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Towards a Framework for Analysis of Human Behavior in VR-based Applications

Master's thesis

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Inimkäitumisanalüüsi raamistiku arendamine VR-põhistele rakendustele

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Declaration

I declare that I have composed this work independently. All the creation of other authors used in the given work has been cited. The present work has not been submitted for any degree or examination elsewhere.

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[14th May 2019]

Annotatsioon

Virtuaalreaalsustehnoloogia populaarsuse kasv on käesolevel aastakümnel paljuski indutseeritud taskukohaste peakomplektide turuletulekuga. Virtuaalreaalsus (VR) on uue meediumina loonud ennenägematud võimalused meelelahutuseks, õppimiseks ja teadustöödeks. Uuringud, mis püüavad vastata küsimustele, mis muudab VR-i kasutja jaoks efektiivseks ja nauditavaks, on mitmeid, kuid enamasti kasutatakse nende läbiviimiseks subjektiivseid küsitlusmeetodeid. Tänapäeval puuduvad lihtsalt liidestatavd lahendused kasutaja käitumise andmete mõõtmiseks ja kogumiseks VR maailmadest. Seega ei oska me VR rakendusi luues täpselt öelda, millised on olulised kompondneid ja milliseid aspekte võib ignoreerida. Objektiivsed mõõteandmed mahukal andmebaasil aitaksid aga nendele küsimustele vastust leida.

Käesolev magistritöö pakub välja võimaliku reaalajas töötava andmete kogumise lahenduse ja metoodika VR rakendustele. Esmalt tutvustatakse VR rakenduse komponente, tavasid ja arendustööd ühe VR rakenduse näitel, mida hiljem kasutatakse andmete kogumissüstemi katsetamiseks ja valideerimiseks. Süsteemi valideerimiseks disainiti ka ekperiment, mis viidi läbi laboratoorses keskkonnas. Eksperimendi käigus koguti esialgsed andmed, mida analüüsides tehti järeldused süsteemi elujõu, sisendandmete valiku ja VR-põhiste leidude kohta.

Magistritöö tulemusena valmis esialgne reaalajas töötav andmekogumissüsteem, mille töövõime ja perspektiiv valideeriti eksperimendi ja tulemuste analüüsi käigus. Leiti, et kõik hetkel kogutavad andmed on relevantsed ning sisendandmete hulka peaks veelgi suurendama. Lisaks leiti, et eksperimendis osalevate inimeste valim peaks olema tunduvalt mitmekülgsem, kui see oli valideerimise faasis. Eksperiment on aga jätkuv ning uusi andmeid lisandub andmebaasi pidevalt. Üheks märkimisväärseimaks andmetest tulenevaks järelduseks osutus vajadus õpetustaseme järgi VR rakandusteks. Andmetest tulenevad leiud olid aga rohkem järeldusi pakkuvamad, kui esialgu planeeriti ning seetõttu kirjeldatakse töös VR-i ka kui õppemeediumit. Esitletud tulemused on esmased ning neile on võimalik rajada tulevasi uurimusi ja arendada välja raamistik inimkäitumise analüüsiks.

Lõputöö on kirjutatud inglise keeles ning sisaldab teksti 69 leheküljel, 8 peatükki, 12 joonist, 6 tabelit.

Abstract

Although begun as a fantasy of science fiction the Virtual Reality (VR) has found its way of becoming a reality. For today VR technology has transformed into a compelling entertainment and research medium. The given thesis suggest methodology alongside with a real-time data communication system for human behavior analysis in VR-based applications. The goal is achieved through describing development and concepts of a holistic VR-based application which is in turn used as a test-bed for a suggested framework. An experiment is employed to validate the method and system. Analysis of preliminary data provided the tendency of the VR towards acting as an excellent way of learning and confirmed the need for tutorial levels in VR-based applications. Given thesis suggest a way to gather versatile user behavior data from VR-based applications and secondly offers hypothetical reasoning why VR succeeds in providing education.

The thesis is in English and contains 69 pages of text, 8 chapters, 12 figures, 6 tables.

