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Computer Simulation in Science

Examination of Load Dependent Exit Choice of Pedestrians –A Virtual Reality Study

Master dissertation

Presented by

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Declaration

I, SivaKartheeka Sreerama hereby declare that this Master's dissertation is my own work and I have documented all sources and material used. This work was not previously presented to another examination board and has not been published. The information used from the other sources is cited clearly.

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Place and Date   **SivaKartheeka Sreerama**

Abstract

During an evacuation process, the exit choice of pedestrians directly influences the evacuation time and the occurrence of congestions. Old simulating software based on shortest path algorithms were ineffective as they lead to congestions and overestimated evacuation times. New models were developed based on the quickest path algorithm to overcome the shortcomings of previous models. In these models pedestrians are able to change their exit choice by estimating the flow of congestions and journey times. Nevertheless, the inability of the models to accurately reproduce the rational thinking of human beings is widely articulated. To understand what drives a human being to choose a particular exit or to change his exit choice midway through a process, an exit choice BASIGO experiment was chosen and modelled using software into a virtual environment. Here the experimentee is assigned the task of navigating a virtual person through a room using a controller and has to decide which exit to take in a series of test runs. The flow and density in front of exit doors differ from run to run and the task is to find what makes participants desist from an exit. Additionally, Linear discriminant analysis is performed to calculate the coefficients and to generate a linear equation. The obtained results are then compared with the real BASIGO experimental values to check for accuracy.

KEYWORDS: Exit choice decision, pedestrian, virtual person, virtual environment and LDA.

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List of Abbreviations

- VR   -   Virtual reality
- GSU   -   Google SketchUp
- VM   -   Virtual method
- VE   -   Virtual experiment
- RE   -   Real experiment
- VENV   -   Virtual environment
- LDA   -   Linear discriminant analysis
- PPT   -   Precision position tracking
- OSGB   -   Open Scene Graphics

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List of Symbols

- ρ -   Density
- v -   Velocity
- J -   Flow
- J_s -   Specific flow
- C -   Capacity
- ΔT -   Time interval
- ΔN -   No. of pedestrians
- t -   Time
- F_1, F_2 -   Discriminant
- $\alpha_1, \beta_1, \alpha_2, \beta_2$ -   Discriminant coefficients

Chapter 1   Introduction

1.1 Motivation

Over the course of history several disasters have happened which were directly aggravated by the poor exit choice behaviour of people, crowd crushes, stampedes, human panic behavior and uneven routing of places. Literature studies [1, 2, 3] have shown that more than a thousand lives were lost due to these disasters. One of the most tragic accidents occurred in Iroquois Theater in Chicago (USA) [3] which cost 602 people their lives because of panic situation and high densities near the exit door. Another accident in 2010 at a concert in Duisburg (Germany) [4, 5] (Deaths: 21/ Causalities: 500) and beach firework incident in 2001 in Kobe, Akashi (Japan) [6, 7] (Deaths: 11) have cost many lives due to stampedes. Despite these incidents, research in this field is still in its nascent stages. With the advent of virtual reality however, we now have the perfect opportunity to recreate such deadly scenarios virtually and understand how they can be prevented from happening again. Results obtained from the conducted research can also be used to design better emergency exit plans for commercial and entertainment venues built to accommodate large congregations of people.

There are many efficient simulation software packages available in the market to simulate pedestrian dynamics. Though they simulate pedestrian movement efficiently, there are certain parameters these software packages couldn't explain. One of them is the behaviour of pedestrians, especially during the exit choice analysis. Hence to study and analyse the exit choice conducts of pedestrians, we are presenting this dissertation work.

Studying human behaviour through experimental methods is very expensive and time consuming, and in extreme situations like fire accidents, impractical. Virtual reality (VR), due to its ability in creating any virtual environment (VENV) we wish to, allows one to study the human behaviour for such extreme scenarios [8]. The last few years have shown that VR is useful in identifying problems. VR was chosen to

simulate problems mainly for two important reasons: Firstly, it is very simple to model. Secondly, it allows one to simulate with n number of pedestrians and at different situations, especially in extreme situations like fire accidents.

1.2 Virtual Studies

Virtual reality (VR) is an unreal environment that is created with software (In this dissertation Vizard was used as VR software) and presented to the user or experimentee in such a way that the person suspends belief and accepts it as a real environment. Virtual reality is used either to:

1. Simulate a real environment to serve for education and research purposes or
2. Develop a hypothetical environment for a game or an interactive story.

Numerous studies have been conducted using VR and valuable information was found about human behaviour and how to conduct a VE. **Erik, Peter and Susan** [9] have studied human route behaviour using navigation (3D maps and free navigation) via virtual environments, and found that 3D maps are very clear and easily understandable for humans than free navigation. In their studies for free navigations, they have allowed participants to walk around virtual environments freely without any constraint. For 3D maps, the participants are allowed only to look at the VEs from a fixed point. **Luo, Wickens, Duh and Chen** [10] have analysed human route behaviour in subway stations via both RE and VEs using with and without 3D maps, and found that the pedestrians are moving faster when they have 3D maps. In the absence of 3D maps, the participant's response time is very slow. Their VE study results showed good agreement with the RE study and also share many results seen in Erik, peter and Susan study on navigation. **Norman G. Vinson** [11] has explained the guidelines for modeling and navigating a complex real environment virtually. His guidelines are based primarily on an extensive empirical literature on navigation in the real world. **Mehdi Moussaid** and his group [8] have analysed human crowd behaviour during high-stress situations via VR, and compared the VR results with those observed in the experiments. Their VR results on the crowd behaviour, movement and interactions show good agreement with the experiments. Although the human behaviour in different scenarios (e.g. Finding routes, traffic etc.) have been studied virtually and practically in the real world, less attention has been paid to exit choice behaviour and our understanding about it is limited. In this dissertation

work we mainly focus on this issue and also check the results with reality i.e. how far they coincide with the real results.

1.3 Aim and Structure of the Dissertation

The aim of this dissertation work is to study the exit choice behavior of pedestrians. The study uses GSU and Vizard software packages to create the VENV where the virtual experiments are conducted. In addition, experimental data and questionnaire forms have been used for analysis of the pedestrians' exit choices. The discriminant coefficient values have been investigated and compared with the ones observed in the real experiments.

This dissertation is organized as follows:

Chapter 2 introduces the concept of pedestrian dynamics, how it works and some basic terminology of pedestrian dynamics.

Chapter 3 explains the Methodology of the VR experiment and also includes brief information regarding the BaSiGo experiment and how to do one of the experiments as performed in BaSiGo by using VR techniques.

Chapter 4 describes the basic setup of the VR experiment used in this dissertation work. In this chapter, the algorithms of VR experiment and data extractions is also explained.

Chapters 5 and 6 demonstrates the qualitative and quantitative analysis of the data generated from the VR experiments in the previous chapter. The results are analysed and compared with the real ones.

Chapter 7 gives a short conclusion about this dissertation work, based on the results obtained.

Chapter 2   Introduction to Pedestrian Dynamics

In this chapter the basic terminology of pedestrian dynamics and the pedestrian models used in this work are explained. In addition, general routing strategies for pedestrian simulations are also explained.

2.1 Basic terminology of Pedestrian Dynamics

In order to effectively design, pedestrian facilities like escape routes (for stadiums, heaters, schools, etc.), and to assess these facilities for big events and transport infrastructure, the following terms play an important role:

Trajectory: Trajectory is defined as the pedestrian path travelled or the path that will be travelled by the pedestrians. Trajectory contains pedestrian positions at each time interval t.

Density: The average number of pedestrians per unit area. Mathematically, density ρ is expressed as

$$\rho \quad = \quad \frac{\text{No. of pedestrians}}{\text{area}}$$

Units: ped/m^2

Velocity: Velocity is the average walking speed of a pedestrian per unit time.

The expression for velocity v is,

$$V \quad = \quad \frac{d}{t}$$

Where d: the average distance travelled by a pedestrian in time t.

Units: m/s

Flow: It defines the number of pedestrians ΔN, who are able to pass through certain time interval i.e. ΔT.

$$J \quad = \quad \frac{\Delta N}{\Delta T}$$

The maximal flow is called the capacity $C = J_{max}$

From other literature studies the flow equation can be written as in terms of product of the specific flow and breadth of the room.

$$\text{Flow equation} = \quad J_s b$$

Where J_s is specific flow.

Specific flow: It is defined as the flow per unit door width in a second. Mathematically, it can be written as

$$J_s \quad = \quad \frac{J}{b}$$

Specific flow can also be defined in terms of density and velocity as follows

$$J_s \quad = \quad \rho v$$

The detailed procedure for calculating and how to choose the parameters density, velocity, flow and specific flow is explained in [12, 13].

2.2 Pedestrian Models

According to the classical definition of a complex system, the behaviour of each component or element depends on the behaviour of other components. A moving crowd is a perfect example of a complex system where the motion of an individual is dependent on the motion of others in the crowd who are also moving in the same path. Most mathematical models which were developed in the past were based on physical similitude of fluids and the movement of their particles which cannot be expected to mimic the exact dynamics of crowd movement because, unlike such physical processes, crowds are made up of rational and intelligent human beings. Since there is no precedent to act as benchmark, any mathematical model we create cannot be considered better or worse than other models. To allow for comparison, we introduce a set of criteria which a model has to satisfy in order for it to be considered good or bad. This distinction arises depending on whether the model in consideration satisfies the set criteria better or worse than the other models.

Pedestrian models are essentially classified into three types depending on their characteristics and degrees of freedom [14, 1] viz. Microscopic, Macroscopic and Mesoscopic models. Each of these types can be further classified into discrete, continuous and mixed models based on spatial discretization. Out of these models, continuous models can be explained either in a deterministic manner or in a stochastic manner. Stochastic models can be again categorized into rule-based, force-based and hybrid models. The general classification of pedestrian models is shown in Figure 2-1.

2.2.1 Microscopic models

The concept behind a microscopic model in pedestrian dynamics is that the complexity of the entire problem can be reduced to the movement of individuals instead of the crowd as a whole. However, the disadvantage here is that the dynamics arising out of a crowd movement cannot be accurately predicted by the dynamics of an individual. This is especially true in phenomena like turbulences and stop-and-go waves.

In general, microscopic models can be classified into discrete, continuous or mixed models depending on whether the variable is of the space, time or state type. The most famous models in pedestrian dynamics are the spatially discrete rule-based models [15, 16], spatially continuous rule-based models [17] governed by pedestrian reactions, force-based models [14, 18, 19] defined by ordinary differential equations (ODE) and hybrid models. In spite of the categorization it is difficult to distinguish between force-based and rule-based models. We just consider models where the dynamics are dominated by the defined forces as force-based models and those models where state variables are affected by spatial decisions as rule-based models. Most models based on Newtonian dynamics assimilate rules to negate side-effects inherent to the main motion equation.

