

**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

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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.

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.

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.

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.

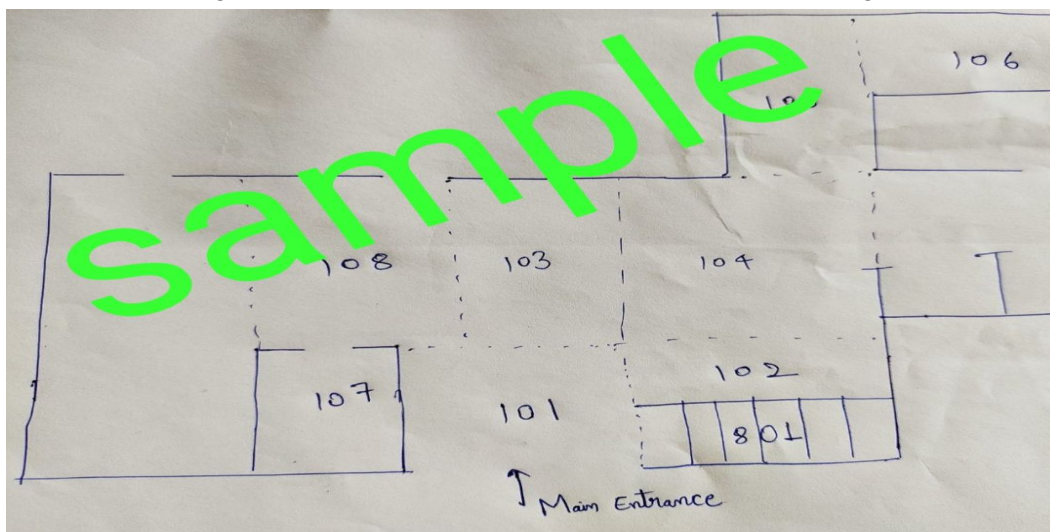
Huang De-Chinga et. al. did a Study for the evacuation of Hospital on Fire during Construction, his focus was on evacuation time of patients and staff that often draws major attention because of the hospital's diverse population, mix of patient conditions, and having multiple units on one floor. They 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.

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

- ³Time 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.

³Time 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.

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).*

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.

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:

$$\text{Time_score} = (1 - 1 / (1 + \exp(-x/10)))$$

$$[0 < \text{Time_score} < 1]$$

Similarly azimuthal score was calculated as:

$$\text{a_score} = \{2\cos(a) + 2\cos(b) + \cos(c)\}/5 \quad \{\text{where } a, b, c \text{ are acute angles from } x, y, z \text{ axes}\}$$

$$[0 < \text{a_score} < 1]$$

Then a final score was calculated using formula:

$$\text{Final_score} = (\text{Time_score} * \text{a_score})^{1/2}$$

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 $0 < \alpha, \beta, \gamma <= 90$:

 It is ok;

 Else if α, β & $\gamma > 90$ and < 180 :

 Do $180 - (\alpha, \beta, \gamma)$:

 Pass:

 Continue till $\alpha, \beta, \gamma <= 90$:

Calculate :

$$a_score^{(i)} = \sum_{i=0 \text{ to } i < n} \{2\cos(\alpha_i) + 2\cos(\beta_i) + \cos(\gamma_i)\}/5 ; n = \text{number of rows in the dataset}$$

Now read the time_taken:

For i less than n :

$$x^i = \text{time_taken}^i$$

$$\text{time_score}^{(i)} = 1 - 1 / (1 + \exp(-x^{(i)}/10))$$

Define total_score:

$$\text{total_score}^{(i)} = \{\text{time_score}^{(i)} * a_score^{(i)}\}^{\frac{1}{2}}$$

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

1	202	203	N.A. (No way out possible because fire is there in the adjacent node)	0.0
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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	0.35588 5
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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

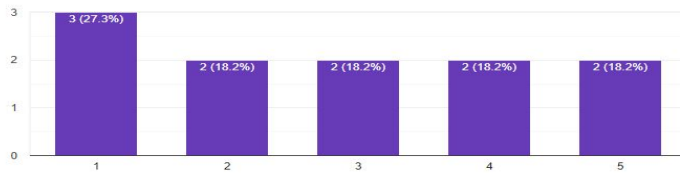
1	207	102	207 , 204 , 203 , 212 , 216 , 802 , 132 , 131 , 992	0.13049553139977288
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Training Methodology:

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:

1. Do you have any prior desktop gaming experience? (rate your scale from 1 to 5)

11 responses



The volunteers were being provided some training in a fake environment to acclimate them in the hospital VR environment.