Glossary of abbreviations

VR	Virtual Reality
HDM	Head Mounted Display
VRBACC	Virtual Reality user Behavior Analysis for developing Coherent applications
VE	Virtual Environment
HCI	Human-Computer Interaction
ELT	Experiental Learning Theory
3D	Three-dimentional
2D	Two-dimentional
UE4	Unreal Engine 4
UI	User Interface
HUD	Head-Up Display
9-DOF	9 degrees of freedom
Fps	Frames per second
UDP	User Datagram Protocol
SQL	Structured Query Language
NASA	National Aeronautics and Space Administration
NASA-TLX	National Aeronautics and Space Administration-Task Load Index
APA	American Psychological Association

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1. Introduction

1.1. Background

The earliest idea of Virtual Reality (VR) similar to what we know today can be traced back to the science fiction story writer Stanley G. Weinbaum. In his 1930s story of Pygmalion's Spectacles, he described a concept of a pair of goggles through which wearer can experience a fictional world. Since then rapid technological expansion of twentieth and twenty-first century has paved the road for bringing the fiction into a reality. Today the global market for VR software is only at its very beginning of blossom as companies like Oculus [1], Sony [2] and HTC [3] are soon to release their next generation of commercial Head-Mounted Displays (HDM). Such rapid developments have propelled the production of the VR-based applications resulting in a wide range of VR research solutions for gaming, professional training, and traditional education [4]. In particular, the field of medicine has taken up the use of VR technology in exceeding pace where it has found application for surgical training [5, 6, 7]. In Psychology and therapy, a sub-field of medicine, it has found use in trauma management [8], research on psychosis [9] and in phobia and anxiety treatment [10].

The thesis is a part of an extensive research project of Virtual Reality user Behavior Analysis for developing Coherent applications (VRBACC) conducted in the Center for Intelligent Systems [11] part of the Department of Computer Systems in Tallinn University of Technology. Based on the results of this thesis a research paper is accepted for publication at Salento AVR 2019 6th International Conference [12].

1.2. Problem

Today almost all the studies related to Human-Computer Interactions (HCI) and cognitive perception in the field of VR are exclusively based on subjective surveys. The given disadvantages inherently result in a state where VR-based application development is based on subjective judgments of the developers rather than an objective knowledge about what constitutes into immersive, knowledge providing VR experience. A similar problem was also stated and researched by [13].

1.3. Purpose

The purpose of the given thesis is to suggest a real-time data communication system for VR-based applications. Such a system would allow gathering objective data about user behavior which in turn would reveal new aspects and correlations between Virtual Environment (VE) and human cognitive perception and performance. A similar combination of subjective and objective data has been previously employed in VR study [14]. Acknowledging the significant factors would enable us to tailor a VR-based application individually to achieve the desired objective. The findings alongside with the suggested data collection method and system of the given thesis should profit both educational and business VR use-cases and lay the first stone in developing a holistic framework for the analysis of human behavior in VR-based applications.

1.4. Goal

The given thesis aims to present, based on a single VR application and its real-time data communication extension, the benefits and development of the application and the extension and additionally, present data-based findings. Therefore, the thesis should answer five research questions:

- How to develop holistic VR-based applications?
- Is UDP based data transmission viable for real-time data communication in VR-based application?
- What data inputs are relevant to collect from VR-based application?
- How to improve user experience in VR-based applications?
- Why and how can VR be utilized as a tool for behavior acquirement?

While answering the questions, six additional sub-goals of the thesis should be obtained:

1. present concepts, and workflow for developing a VR-based application.
2. suggest a novel system for real-time data communication for VR-based applications.

3. validate the methods and proof-of-concept of the proposed real-time data communication system.
4. provide preliminary results of the data collected via the suggested system.
5. provide suggestions for future developments regarding the proposed real-time data communication system.
6. present preliminary collected results.

1.5. Approach

Conclusively, this thesis is carried out to find the answers to the questions stated in Section 1.4. The thesis applies both qualitative and quantitative methods to attain the presented aim. On that score, the development process of a previously delivered VR-based application is discussed. The VR experience created in collaboration with Swedbank [15] serves as a test-bed for the suggest a real-time data communication system and method. It is then modified with a real-time data communication system. The development and methods for the system are presented. An experiment for real-time data collection is designed and the results of the gathered data analyzed. Based on data trend and previous studies the arguments for VR being an educative medium are presented.

1.6. Contents of the thesis

While binding psychological components into the field of computer science the presented work is both practical and theoretical. Given thesis consists of eight sections. The first section is an introduction that states the purpose, problem, goals, and approach of the given work. The second section is devoted to introducing background and definitions. In the third section essential concepts, tools, and workflows for developing a holistic VR-based application are presented. The following fourth section is dedicated to describing and justifying how and why the VR-based application was modified to support real-time data collection for academic research purposes. The fourth section also includes a description of the conducted experiment. In the fifth section, the results of preliminary data collection are presented and analyzed. The sixth section presents the determinations and suggests implementations of a fully automated solution for real-time data collection. The seventh section is devoted to offering arguments for employing VR-based applications in behavior acquirement and education. The thesis is closed with a conclusion in the eight sections. Every section is complemented with additional goals dedicated to a given section exclusively simultaneously, however, providing input to general aims of the given thesis.