2.2.2 Macroscopic models

In large public events, e.g.: music concerts and Hajj, freedom of movement of an individual is constricted within high density regions and so the usage of a physical analogy of gases and fluids to describe human crowd behaviour is justified. Herein, aggregate variables like the density and flow of the crowd come into play [14]. This method of observation of the state of a system as a whole entity is called the
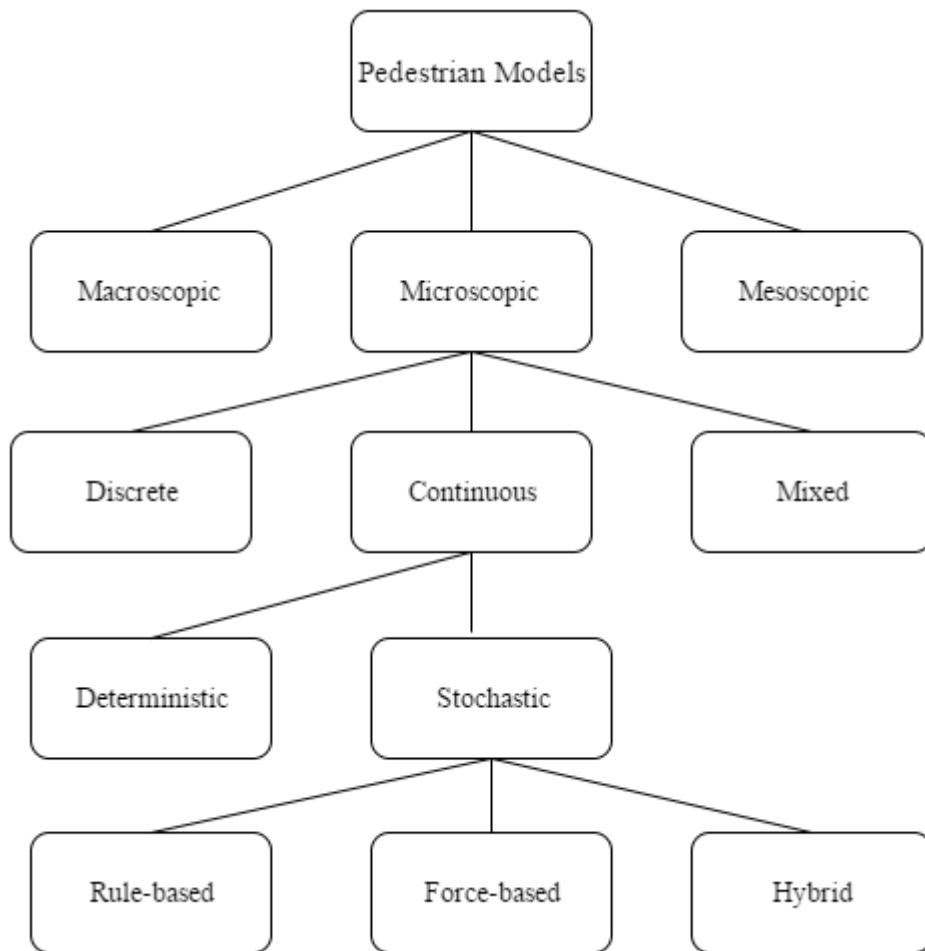
Figure 2-1 Pedestrian model classification

macroscopic model. These models are accurate to a certain degree in finding out the average inflow and outflow in extremely crowded situations. However, conservation laws like momentum and energy cannot be accounted for in a human crowd and so their ability to describe less dense situations, where the degree of freedom of individuals is not so restricted, is questionable.

Further information regarding macroscopic models can be found in [20, 21, 22].

2.2.3 Mesoscopic models

Mesoscopic models, on the other hand, fall somewhere in between micro and macroscopic models in that they group a bunch of homogeneous elements together and analyse for the behaviour of these tiny groups. Further information about mesoscopic models can be gathered from the paper [23].

2.3 Routing Strategies

A route defines the way or course taken in reaching a destination point from an initial position. For an accurate reproduction of pedestrian behaviour in computer simulations, route choice of pedestrians and the underlying factors, like the crowd density and the history of pedestrians which made them choose the route need to be considered. However, these factors cannot be measured directly. This is because many simulations start with the pedestrians already assimilated into the crowd without taking into account the act of them entering the crowd and their memory of route choice. This may indeed have considerable influence on their exit choice behaviour. Keeping this in mind, we categorize paths into objective and subjective groups as shown in the Table 1. During evacuation, the inherent nature of the crowd is to choose the quickest path i.e. the path with the least possible time to reach a destination. However, the ability to choose this path depends on certain factors such as familiarity with the surroundings. In the absence of this, the instinct of the pedestrians is to follow the crowd in front but this could lead them to jeopardy if followed pedestrians commit an error. The aim, therefore, is to model the quickest path by methodical avoidance of congestions. Cellular Automata (CA) models use enhanced dynamic floor fields to achieve this. Density in front of the moving pedestrians [16], distance to exits [24, 25] and navigation fields [13] constitute the enhancements. Continuous models generally use a set of destination points to optimise the Travel time. This method of construction of a network of predetermined

or adjustable destination points is called the graph-based routing. In [26] the Hamilton-Jacobi-Bellman equation is solved to yield the optimal path for pedestrians at each time step. In [27] however, a graph-based routing system is combined with Cellular Automata and by employing a heuristic A*algorithm [28] which computes the fastest path. [29] employs visibility graphs and the Dijkstra method to determine the route of pedestrians while [30] uses a queue principle to find the optimal paths for pedestrians.

Table 1 Examples of path type classification inside a facility and possible influencing criteria. The table is taken from [1]

	Type	Criteria
Objective	Shortest path (global, local)	exits in sight range, signs, experience, etc.
	Quickest path	jam in sight range, experience, etc.
	Given path	Directives from signs or panels, personal, etc.
Subjective	Pleasant Path	design, clarity, lighting, exp--erience, emotional state, etc.
	Safest path	Experience, overview, walki--ng in group, etc.
	Known path	experience, overview, identification of signs, etc.

2.3.1 Graph construction

To construct a graph, we use nodes to connect decision areas. A decision area in the real world can be thought of as exit doors and passageways where, a pedestrian needs to make a decision about his/her next move. Connecting all the nodes from the first decision area to the last decision area in order gives us the graph/network.

To determine the optimal path, we use the Floyd-Warshall algorithm but, optimal path is only possible in case of non-congestion. In such a scenario, the global, the shortest and the quickest paths are all the same. Additionally, each node of the graph provides the following information:

- connected nodes and distances,

- distance to all final destinations,

- shortest paths to reach all final destinations.

2.3.2 Shortest path

2.3.2.1 Local shortest path

When pedestrians are unaware of the global information, the local shortest path is chosen. This means that pedestrians are only conscious of the nearest node and so they follow the exit signs in the facility from one node to the other until they reach the nearest exit. This is generally applicable for first time visitors of a stadium.

2.3.2.2 Global shortest path

When pedestrians are familiar with the facility, for e.g. regular sport spectators, the global shortest path offers the most appropriate strategy. This allows a pedestrian to choose the shortest path to the final destination irrespective of their location in the facility. An example for this technique is the Floyd-Warshall algorithm.

2.3.3 Quickest path

The quickest path technique is dynamic in nature and tends to vary with time. In this, pedestrians first start with the shortest path technique (either global or local, depending on their knowledge of the facility) but when jams/congestions arise, are rerouted to reach the nearest exit in the fastest time possible. In other words, the variable in this technique is time and we endeavour to dynamically end pedestrian movement in the shortest time possible.

Other path finding strategies like the heuristic approach, probabilistic choice method and straight and long legs (SALL) method also exist. More information regarding these strategies can be inferred from [31].

Chapter 3   Methodology for Experiment

In this chapter, requirements to perform the BaSiGo experiment virtually are dealt with and how to carry it out is explained.

3.1 BaSiGo Project

Safety is of paramount importance in the modern world, especially so in large public events. Tragic incidents from the recent past, like the Love Parade in Duisburg, show us how critical a proper security planning of an event is. However, the varying complexity of the events makes it that much more difficult to use the standard safety concepts.

Project BaSiGo, an undertaking by the German Federal Ministry for Education and Research (BMBF), aims to bridge this gap by developing a basic modular approach for planning and evaluating large public events. To achieve this, BMBF has collaborated with universities and research institutes like Forschungszentrum Jülich to plan and execute large-scale laboratory experiments, sometimes involving test persons to the tune of a 1000. Extraction of pedestrian trajectories as well as developing methods to analyse and model pedestrian flow using computer simulations form part of the experiments. Efforts have also been made to integrate results of previous research projects like Hermes and EVA.

Of particular interest to us is the scientific identification and eventually, incorporation of design parameters into the basic modular concept of BaSiGo. The objective is to realize these parameters in controlled laboratory conditions to the extent that they can be used to improve computer simulations in finding out congestion areas in advance, thereby allowing event organizers to plan the event accordingly.

The experiments would be the world's largest of its kind. For the implementation, they have sought up to 2,500 subjects and additional helpers. The allowance amounts to 50 € per person per day. The experiments were conducted at Messe
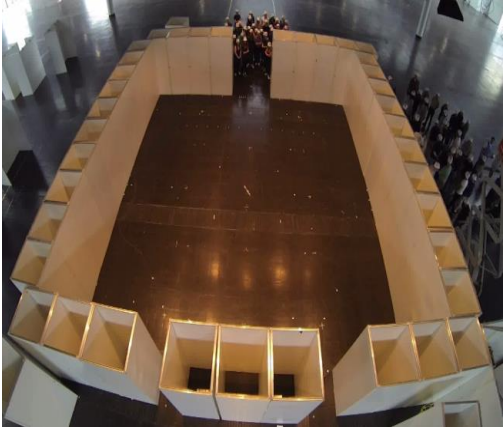
Figure 3-1 BaSiGo experiment

Dusseldorf, hall 14, Pedestrian Entrance East Stockumer Kirchstraße from 19/06/13-22/06/2013 [32].

Out of the pool of the experiments conducted from this project we have chosen one experiment for this dissertation work. The experiment chosen for this dissertation is shown in top left side of the Figure 3-1.

3.2 Requisites for VR

Using the following tools, we modeled the experimental set-up in VR, conducted it on voluntary participants and analysed the results in comparison with real world results.

1. Google Sketch UP
2. Vizard, a VR software
3. Oculus Rift headset
4. Input controller
5. R, a data analysis software

3.2.1 Google SketchUP (GSU)

GSU is a simple and user friendly modelling software that enables users to be 3D designers. GSU can be used for a wide range of applications such as architecture, 2D layouts CAD designs, civil and mechanical Engineering and so on. This software was initially developed in 2000, was later acquired by Google in 2006 with the first free version of the software getting released in the same year in the month of April. At present this software is owned by Trimble Navigation and its free version is available as SketchUp Make, while it also has a paid version with additional features in SketchUP pro. As for normal usage GSU free version is enough to model designs.

GSU has the following advantages and uses from other design software:

1. The software is available freely for students and others.
2. This has additional functionality for importing 3D geometries from 3D ware house.
3. It's easy to use and is available as an open source.
4. Additional support from Extension ware house to import 3D geometries from Google earth is provided.

