Research Council of Canada Ottawa,
Canada KIA OR6, "Human Behavior in the World Trade Center Evacuation"
8. Sheeba Angel A.*, Jayaparvathy R. Department of Electronics and Communication
Engineering, SSN College of Engineering, Chennai 603110, India," Performance
modeling of an intelligent emergency evacuation system in buildings on accidental
fire occurrence"
9. Huang De-Chinga , Chien Shen-Wenb,*, Lin Chien-Hungc , Huang Po-Tab , Song
Yi-Tingb , Sie Huei-Rub a New Taipei City Fire Bureau, New Taipei City 22065,
China b Central Police University, Kueishan Hsiang 333304, China c Yunlin County
Fire Bureau, Douliu City 64054,China," A Study for the Evacuation of Hospital on
Fire
18
during Construction "
10. Adam Stančík1,*, Roman Macháček2 , and Jiří Horák1 1Brno University of
Technology, Institute of Computer Aided Engineering and Computer Science, 602 00
Brno, Veveri 331/95, Czech Republic 2Czech Technical University in Prague,
Department of Steel and Timber Structures, 16636 Prague 6, Czech Republic ," Using
BIM model for Fire Emergency Evacuation Plan"

11. Wang, J., de Vale, J.S., Gupta, S., Upadhyaya, P., Lisboa, F.A., Schobel, S.A., Elster, E.A.,
Dente, C.J., Buchman, T.G. and Kamaleswaran, R., 2023. ClotCatcher: a novel natural language
model to accurately adjudicate venous thromboembolism from radiology reports. *BMC medical
informatics and decision making*, *23*(1), p.262.

12. Gupta, S.A.R.A.N.S.H., 2019. A Machine Learning based path guidance system for safe
evacuation of a hospital building in case of fire. *Kharagpur: Indian Institute of Technology*.