2. Background

This section presents definitions and motivations for the given thesis. As the research about the VR is broad, it is necessary to introduce definitions for both VR and aspects bound to the field. Furthermore, motivational drivers for business and academic adaptation of the technology need to be explained.

2.1. Definitions for VR

At present day VR as technology is popularly regarded as specific hardware consisting of goggles and controllers that allow interacting in a simulated VE. A similar definition was provided already by [16] and [17] in 1992 but described in means of technology available to that period. However, a widespread description is challenged by [18] who defines VR through terms of telepresence and individual experience of being present. Therefore, he defines VR as an overall cognitive experience complemented by vividness and interactivity, rather than a hardware and software combination.

In the given thesis, a more conventional way of definition is used. When referred to a „VR" the holistic package of software and hardware is regarded. „VR-based application" or „VE" is regarded as a software part of the described package. „VE" is further considered as a virtual world that user perceives through HMD. The definition of interactivity, however, is suitably presented by [18]: „Interactivity is defined as the extent to which users can participate in modifying the form and content of a mediated environment in real time." From which definition of interaction can be derived: „Interaction is defined as the action with which users can participate in modifying the form and content of a mediated environment in real time."

2.2. Immersion and presence in VR

Immersion and presence are considered two main contributing factors to VR. Given factors are responsible for creating a feeling of being inside the simulation. Steuer even suggests that presence sensation is a core feature of VR [18]. Although immersion and presence are frequently considered interchangeably in popular literature, they are regarded as separate in the academic field. Presence is viewed solely as a subjective psychological state of being in a VE. Immersion, however, is considered to be a description of the technological capabilities of hardware and software. Immersive stimuli are regarded as one of the main ingredients that lead to the cognitive state of presence [19, 20, 21].

Consequently, when developing a VR-based application, creating the feeling of presence inside the simulated world is at utmost importance — leaving given feature unaddressed results in a mundane and fabricated representation of a VE. The immersive VE and VR technology need to provide meditative features that lead to presence phenomenon. To achieve the aim, however, objective factors need to be stated which a developer can follow. A range of theories by various researches has proposed measures for indicating the level of presence. An overview presenting a spectrum of possible factors was concluded by [22]. The list is the following:

1. Slater and Usoh [23]:
   - High quality, high-resolution information,
   - Consistency across all displays,
   - Interaction with the environment,
   - Virtual body, the representation of the user's body in the VE,
   - Effect of action should be anticipated.
2. Witmer and Singer [24]:
   - Sensory factors - the richness of the displayed information and consistency across displays,
   - Distraction factors - how much the user is distracted from the VE,
   - Realism factors - pictorial and social realism of the VE,
   - Control factors - the control the users has.
3. Sheridan [19]:
   - The Extent of sensory information,
   - Control of relation of sensors to environ- ment,
   - Ability to modify the physical environment.
4. Lombard and Ditton [25]:

- The form in which the information is presented,
- The content of the information,
- User characteristics.

5. Steuer [18]:

- Vividness which refers to the ability of technology to produce a sensory-rich mediated environment,
- Interactivity which refers to the degree to which users of a medium can influence the form or content of the mediated environment,
- User characteristics refer to the individual differences in users.

List above only acts as an illustration to offer a variety of plausible theories for presence. Today the current research is conducted mostly through subjective surveys. Therefore a range of insufficiencies within the data prevent developing a fundamental approach, which is also concluded by the study mentioned above [22]. The factors used for developing a VR-based application described in the given thesis are presented in the Section 3.6.

2.3. Motivations

Motivations for VR business adaptation are many due to its wide range of potential benefits. What is more, VR technologies concurrently provide novel approaches to research fields of human behavior and HCI.