5. Easy to create and use textures for the 3D models.

6. Easy to present mathematical concepts and geometry visualization.

7. We can use Building footprints captured from Google Earth.

8. We can draft the models easily here.

3.2.2 Vizard

Vizard is a virtual reality software used to provide 3D visualization and simulation applications and is owned by WorldViz. This software is freely available in market. The execution time of free software is limited to 5Mins and comes with a water marked label. 3D visualization finds application in product visualization, human behavioural and perception research, safety training, architecture visualization, and other fields of research interest.

Vizard software has support for input and output devices, including head-mounted displays, Caves, Power walls, 3D TVs, motion capture systems, Haptic technologies and Gamepads. Vizard interface uses Python for scripting and OpenSceneGraphics (*. osgb format) for representing visual graphics in VENV.

It also has a hardware support of Precision position tracking (PPT). PPT is used for real time motion tracking in virtual reality applications. It is used to track motion for large areas and six degrees of freedom. It also incorporates a hand cooperation device that gives clients a chance to explore and control virtual scenes and virtual items. Additionally, a pair of remote 3D glasses following framework for overhauling a client's perspective in conjunction with CAVE or Power walls 3D show frameworks. The motion tracking system used for this dissertation work is shown in Figure 3-2.

Figure 3-2 Motion tracking device

Vizard software has the following features and tools

1. Vizard Inspector to quicken advancement of virtual universes with a coordinated proof reader and editor for Vizard open scene graph compatible 3D models.

2. Vizconnect tool to effortlessly coordinate with presentations, headsets, trackers and information gadgets utilizing the visual arrangement interface.

3. Full access to open-source group libraries and tool boxes - For Python scripting.

4. Real-time directional, ambient and spot lights and shadows.

5. Consolidate virtual and physical reality utilizing the augmented reality toolkit module.

6. Additionally, it has some advanced features like

    i) a Physics engine for simulating high rigid body dynamics and robot applications

    ii) SDK/Expendability

3.2.3 Oculus Rift headset

Oculus Rift is perhaps the most famous VR headset of the present day. It was developed by Oculus VR, a startup founded specifically for the development of the device. The company was later purchased by Facebook for about $2 billion. Starting as a Kickstarter campaign, Oculus Rift proved immensely successful among individuals and companies who saw potential in Virtual reality and was eventually able to attract $2.5 million of funding.

Over the course of the last 4 years since the concept's inception, many pre-production models were developed out of which five were demoed to the public to gather feedback. Two models were also sent to developers to develop apps and interactive content in time for the Rift's release. Owing to the positive feedback received from tech circles, these development kits saw impressive demand from enthusiasts who wanted to try out the preview technology. We are using the Oculus development kit 2 for our work. The sample figures of a person wearing the Oculus headset and inside view of the headset are shown in Figure 3-5, Figure 3-3 and Figure 3-4.

Figure 3-3 Oculus Rift headset (www.occulus.com)

Figure 3-4 Oculus Rift headset -Backside view

Figure 3-5 Participant wearing oculus headset

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Coming to the technical specifications [33], we are looking at an angle of view of 110°, integrated headphones to create a 3D audio effect and an OLED display resolution of 2160 x 1200 with a refresh rate of 90 HZ. The Rift has a position tracking system as well called the Constellation which uses an infrared sensor to pick up the light emitted by IR LEDs. The senor is usually setup on the user's desk to create space for the user to move about freely while using it.

The minimum specifications required for Oculus Rift DDR2 is [33]:

Video Card NVIDIA GTX 970 / AMD 290 equivalent or greater

CPU Intel i5-4590 equivalent or greater

Memory 8GB+ RAM

Video Output Compatible HDMI 1.3 video output

USB Ports 2x USB 3.0 ports

OS Windows 7 SP1 or newer

3.2.4 Input controller

Normally in pedestrian simulations, input controller plays an important role. The steering behaviour is remarkably dependent on the type of input device used. In practice we can use

- Human interruptible with sensors
- Touch pad sensors
- Gamepad with wire or wireless controller

Figure 3-6 Input device- Gamepad controller

For our dissertation work we have used gamepad as an input controller for steering inside the VENV because of the cost, handling and installation of the device. The gamepad used in our case is shown in Figure 3-6.

A gamepad is also called joypad or controller. It is used to provide input with the help of thumbs. It has two joysticks. The upper one is used to move front, back, left and right. The lower one is used for the rotational view of the VENV.

3.2.5 R, a data analysis software

R is a software developed by Bell Laboratories for statistical and graphical computing. It packages many techniques, both graphical and statistical, such as time series analysis, linear and non-linear modelling, clustering etc. In this dissertation work, R along with Python3 are used to analyse data from the experiments. Quoting [34], R has the following features and tools

- An effective data handling and storage facility,
- A set of operators for calculations on arrays, especially matrices,
- A large, coherent, integrated collection of intermediate tools for data analysis,
- Graphical facilities for data analysis and display either directly at the computer or on hardcopy, and
- A well-developed, simple and effective programming language (called 'S') which includes conditionals, loops, user defined recursive functions and input and output facilities. (Indeed most of the system supplied functions are themselves written in the S language.)

R is not just another data analysis software, it is a full software environment with a planned, coherent system in addition to specific tools. Over the years, it has developed into a Launchpad for new data analysis methods.

Chapter 4   The VR Experiment

This chapter deals with the methodology involved in creating the setup and conducting the experiment.

4.1 Model setup

The fiction of the spatial geometrical environment plays an important role in pedestrian simulations. The quality of the model determines the accuracy and validity of the pedestrian simulations. Depending on the simulation situations, the geometry varies. For instance, the geometry is straight for aircraft and circular for stadiums, some of the virtual and real created models are shown in Figure 4-1.

I. Movie theatre (http://stadiumseating.com/)

II. Building with roads (http://www-personal.umich.edu)

III Football Stadium (http://www.wembleystadium.com/)

Figure 4-1 Different geometry models

The aim of this project is to study the exit choice behaviour of pedestrians. For this purpose, the same exact geometry depicted in the top left side of the Figure 3-1with

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two exit doors was chosen. The virtual model for our dissertation work is shown Figure 4-2.

(I)

(II)

(III)
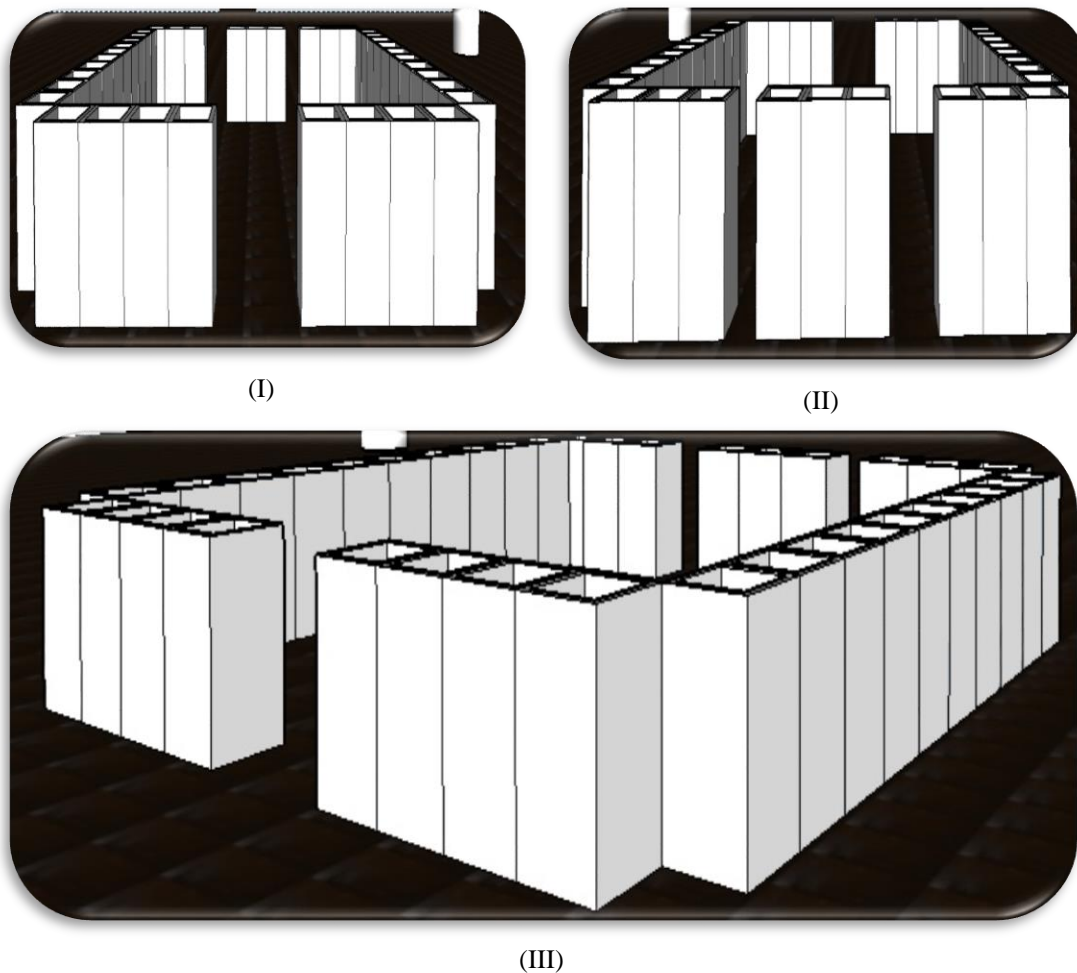
Figure 4-2 Geometry of experimented model. (I) ISO Metric view. (II) Front view. (III) Back view

The virtual geometrical model for VENV was created using GSU Make Software. A detailed procedure to build the 3D model is discussed in [35, 36, 37]. The specifications and 2-D figure of the geometry of the model are shown in the Table 2 and Figure 4-3.