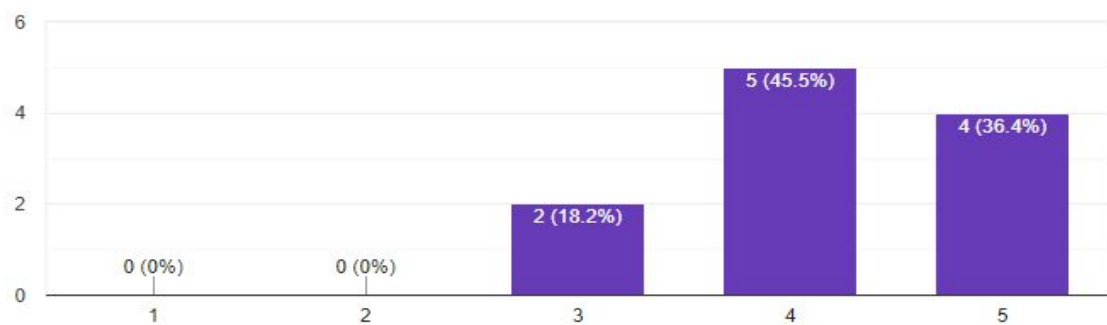


Fig: udayaditya singh giving training to use oculus controllers

As per the survey, it was not difficult for most of the volunteers to get acquainted in the VR environment:

5. How quickly you got acquainted in the virtual environment

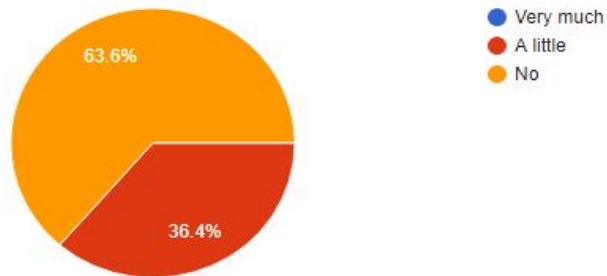
11 responses



However some sort of headache/nausea/ Motion-sickness was experienced by some of them as revealed by the survey:

3. Did you experience headache/nausea/ Motion-sickness while playing in VR?

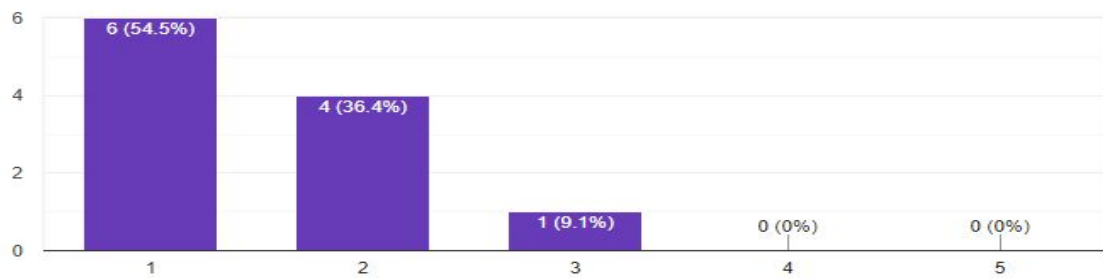
11 responses



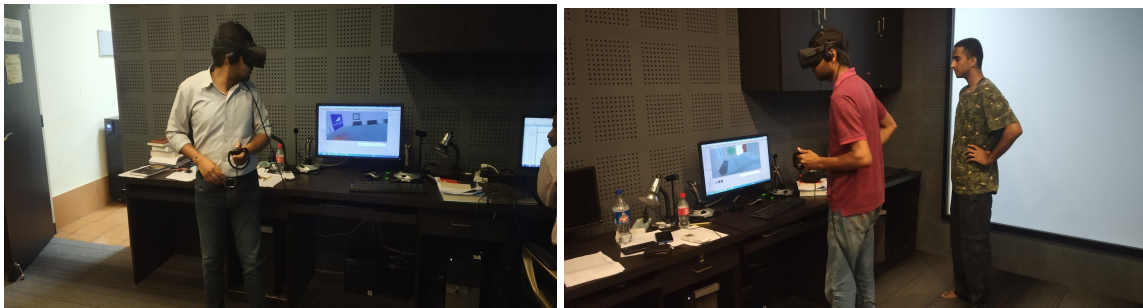
According to the survey, 54.5% volunteers think that the system is very easy to understand:

8. How complex is the system to understand?

11 responses



Here are some snapshots of the training process:



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.

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.

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