2.3.1. Benefits of VR technologies

VR as a medium has become available for a wider audience only in recent years as the commercial HMDs have become affordable for wider audiences. Therefore, professional institutions are eager to reap the benefits of VR and integrate it into their everyday businesses as a range of corporate challenges, to which VR can provide a solution. When considering challenges influencing our national social welfare, it is impossible to overlook the state of the labor market where the demand for highly skilled professionals is great and proliferating [26]. Even when a suitable operative is found, the competition for hiring such candidate between companies is tight. Therefore, businesses have taken an approach to educate their employees by themselves. Providing training, however, is expensive and imposes a risk of a negative return on investment if a qualified employee leaves the position. Considering that businesses are in relentless pursuit of the additional workforce and solutions to reduce the costs of training, virtual reality can be considered as one possible solution for training professionals with lower price. VR provides an opportunity to hire labor with disrespect to location restrictions by providing a possibility to conduct teamwork within a virtual workspace. Simulated workspace would diminish an essential requirement for professionals to relocate or travel. Gradually, it might result in a global borderless job market. One such solution available already today is Glue [27]. It provides the following functionality: all the stakeholders involved in a project can meet and develop a plan together being virtually together in a custom virtual environment. It can facilitate teamwork, training, and marketing. A virtual coworking space enables us to bring together professionals from all around the globe with minutes. Such solutions, however, are still in a relatively early phase of development and prove themselves as novel concepts.

Another promising VR business use-case is to employ it as a marketing tool, allowing to demonstrate the business's candidness to novelty. Exhibiting innovative side of doing business is eye-catching and provides opportunities to attract new customers and even employees. Employing VR as a marketing instrument is a straightforward way how companies can implement the initial phase of new technology integration since generating novel concepts of VR-based serious games can be tiresome, and the whole idea of incorporating VR with the business might end up going nowhere. Therefore, companies can go with a relatively well-known marketing road, which demands less creative effort. In addition to marketing benefits gained from marketing purposed VR-based application, it would also catalyze corporate creativity as enabling the company to communicate its openness to novelty through actions. Therefore, employees, clients, and other stakeholders can provide new ideas on how in their mind the establishment can benefit from the VR technology. The slower and more subtle adoption of VR technology into daily business is also suggested by [28]. VR application for meeting purposes in financial services was researched and concluded with suggestions to avoid previous mistakes made while integrating novel technologies.

2.3.2. Aspect of human behavior

The research on the field of human behavior in virtual environments is broad. However, the results are often drawn from the subjective emotionally biased feedback of the test subjects. The individual personal feeling-based input to the questionnaire is not measurable in any objective manner. We can also conclude it to be biased by the individual's previous experiences and beliefs. Therefore, exists a need for a system able to gather and analyze user behavior and interactions in virtually simulated environments. Such a solution would allow to predict and explain human behavior and player success rate in the virtual environment depending on the personal characteristics of a player profile. Secondly, it would provide a better understanding to the question whether the subjective self-evaluation of feeling a presence sensation, motivations and success rate of the player correlates the objective measurement data by measuring his movements and actions in a VE. Having the data about user actions helps to understand the human behavior inside the VR-based applications better. Thus, it enables us to conclude creating better, more compelling VE-s that are optimized to provide a user with prearranged benefits. Optimization needs to be software as well as game logic wise. Optimization would lead to VR-based applications that have lesser hardware requirements at the same time eliminating virtual elements unnecessary to the game. Binding together these motivations should lead us to discover how to build efficient virtual environments that provide a higher level of presence at the same time using less computing power. The possible benefits are equally desirable for serious and entertaining VR-based applications, allowing to reduce the cost of developing.

Today, studies which try to fill the void of objectives in a given field are already published. Recent research conducted by Pharm [29], the HMD and motion controller movements are tracked, and method for human gaze and gait-based identification in VR-based applications are proposed. However, the use of the method is not to follow human interaction and behavior but to make distinctions between the individuals. The trivial simulation used in the described experiment is developed for testing purposes only and finds little usage otherwise. Moreover, the feeling of presence and immersion in experiment targeted applications are questionable. Therefore, researching human behavior in VR-based applications was attractive for the author and the Department of Computer Systems in TalTech, since fully immersive VR-based applications have already been developed within the same department. Having a holistic VR-based application in the disposal presented an opportunity to research the field with relevant tool approved by users who have reported their positive regard and presence sensations for the VE application described in Section 3.

2.3.3. Research induced VR-based application development

Understanding human behavior in VE allows developing future VR-based applications in a manner that exceeds in facilitating learning and user experience. Users of such VR-based applications will be able to adapt them into the VE with seamless effort, keep high-level immersion and gain in-depth experience-based know-how. Researching the field allows gaining an understanding of the vital components of immersive and joyful VR-based applications. Knowing the right recipe should much minimize the business risk of failing to integrate new technology into training, everyday operations, and services. Developing applications that produce the above-noted results would significantly benefit businesses in workforce acquirement and training processes — concurrently providing an understanding of human behavior and HCI in the field of academic research.