Table 2 Specifications of the model

S. No	Specification	Units/Number
1	Length of the Experimented room	10m
2	Breadth of the Experimented room	10m
3	Height of the Experimented room	2m
4	Number of Exits	2
5	Length of the Exit door 1	0.7m
6	Length of the Exit door 2	1.1m
7	Number of Entrances	1
8	Length of the Entrance	2m
9	Each Cube Dim	1x1x2m
10	Length of the Hall	50m
11	Breadth of the Hall	50m
12	Height of the Hall	5m
13	Length of the Whole Room	80m
14	Breadth of the Whole Room	100m
15	Height of the Whole Room	10m

Figure 4-3 2-D Geometry of the experimented room

Figure 4-4 Final geometry of the virtual model

After completing the construction of the basic sketchup i.e. the skeleton of the virtual workspace, the next step is to bring similar real working environment into VENV. This includes importing the pictorial view of the re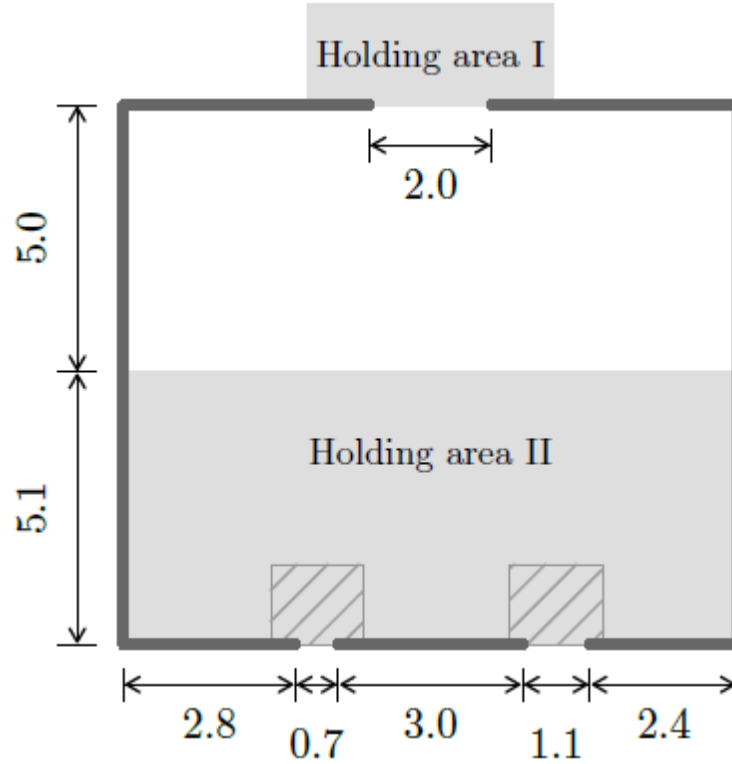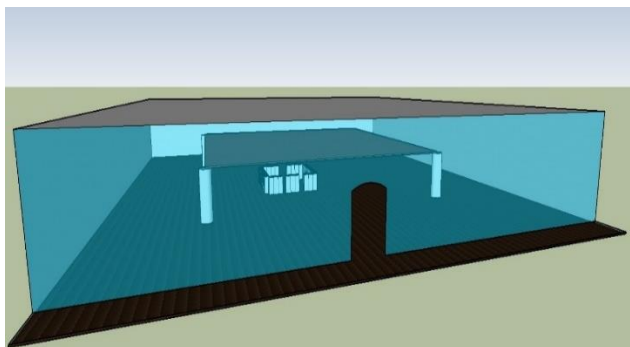al work space and integrating into virtual reality workspace in the form of a COLLADA file (*.dae format). After successfully creating the workspace in GSU, it is validated in Vizard inspector and the final geometry is exported in *. osgb format, for further performing of VR experiments and is shown in the Figure 4-4.

4.2 Method

The virtual walking experiments were conducted in a room at the faculty building of Civil Engineering, University of Wuppertal and at Jülich Research Centre. The experiments were carried out totally in 4 days at two places in two phases; one was from 9:00am - 12:00pm and another 2:00pm - 4.00pm. At first place, i.e. at University of Wuppertal 25 people participated, 14 participated in the first phase and rest in the second phase. At the Jülich research centre 11 people took part in the experiment, 7 people were in the first phase and remaining in the second phase.

4.2.1 Participants

The total number of voluntary participants for carrying out our test runs is 36. The participants were either students or faculty members, and were either from the University of Wuppertal or from Jülich research centre. Out of 36, 10 participants were female and the rest were male. The participants are young (<25), middle aged group (<50) and a few of them are seniors (>60). No participant had prior knowledge about virtual environment and hypothesis of the experiment. All participants had normal or corrected to normal vision. One participant (male) had to be excluded because of dizziness during the first trial of the experiment. The participants lacking in our experiments are teenage persons (<20) and children.

4.2.2 Virtual environment

The virtual environment was generated by using Vizard VENV Libraries. The VENV consists of a big room with a hall of textures similar to the real model as shown in Figure 4-5. In that hall the experimented room was created with a dimension of 10×10×2m. The experimented room has two exits with 0.8m and 1.1m, entrance 2m and virtual avatars were standing at the entrance door. We will use the same environment 6 different times for one complete experiment. Each time the Virtual Avatars at the entrance door vary from run to run. The number of avatars

(A)

(B)

(C)

(D)

Figure 4-5Virtual environment view in perspective of a participant

I. (A) and (B) with 40 pedestrians starting and middle position

II. (C) and (D) with 18 pedestrians starting and middle position

standing in-front of the door in each run is either 40 or 18. An experimental session always started with the participant 5m away from the entrance of the experimented room. Figure 4-5 shows the participant's view from the virtual environment.

4.2.3 Experimental setup

The basic virtual experimental set up for our work is shown in Figure 4-6. To begin our experiment with virtual reality there are certain prerequisites which have to be met. The primary requirements include

1. Personal Computer having windows 7 or higher version of OS installed with python and Vizard software.
2. Hardware devices: Oculus headset and Gamepad. Both must be connected to a personal Computer
3. Code developed for VENV (In our case, the code was developed in Vizard)
4. Code for linkage between hardware devices and the virtual environment setup.
5. Input trajectory files having positions of the remaining pedestrians from the BaSiGo project.
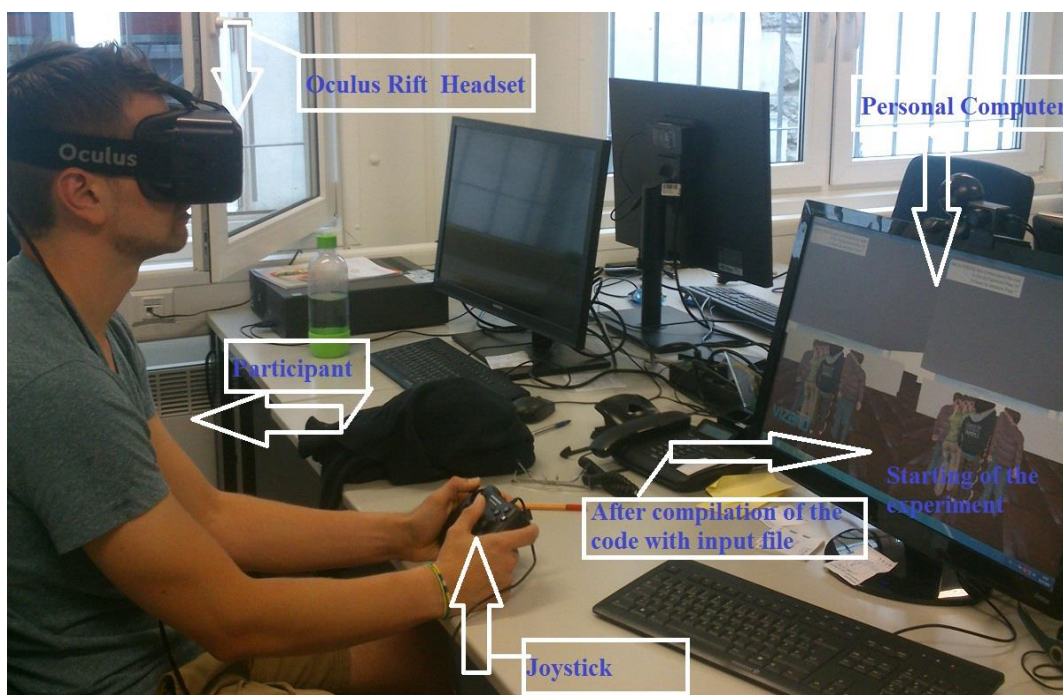

Figure 4-6 General overview setup of the VE

After connecting the devices and installing software packages on the PC for the experimental setup, the virtual environment was presented on a standard 19" PC screen. Participants sat before the screen on an office chair from a distance of roughly 70cm. Using a standard gamepad, they controlled through the virtual environment. Translation and rotational speed could be balanced independently by the two simple controls. Maximum rotation velocity was $26°$ per second. All participants had time to get familiar with the gamepad initially, but were not allowed to steer inside the experimented room before the start of the experiment.

4.2.4 Experimental procedure

The general flowchart of the working procedure of virtual experiment is shown in Figure 4-7. The procedure of the experiment is explained below:

4.2.4.1 Before experiment:

Before doing the experiment, participants are asked to read the statement of agreement and agree to it. The statement of the agreement states that with their signatures they allow the experimenters to evaluate the data collected by this study for scientific purposes. Furthermore, they confirm that they have been told about the study, its procedure and possible risks related to the participation in the study and that they are participating at their own risk and by own choice. If they feel unwell they can cancel their participation at any time. All data and statements will be edited and evaluated anonymously and can never be related to them.

4.2.4.2 Experiment procedure:

The pre-calculated trajectory results of the BASIGO Experiment are simulated in the virtual environment. A human participant is allowed to interact with the virtual simulated subjects, introducing himself as an avatar and this avatar can be controlled using the input device. Before commencing the experiment, certain instructions are to be followed, which are mentioned below:

1. The experimentee has to wait until all the avatars enter the experiment area

2. While doing the experiment the participants are not allowed to hit the other avatars.

3. The participants can over-take the other avatar only if sufficient space is available for one person to walk through it.

After finishing the formalities stated in the section 4.2.4.1, the experimenter will present the participant what to do in the experiment. Each experimentee has to do the experiment for 6 different runs with a different trajectory input file of the BASIGO experiment in each run. Each trajectory file contains data of really conducted experiments. i.e. 40, 40, 18, 40, 40 and 18 avatars. The experimented person is the last person of all the avatars and he has to complete the experiment without violating the instructions as stated earlier. The experiment will begin by pressing the predefined start button - 'm' button on the keyboard.

The main aim of the experiment is to wait in front of the entrance door and wait until all the avatars start to move and follow the avatars to exit the room from one of the two exit doors. During the experiment after finishing each run the experimenters will ask questions regarding the exit chosen of the pedestrian. He or she has to repeat the run for 5 more times for different trajectory files of pedestrians. During each run the trajectory followed by the experimentee is exported as a text file for further research.

4.2.4.3 After Experiment:

After completing the experiment successfully, the experimentee has to fill a questionnaire form. This form includes the experimentee identification details; the experimentee ID number, gender details, age, his decisions for choosing exits for different runs and his feedback about the virtual reality experience. This questionnaire is for the sole purpose of feedback for later study by the researcher.
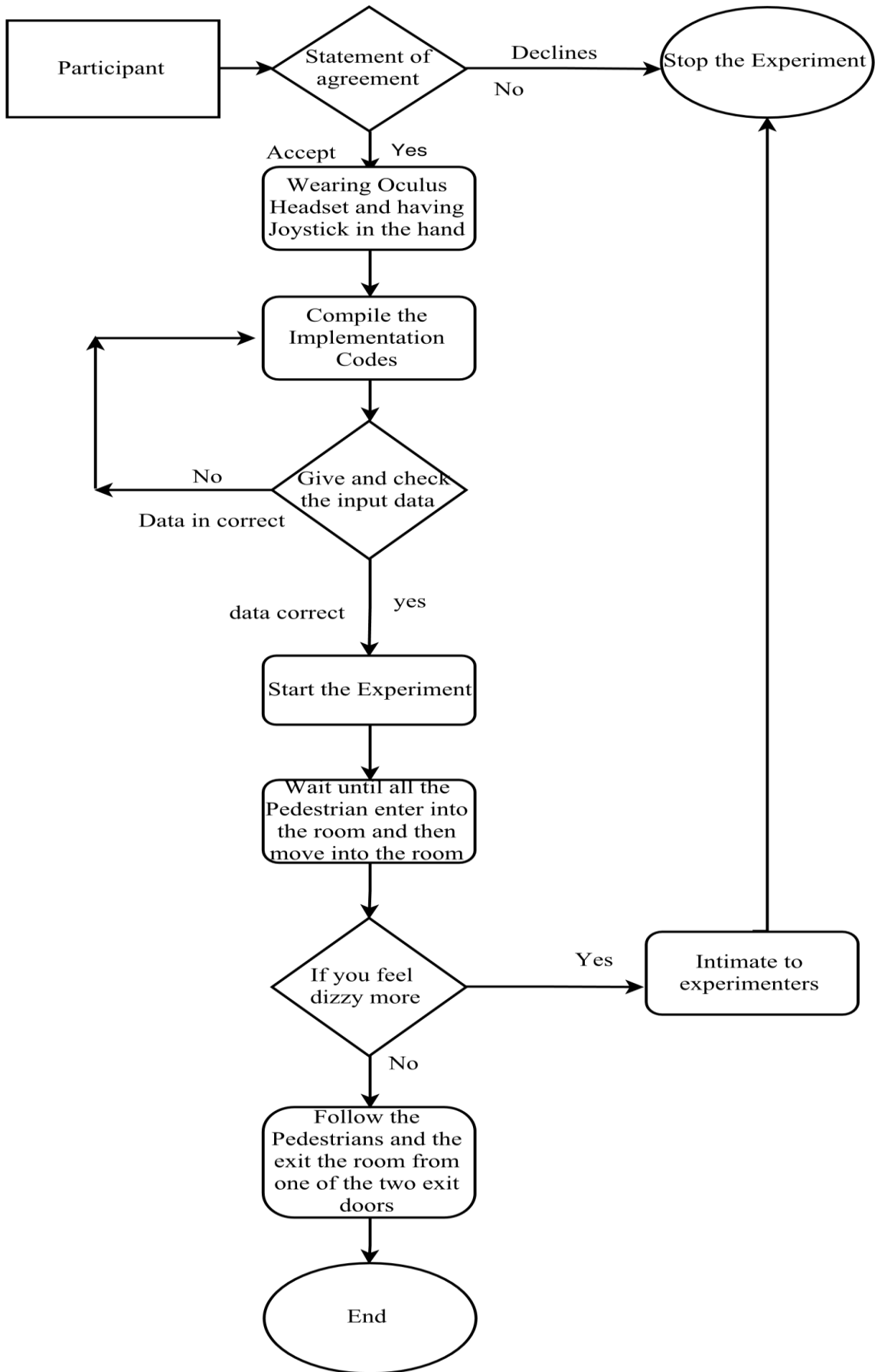
Figure 4-7 Flow chart for working procedure of VE

Chapter 5   Study Analysis of VR

In the previous chapter the VR experimental setup and the procedure of VR experiments were explained. In this chapter the exit choice behaviour of pedestrian is analysed using Linear discriminant analysis.

5.1 Results from Questionnaire Form

All the virtual experiments were carried out in 4 days, i.e. 24th Feb, 26th Feb, 14thMarch and 26th July. The data and questionnaire forms were collected for all runs of the experiment. At first the data from the questionnaire forms was analysed.

In this Questionnaire form we had asked the following questions, in-order to study the influence of certain characteristics on the behaviour of pedestrians during the experiments.

1. How often they play video games? If they do, what kinds of games they play.
2. The difficulty level in handling the input controller (On a scale range of 1-6; 1- Too Easy; 6- Too Difficult)
3. How do you feel after the experiment? (Means dizziness level after doing the experiment in scale range of 1-6; 1- Well; 6- Unwell)
4. Reasons for his or her exit decision.

5.1.1 Input device handling

In our experiment we had used a gamepad as an input device for navigating the VENV. Out of 36, 11 participants never played video games, 6 participants play rarely, 4 participants play frequently and the remaining participants play regularly. Participants who never play video games and who play frequently found it easy to handle the input device, whereas participants who rarely play video games had little difficulty in handling the device.
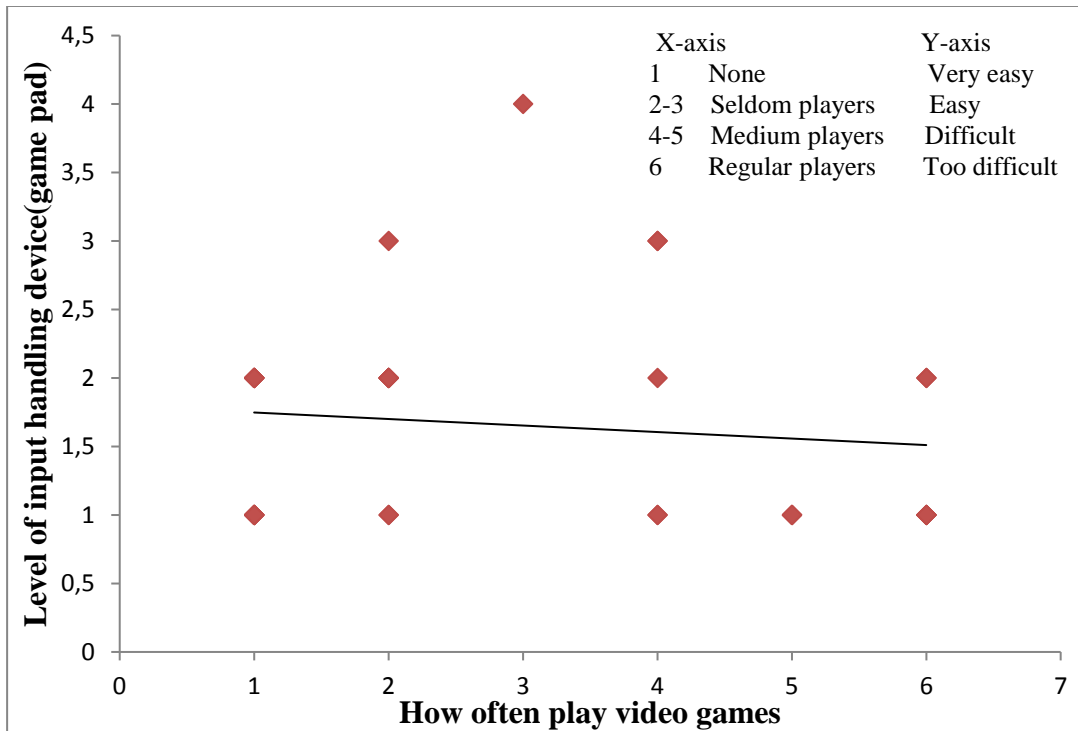
(I)
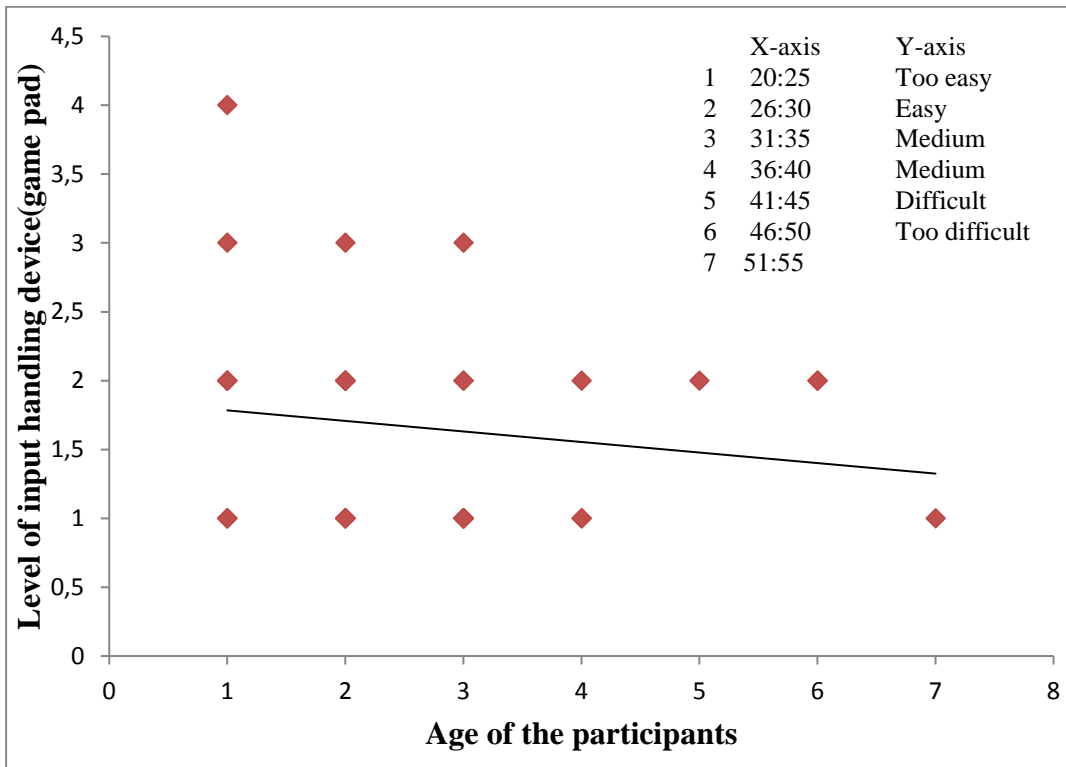
(II)

Figure 5-1 Input handling of the device with respect to the (I) how often play video games and (II) age of participants

The Figure 5-1-I represents the scatter plot between how often participants play video games and the difficulty level in input device handling. From the figure it is clear that there is no linear relationship between the parameters. The correlation factor for the scatter plot is 0.12 which means that there is a very weak dependency between both parameters. The dependency is a weak uphill linear relationship. The Figure 5-1-II gives information about the age of the participants and the input device handling. The correlation factor is -0.15 which means there is a very weak downhill linear dependency between the parameters.

From the Figure 5-1 and the correlation results, we found that there is no correlation between the age of the participant or how often they play video games and the handling of the input device. Thus, we can mainly exclude that differences in the behaviour of the probands are caused by the input device.

5.1.2 Dizziness level

Dizziness means person having a sensation of spinning around and losing one's balance. It discussed here since during the course of further research participants will be required to walk around the simulated room to perform the study. But in reality the participants would be sitting before a computer. Because of this imbalance the participants might feel a little dizzy. In our VE's one person completely stopped the experiment because of dizziness after the first run of the experiment.