3. VR-based application

Given section is dedicated to describing the development of a single VR-based application. The motivations, requirements, tools, workflow, concepts, and contents of the VR-based application are presented. The VR-based application described in the following chapter was developed as a project by a team of students and IT faculty staff. During the development phase, the author of this thesis was responsible for the game visual and conceptual consistency, daily teamwork management and 3D modeling and texturing.

3.1. Motivation

The stated benefits to businesses of VR technology in the introduction paved the way to collaboration project between Tallinn University of Technology and Swedbank Estonia [15]. The objective of the project was to make an entertaining virtual reality experience to Swedbank for marketing events, job fairs and for showcasing in Swedbank's Estonian headquarter as-well in TalTech Mektory innovation center [30]. An additional advantage to Swedbank for developing a virtual reality experience in collaboration with the university was the opportunity to tighten the strings with the largest university in Estonia, also to highlight one of their purposes to contribute back to the society. The official name of the VR-based application is *Swedbank VR Experience*.

The VR-based application described in the following chapter was developed as a project by a team of students and IT faculty staff. During the development phase, the author of this thesis was responsible for the game visual and conceptual consistency, daily teamwork management and 3D modeling and texturing.

3.2. Requirements for the VR-based application

The Swedbank virtual reality experience was to be a casual game in its essence, meaning the designated tasks in the game are simple and straightforward to understand and complete. By the idea, to be successful in the game would not need any guidance. The concept of the gameplay and requirements were developed in collaboration between the development team and stakeholders from Swedbank over two months. The gameplay concept developed is the following: the player needs to collect as many points within a limited two-minute time frame as possible. A player is rewarded with points by collecting virtual objects — each kind of an object holding with a different number of points. Solution for virtual locomotion was teleportation, as it is regarded as typical in VR-based applications.

The requirements for the gameplay imposed by Swedbank were the following:

- The player score needs to be saved into an online leaderboard.
- The score needs to be visually available for the player at all time.
- The score is required to be coupled with the player's name in the leaderboard.
- The remaining time needs to be visually accessible for the player during the main level.
- The user interface and virtual objects inside the game have to follow Swedbank brand's color, design and font schemes.
- The game level has to have a 3D model of an oak tree, which represents the logo of Swedbank.
- The game has to provide an element of competitiveness between players.

3.3. Toolset for VR-based application development

To give an adequate description of how the VR-based application was developed, it is first necessary to introduce the software that is utilized to create such applications. The virtual reality application was built using the following software tools:

Autodesk Maya

Autodesk Maya is a 3D modeling software delivered by Autodesk [31]. It is regarded as an industry standard for creating quality 3D models. Autodesk Maya was employed for creating 3D objects for the presented VR-based application. 3D objects were developed using polygon shapes and modified with functions such as extrude and append.

Photoshop CC

Photoshop CC is an image manipulation tool delivered by Adobe Systems [32]. It was used to create custom textures and visual image assets that were later applied to 3D objects or in user interface creation.

Substance Painter

Substance Painter is a tool for painting 3D objects and is delivered by Algorithmic [33]. It allows applying custom textures created in Photoshop CC to 3D objects. Besides, it simplifies additional color manipulation as it will enable to choose material finishes like the metallic or matte look.

Unreal Engine 4

Unreal Engine 4 (UE4) was chosen as a game engine for the project. It is a well-known and efficient solution for creating virtual reality applications [34]. Using the primary game engine significantly benefits the development since such engines offer a wide range of reusable codes, libraries, and plug-ins. Also, they are built to support the leading HMD devices on the market. In UE4 as a game, the engine is in charge of compiling the 3D objects together with game logic into playable VR game. The straightforward *editor mode* in UE4 allows to test and run game after every modification to the assets or game logic. Unreal Engine 4 was chosen for this project mainly because the development team had the most experience with a given engine compared to other possible options like CryEngine

[35] and Unity3D [36].

3.4. Software development workflow for VR-based application

The virtual environment was produced as teamwork and delivered within six months. The team was self-organizing, and development was done using agile methodology principles. The technical process for holistic virtual reality based application production was completed in the following separate stages:

- Creating game level design and environment.
- Modeling 3D objects and texturing.
- Designing a user interface.
- Setting up player and game logic.

Given workflow is simplified since the main focus is not describing the development of a VR-based application.

3.4.1. Creating game level design and environment

The primary purpose of the given phase is to set up a custom canvas that will facilitate game attributes and components alongside with visual objects. During the phase level design was implemented using following UE4's level editor tools: Landscape tool, Paint tool, and Foliage tool. Tools were mainly used to implement ground with various attributes like amplitude differences, lifelike textures and grass on top of it. The phase also involves creating *MotionControllerMap* which defines the navigation map and area for virtual locomotion. Creating and adding surrounding background and initial lighting are additional tasks of this phase. In given project UE4 VR template was used, this dramatically reduces the workload on VR related game logic tasks. VR template allows using of premade C++ and blueprint classes previously integrated into the game engine.

3.4.2. 3D modeling and texturing

In the 3D modeling and texturing phase, custom 3D assets were designed and modeled. The workflow is divided into two large sub-phases: 3D modeling and texturing. The stages are conducted sequentially for every single object. 3D models were created in Autodesk Maya using polygon shapes. Shapes of planes and rectangles were used depending on the desired end-goal in mind. Polygons were then manipulated using edit mesh menu tools including extrude, bevel, merge, connect, detach, bridge. Planes were mostly used for creating nature assets like grass and plants. Three-dimensional polygons were edited into stones, tree stems, and collectable items. After finishing a 3D object, materials are assigned to the objects. Materials are best described as a set of attributes defining how surfaces reflect light. The collection of light reflection characteristics can later be edited in the game engine. Depending on the object there might be more than one material wrapping a single object. Only when the material is defined, a texture can be loaded into the material as an attribute giving a visual representation of the color. The texture is a 2D image file, and in the case of UE4, the file format is not strictly restricted. Range of *.bmp, .float, .pcx, .png, .psd, .tga, .jpg, .exr,* and *.dds* of texture formats are supported. Last and the most critical part of texturing sub-phase is UV mapping. Achieving result with excessive quality is at the highest importance, since failing to do so will result in odd-looking visuals of a 3D asset. UV mapping is a procedure of projecting a 2D image to a 3D object's polygons and can be considered as a glue we apply between the 3D model and texture to fix them together.

3.4.3. User Interface design

The phase of User Interface (UI) design and implementation are set out to achieve the smooth interaction between the user and the application. It is essential to point out that UI was only created for desktop. Simple UI text elements to indicate the start and end of the game, last 10 seconds and the final score were used for HMD. UI is tasked to guide user seamlessly through the game. Hence it needs to be simple and straightforward. A client's design representative handled UI sketch, and it covered the main menu and leaderboard screens. Other screens were later additionally created using visual guidance of the provided menu screens. UI is implemented using the UE4 menu editor.

3.4.4. Player and game logic setup

Once previous phases are accomplished, all the artificial 3D and logic models are placed into the game engine's virtual environment. Game logic is implemented using UE4 blueprint scripting. Blueprints can be considered a way of visual programming as the blueprints are interconnected blocks which have predefined C++ code inside them. Developers still have an option to write game logic using C++ scripting. Regarding given VR-based application the game logic involved scripting following systems: score, time and interactions of interactive objects. Additionally, predefined VR classes are included into the levels: HUD, player controller, *VRPawn* for motion controller and teleportation handler. Virtual robot hands, a part of *VRPawn*, that represent player hands in the VE were modified to facilitate point counters on both sides and a timer showing remaining time on the right wrist.

3.5. Contents of the delivered VR-based application

Swedbank VR Experience is a complete gaming experience and consists of three main components: main game level, tutorial level and a user interface (UI). The tutorial level and UI are acting as a supportive element to the main game level. Moreover, they provide a holistic game experience which is seen in consumer-directed videogames on the market.

The action of the main game level is situated in the hill-top virtual environment. The overall visual goal of the given level was to provide a recreation of fresh and vibrant visual amusement we can scoop in the natural environment of the Alps. Although the navigation area is seemingly small and restricted, the level was designed to give a user a feeling of a borderless environment and a sense of freedom. The navigation area was not marked in any obvious way. The borders of navigation area were invisible for the player. Therefore he had to apprehend boundaries by experiencing them.

The collectable Items in the level were each time randomly generated by the algorithm and scattered around the defined playable navigation area of the level. Exact locations of the collectable items were not determined and never spawned to the same coordinates again. Players were obligated to teleportation feature in the virtual environment to move around the play-area since the distance between collectable objects were random and often far apart. Additionally, players had to physically move around since the item spawn height varied randomly like the location. In total, there were four kinds of collectable items in the game. Three types of leaves each different color: yellow, green and orange. The fourth collectable item was Swedbank coin. Each item rewarded the player with 1, 2, 3, or 10 points respectively.