The participants who play video games frequently had very little uneasiness whereas 50% of participants who never played video games had dizziness, the remaining 50% felt well. 75% of participants who do not play video games frequently had dizziness. The Figure 5-2-I represents the relationship between how often participants play video games and dizziness level after finishing the experiment. From the figure it clearly shows that only 40% of participants felt nothing and the remaining 60% felt little dizzy after finishing the experiment. In the 60% of participants 20% of the participants had high dizzy levels. The correlation factor for the scatter plot is 0.31 which means that there is a dependency between both parameters. The dependency is a weak uphill linear relationship.
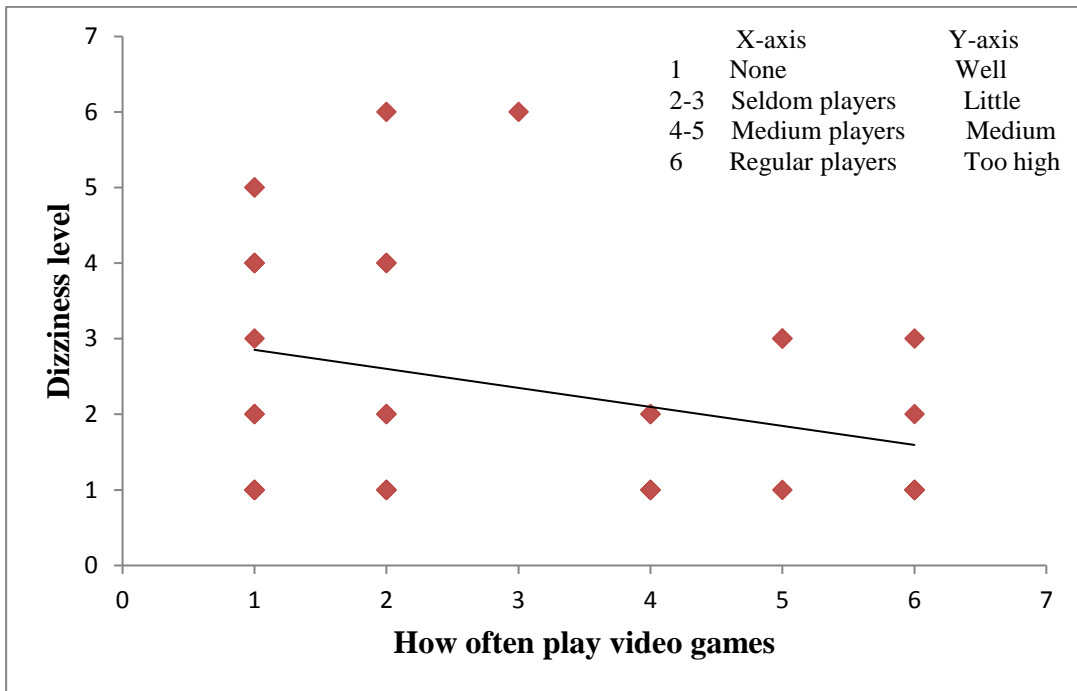
(I)
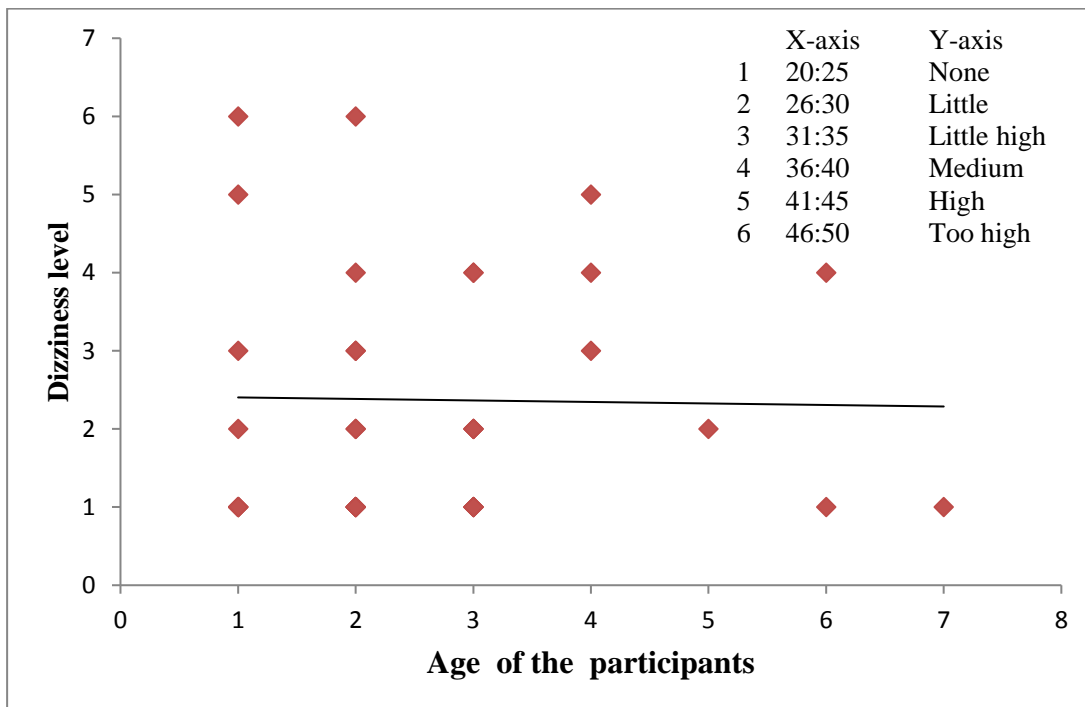
(II)

Figure 5-2 Dizziness level of participants with respect to the (I) how often play video games and (II) age of participants

The scatter plot of the Figure 5-2-II describes the relationship between the age of the participants and the dizziness level. The correlation factor is -0.018 which means there is no dependency between the parameters. The age of participants doesn't reflect on their dizziness level as it clearly shows that the correlation factor is nearly equal to 0.

5.1.3 Reasons for choosing exit choice of pedestrian

While carrying out the experiments, each participant has to choose one of the two exit doors. After finishing each run of the experiment the experimenter inquired for the reason for choosing his or her exit. The reasons stated by the participants are given below:

1. 29.04% of the participants' runs culminated in the decision to fill gaps or spaces inside the room, they filled the gaps so that they can exit the room faster

2. The second most taken decisions by the participants was by observing the number of people (density) on a side (less or more) with about 22%.

3. By watching the queue in front of the doors (How fast it is moving, travel time of the queue) they change their decisions. It amounts to 10% of the runs.

4. By noticing the door size difference in 9.52% of the runs participants opted for another exit.

5. In 8.57% of the runs, participants made intuitive decisions.

6. By following the behaviour of predecessors (i.e. If more predecessors chose one exit he or she shifted to another or simply standing, etc.) the participants changed their mind to another exit in 7% of the runs.

7. By the combination of 1st and 2nd reasons 4.28% runs resulted in jumping to the other exit.

8. Some participants didn't change their mind (Started on one lane so stayed on first lane) in 5.71% of the runs

9. The rest of runs yielded strange decisions, namely,

   a. Sticking to the decision from the first run in their subsequent runs as well.

   b. First observed how people are going and then took the decision.

   c. Following opposite genders, colour of the dress ...

5.2 Distance to exits

The path travelled by the virtual pedestrians from experiments carried out in Chapter 4 is shown in Figure 5-3. The figure gives information about routes of virtual pedestrians describing their distance to the exit doors viz. (exit1 and exit2).
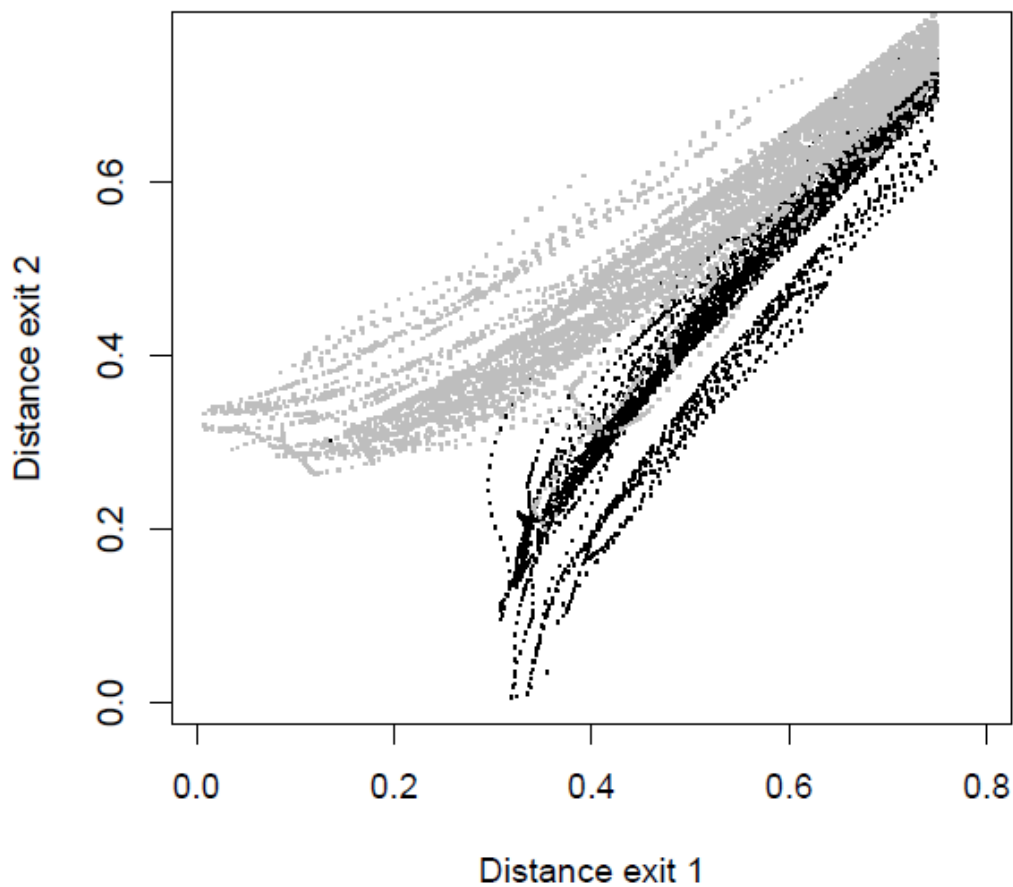

Figure 5-3 Virtual pedestrian path to their exit distances. The unit in this figure is meter

5.3 Linear discriminant analysis

Linear discriminant analysis (LDA) is a technique used to reduce dimensions in the pattern-classification and machine learning applications during the pre-processing step. The LDA was defined by Ronald A. Fisher in 1936 (Use of Multiple Measurements in Taxonomic Problems), and it is also used in other applications as a classifier. The first LDA was developed for a 2-D problem and was later described as "multi-class LDA" or "Multiple Discriminant Analysis" by C. R. Rao in 1948 [38]. In general, the fundamental method of LDA is quite similar to that of the Principal Component Analysis (for more data about the PCA, see the article [39]).

LDA is based upon the idea of linear combination of variables (indicators) that best isolates two classes (targets). In our case, we propose to create measurable models for the ways chosen by the participants in experiments. The models are analysed by considering distance based and distance-density based models.