Figure 1. *Four collectable items*

In contradiction to the main level, the tutorial level was designed to hold the player in boundaries and to direct him to complete specific tasks. Therefore, the tutorial level took place in a modern circle shaped hall with a dome which with its open environment induces a player to take desired actions leaving only minimal possible distractions. In the level, only one of each collectable item was placed in specified locations. Locations were indicated by the hologram walls in the level to smooth user experience and make the task straightforward to users. No time limit was set in the tutorial level. The dome in which Tutorial level was situated had its walls illustrated with instructions all the necessary instructions for a player to be successful in the game. The dome walls additionally facilitated a leader board. The need for tutorial level revealed itself during the process of initial game level testing as it became evident that users did not navigate nor understand the game purpose intuitively. It was especially apparent for first-time virtual reality users that there is a need for warm-up before the main game. The phenomena found further proof during the experimental setup for this thesis and are described in the Section 4.2.

User interface consisted of 4 different menu-pages: main menu, scoreboard, credits, and user data input form. User interface pages can divide into two, primary main menu and secondary linked pages to the main menu. Menu system provides an introduction and guidance of a game. It can be considered as covers, page numbers, and table of content of a physical book. Additionally, UI provided the functionality of collecting and showing the player high-score data. The purpose of the scoreboard was to integrate psychological competition between the players into the game. The scoreboard was available for every player to get acquainted with best performances via the UI and the introductory tutorial level before entering the main game level.

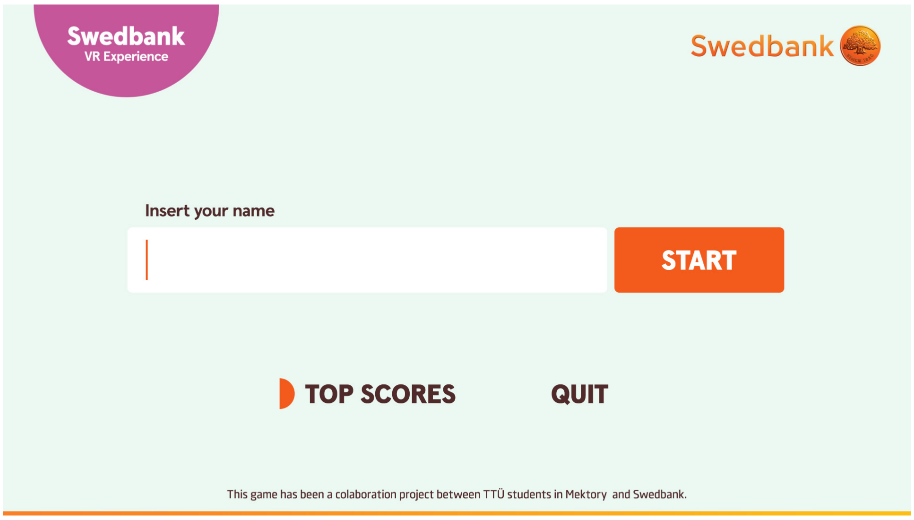

Figure 2. *Main menu page of VR-based application*

3.6. Presence in VR-based application

Providing presence feeling through immersive VE of the *Swedbank VR Experience* was a feature that the development team could leave to chance. As described in the Section 2.2 there exists a range of theories for presence. In the development of Swedbank VR-based application no single approach was used, but a combination from proposed factors. The implemented elements were chosen to match the specific characteristics and imposed requirements of the given application. The most important factors included in *Swedbank VR Experience* are: (a) High quality, realistic and vivid VE, (b) virtual body in the form of robot hands, (c) interactions to the environment. Additionally, in the main game level, an extensive user involvement aspect was included. Involvement's importance was introduced by Witmer and Singer [24]. Involvement is described as a result of focusing the player's attention to activities. Therefore, in *Swedbank VR Experience* the involvement was inherited from the game design of the main level where the user has to keep his attention to remaining time and continuously seek for new collectable items.

3.7. Delivery of the VR-based application

Described VR-based application would mostly be played in group setups, therefore, the HMD display needed to mirror to the desktop at all times. The game is served with HTC Vive. The HMD provides 1080x1200 resolution per eye and the 9-DOF with two lighthouse tracking systems. The controllers are equipped with 24 sensors, dual-stage trigger, and track-pad. Running the game with HTC Vive requires up to date top of the line hardware. The PC responsible for running the application was equipped with a 4.00 GHz Intel i7-6700 processor, 32 GB RAM, and an NVidia GTX 980 graphics card. Given hardware provides a reliable performance of the application. The only concern being fluctuating frame-rate, which is not caused by the hardware deficiencies but somewhat poorly optimized game logic or 3D objects or both. The desired frame-rate for VR-based applications was to be 60 frames per second continuously. The wanted framerate was achieved but not at all times, and it was ranging from 30fps to 60fps.