In the first case, exit function as a function of distance only is chosen. The discriminant between two exits i and j is

$$Y_1 = \gamma + \alpha_1 D_1 + \alpha_2 D_2 \qquad (5\text{-}1)$$

In the second case, exit function as a function of both distance and density is chosen. The discriminant is given by

$$Y_2 = \gamma + \alpha_1 D_1 + \alpha_2 D_2 + \beta_1 \rho_1 + \beta_2 \rho_2 \qquad (5\text{-}2)$$

Where

D_1 is the relative distance between exit 1 and the maximum distance (d_{max})

D_2 is the relative distance between exit 2 and the maximum distance (d_{max})

ρ_1 is the relative density in the square in front of the exits 1 to the maximum density (ρ_{max})

ρ_2 is the relative density in the square in front of the exits 2 to the maximum density (ρ_{max})

Let Y^1 and Y^2 are the discriminant values for the exits 1 and 2

The parameter estimation $P = f(\gamma, \alpha_1, \alpha_2, \beta_1, \beta_2)$ is estimated by the sum of the discriminant variances chosen by the exit:

$$P' = \arg\min_P \sum_i var(Y^i(P)) \qquad (5\text{-}3)$$

The parameters for the equation (5-3) are estimated by considering the values from an article submitted to the journal [40] with $d_{max} = 12$ m and $\rho_{max} = 6$ ped/m^2. The values are shown in Table 3.

Table 3 Estimation of the parameters for the discriminant variable -Virtual Reality

Model	γ	α_1	α_2	β_1	β_2
Distance based	0.425	14.87	-15.69	-	-
Distance and Density based	0.4804	14.73	-15.6	0.41	-0.47

Note: Number of observations used here to calculate the parameters of LDA is 9268

Table 4 Fisher test P-value -VE

Fisher test $\sigma_{Y1}^i > \sigma_{Y2}^i$	Virtual Experiment
P-value	9.19583e-01

The discriminant substantiates the exit choice either as a function of distance or as a function of distance and density. The choice of the first exit is denoted by a positive value, while negative values denote the second exit (in decision model). However, the sign of the coefficients α_1 and β_1 is positive while that of α_2 and β_2 is negative. In other words, the first and the second coefficients have opposing signs while γ is a constant (either positive or negative). γ lies below the value of 1 indicating that there is no bias as parameter estimations differ from sample to sample.

Histograms of the discriminants calculated over the sample trajectories of experimentees are plotted in Figure 5-4. Percentage of wrong classification is given by the misclassification error. The error shoots up when a distance-density model is used underlining the irrelevance of density (i.e. variability of density is inconsequential). The comparison test for discriminant variances is shown in Table 4
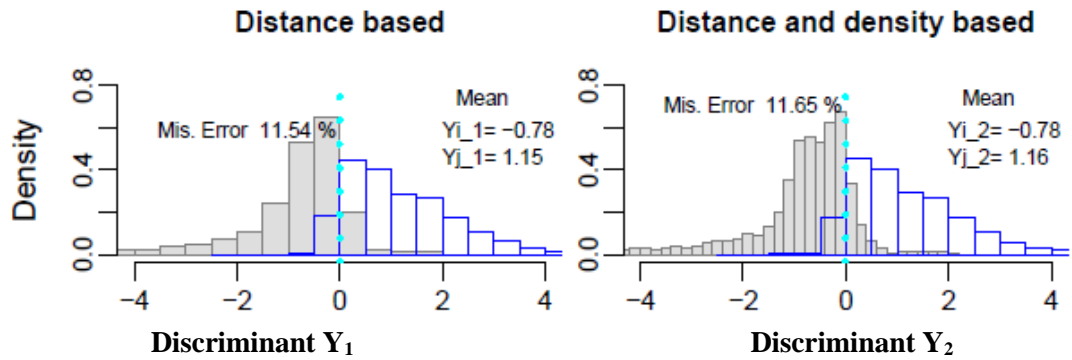
Figure 5-4 Histograms of the discriminant for Virtual Experiment. The grey one corresponds to the discriminant of the chosen exit while the blue corresponds to one of the other exits. I above one represent the distance based II below one represents the distance and density based

(I)

(II)
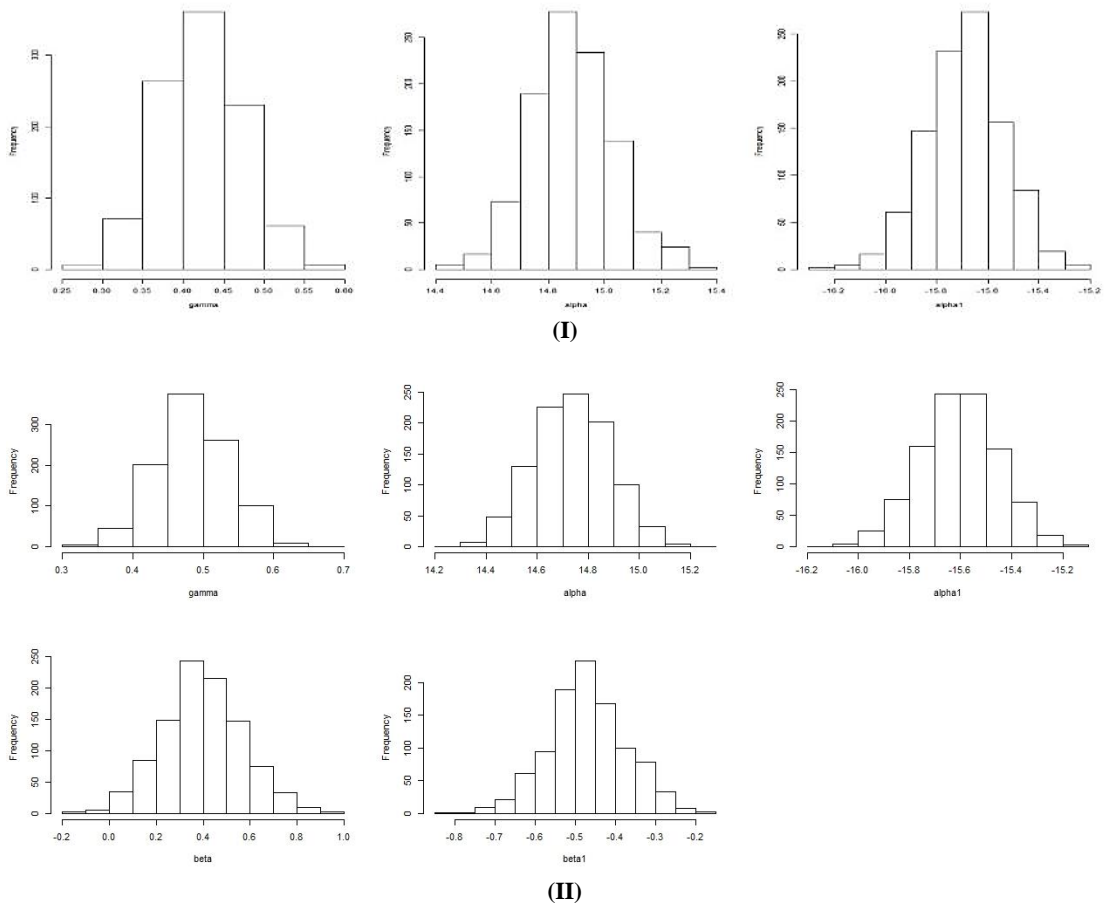
Figure 5-5 Histogram of the parameter estimations (γ, α_1, α_2, β_1 & β_2) on sub-samples of the exit choice model based on I. Distance based and II. Distance and density based

with the p-value returned as 0.9. This again validates the insignificance of density in the chosen decision model.

Histograms of the discriminants for randomly generated subsamples of different sizes limited to the same data are shown in Figure 5-5. From this figure, it is clear that the results are precisely as expected and are negative for one exit and positive for the other.

5.3.1 LDA for different density examination

The coefficients for the equation (5-3) are estimated for different density considerations of the experimented room as shown below:

I. In the first case the room is divided vertically into two and then densities to the left and to the right of the longitudinal vertical axis are considered. It can be seen in the below figure.

II. In the second case I have introduced a lateral axis to cut through the room horizontally and the density of the two quadrants above the horizontal axis are considered and it can be seen in below figure.
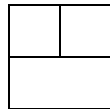
III. In the third case densities of the two quadrants below the horizontal axis are considered which is apparent in the following figure.
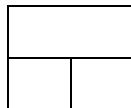
The parameter values and histogram diagrams for the three cases are shown in Figure 5-6, Table 5 and Table 6. As in the previous analysis the values obtained here are positive for one exit and negative for the other. The magnitude of these values are quite similar for distance based discriminant model, but for distance and density based models the parameter values β_1 and β_2 vary from case to case. But despite the fluctuations in the magnitude of β_1 and β_2 from the first half of the room to the second half of the room, overall density coefficients amount to only a tiny fraction of that of the distance coefficients in value. Therefore, it is safe to assume that the density in front is not of much importance in the exit choice to pedestrians. This claim can be further validated by a non-zero P-values obtained from the fisher p-value test which are shown in Table 7.

40
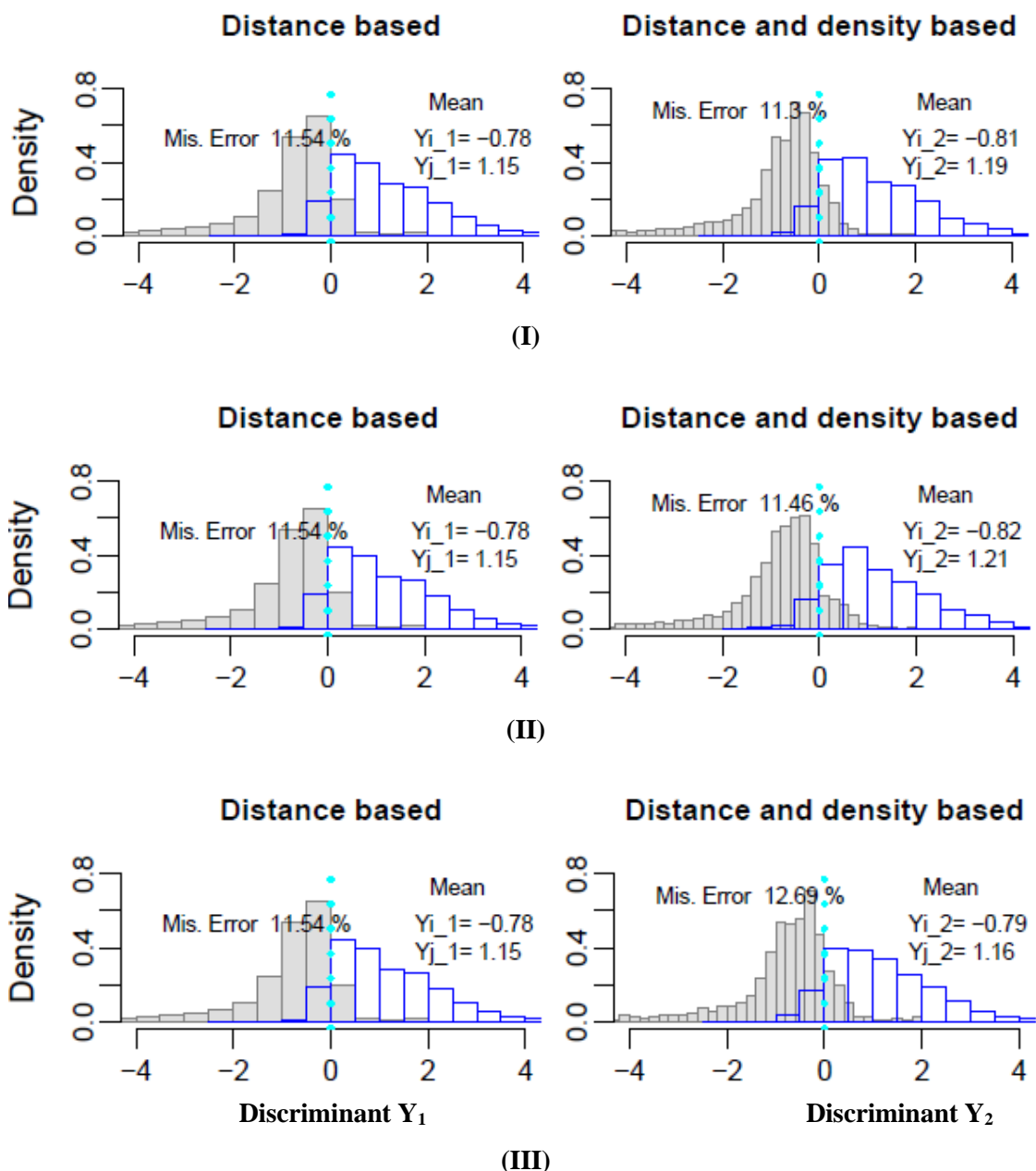
Figure 5-6 Histograms of the discriminant for different density considerations. The grey one corresponds to the discriminant of the chosen exit while the blue corresponds to one of the other exits.

Table 5 Estimation of the parameters for the discriminate variable for different densities (Distance based model)

Chosen density	Distance based		
	γ	α_1	α_2
Case I	0.4255894	14.8780319	-15.6915820
Case II	0.4255894	14.8780319	-15.6915820
Case III	0.4255894	14.8780319	-15.6915820

Table 6 Estimation of the parameters for the discriminate variable for different densities (distance and density based)

Chosen density	Distance and density based				
	γ	α_1	α_2	β_1	β_2
Case I	0.5568615	15.1644836	-15.3312844	2.1876252	-6.2861759
Case II	0.8444788	14.6982358	-15.2805107	1.2865129	-4.3733991
Case III	0.3079561	14.8945300	-15.3333306	1.5869487	-2.8503191

Table 7 Fisher test P-value table for different density considerations

Chosen density	Fisher test (P-value)
Case I	0.5290876
Case II	0.2459673
Case III	0.7951846

Note: Number of observations used here to calculate the parameters of LDA is 10,526.

Chapter 6   Comparison between Virtual and Real Experimental Results

In this chapter comparison between the virtual and real experimental results is presented. This comparison shows the difference between the virtual and real experimental coefficients. It also validates the VR model used in this study.

Table 8 and Table 9 shows the comparison of VE and RE discriminant coefficients. The coefficient sign is similar for both VE and RE, i.e. α_1, β_1 have a positive sign while α_2, β_2 have negative signs in both environments (Here the positive sign indicates choice of the first exit and the negative sign indicates the choice of the second exit). But with regards to the magnitude, VE coefficients are larger from

Table 8 Comparison of the VR and real experimental coefficients based on the distance

Experiment	γ	α_1	α_2
Real	-0.22	9.89	-9.01
Virtual	0.425	14.87	-15.69

Table 9 Comparison of the VR and real experimental coefficients based on the distance and density

Experiment	γ	α_1	α_2	β_1	β_2
Real	-0.36	10.08	-9.06	1.61	-1.45
Virtual	0.4804	14.73	-15.6	0.41	-0.47

Note: The real experimental coefficients were taken from [40]. In the real experimental study, 50 000 observations were used to calculate the coefficients

Table 10 Comparison of VE and RE Fisher Test P-value

Fisher test $\sigma_{Y1}{}^i > \sigma_{Y2}{}^i$	Virtual Experiment	Real Experimental data taken from [40]
P-value	9.19583e-01	1.10e-01

those observed in the real experiments. This difference in magnitude is mainly due to the variation of sample size to the RE (Number of observation or data used). Experimental study [40] validates the argument that the difference in magnitude is attributable to the difference in sample sizes. However, the same signs of the coefficients indicate that the choices of pedestrians in VE and RE are similar.

The histogram comparison of VR and real experimental discriminants is shown in Figure 6-1. The mean value distribution of the VR discriminant (based on distance) is around the values of -0.78 and 1.15, which is slightly closer to the values of -1.67 and 1.4, observed in the real experiments. The mean distribution value of the VR discriminant (based on distance and density) is also around the same values of -0.78 and 1.15, which is slightly closer to the values of -1.69 and 1.4, observed in the RE. It suggests that the pedestrian's choice is similar in both the environments. The misclassification error in VE increases in comparison to the RE due to inexperienced handling of the VR by participants, and also due to the fact that the dynamic condition of VENV is not the same as the real one. The error in VE increases when distance-density model (11.65%) is used compared to the distance only model (11.54%). However, in RE it is exactly the opposite. RE had about 136 participants in a fraction of the observations trying to exit through the doors in the designed room which led to densely congested areas at the doors and obviously, density plays a much bigger role in such scenarios. Thus, the distance density model is more accurate here and the misclassification error lower than in the distance only model. The fisher test value for both experiments is shown in Table 10. As can be seen, the P-value in RE is almost zero which again confirms the importance of density in pedestrians' exit choice.
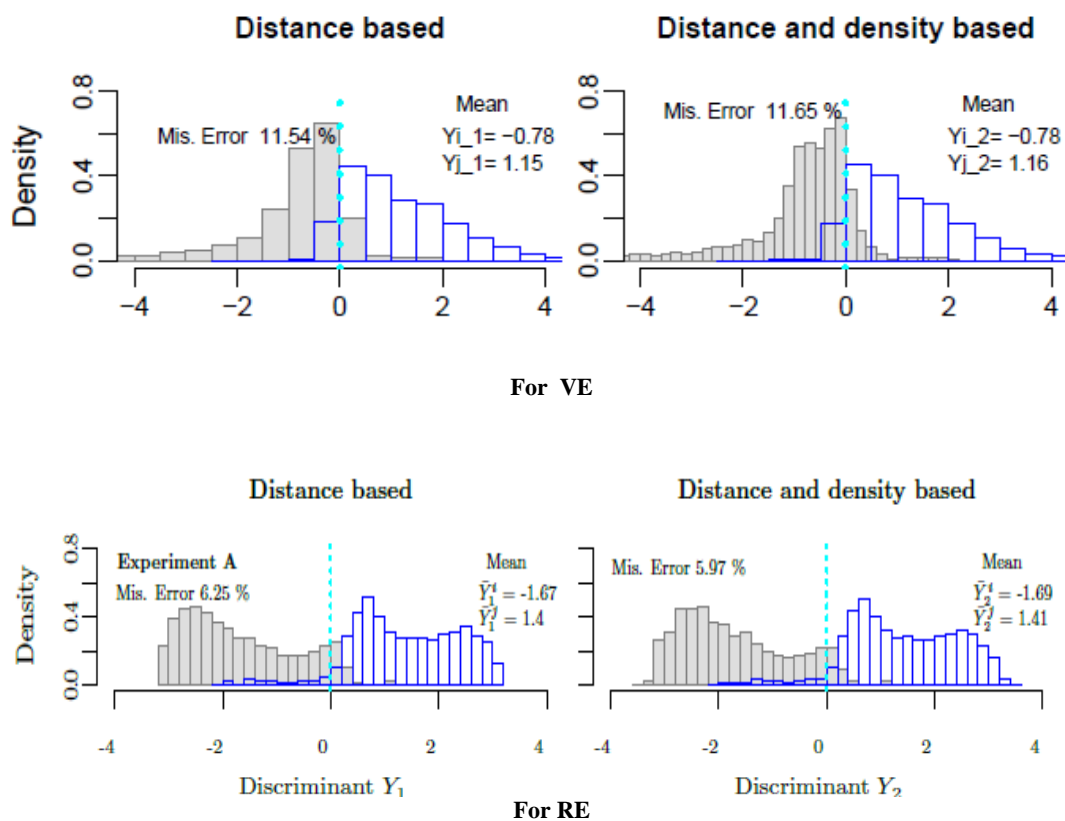
Figure 6-1 Histograms of the discriminant for real experiments, the grey one corresponds to the discriminant of the chosen exit while the blue corresponds to one of the other exit [40]

Chapter 7　　Conclusion and Outlooks

In this dissertation work, the exit choice behaviour of pedestrians has been studied via Virtual Reality. Several conclusions drawn from the study are summarized as follows:

- Almost all the participants are comfortable with VR environment and VR devices (Oculus rift and game pad), even of different age groups. A very few participants had dizziness and head mounted problems. However, future technology should reduce these problems and make these devices comfortable.

- The study shows that 90% of pedestrians are dynamic in their decision making and are willing to change their decisions to another exit door due to various reasons. The reasons given by the participants in changing their exit door from one to another are a) space in the way (29 % of the participants) b) smaller queue (10%) c) larger door size (9.52%) d) intuitive feeling (8.57%). This is in contrast to a very few who were very dogmatic in their approach and stuck to the exit choice decision they first made. Further research might be needed to ascertain if cultural differences play a role in this aspect.

- The comparison of VE and RE parameters show that the VR coefficients have the same sign as the RE coefficients which was expected. But the magnitude of the VR coefficients largely differs from the RE coefficients. However, this difference is not very important because the magnitude of the coefficient varies depending on the number of observations and the number of participants used in the study.

- In the study, the LDA coefficients are calculated based on 1. Distance based model and 2. Distance and density based model. The distance based model produces less error compared to the distance and density based model. So it can be suggested that the distance based model can be preferred for this type of study.

Future Scope

Once the logistics involved are ironed out, VR can be extended to conduct an experiment on multiple volunteers simultaneously with each of the participating subjects populating the experimental floor. This will eliminate the need for modelling of virtual subjects and simulations of their movements. This should provide for a more accurate test finding as each of the pedestrians in the VENV is controlled by a real person and they interact with each other rationally just as in the real world.

Advantages

·   VR experiments are cost effective and easy to conduct.

·   Deadly scenarios can be recreated and analysed under controlled laboratory conditions without posing any threat to the participants.

Shortcomings

Simulation sickness is very real as a fair share of participants felt dizzy after the run of experiments. We might be a couple of iterations away from completely eliminating simulation sickness.

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