Figure 3. *Screenshot of the gameplay*

4. The development of a real-time data collection system

Given section describes the requirements, methods, and elements for developing User Datagram Protocol (UDP) based real-time data communication system for VR-based applications. Additionally, a custom designed experiment and its process are presented.

4.1. Real-time data communication solution for VR-based application

The following solution needs to be considered as preliminary since the goal was to explore one possible solution to the challenge and discover the shortcoming and define exact requirements for collectible data. The solution is a part of a more extensive project of VRBACC conducted in the Department of Computer Systems of TalTech.

Exploration of the challenge of real-time data communication solution for VR-based applications led to the conclusion that on the firsthand it was necessary to collect user data that could be analyzed. The VR-based application described in the section was initially not built to facilitate any data collection and transmitting. Secondly, the application was installed only into a small number of PC-s and had no network version update system. Given conditions created a situation where the data could only be collected through a distinct experiment in a laboratory setup. Therefore, besides a technological solution also an experiment scenario was developed and implemented.

In this section state-of-the-art, a real-time data communication solution for VR-based application is described. The contents of this chapter are the following. First, the motivations, requirements, and concept for such a system are described. Next, the conducted experiment, collected data, and technological aspects are presented. The chapter is concluded with considerations of the outcomes relevant to data communication in a given manner.

4.2. Designed experiment

To avoid exhaust the participants nor create negative emotions in them the length of the experiment from start to finish needed to be short. Additionally, the experiment had to be practical on a large number of participants. The course of the designed experiment was the following: First, the participant filled the form of multiple-choice questions in the UI. He needed to agree to share the data for research purposes; without agreeing he could not proceed. After completing the form, the first two-minute game session started. Immediately after the first session, the second two-minute repeat session was started. Finally, after completing both game sessions, the participant was instructed to fill in a survey on a separate computer. Both of the game sessions need to take place in the same game level to gather data about performance improvements. Thus, no tutorial level could be used in a given experiment since it would give a participant a better notion about the gameplay. The experiment for single partaker lasted 5-6 minutes.

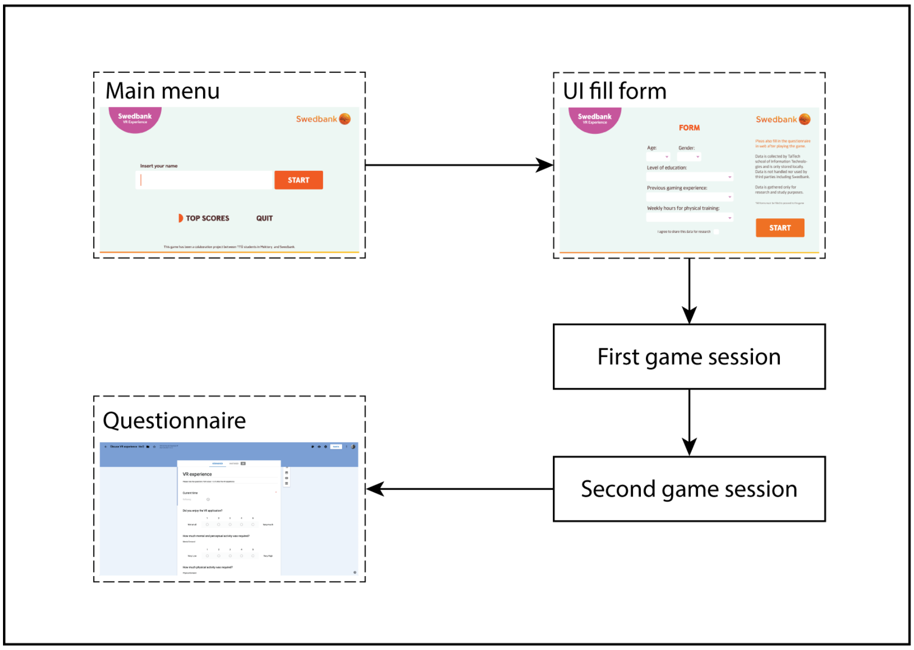

Figure 4. *Flow of experiment*

The goal of the experiment was to collect initial sample data to validate the data collection methods. The secondary objective was to make observations of possible shortcomings concerning the technological solution, VR-based application, game logic, and user behavior.

4.2.1. Illustration of the experiment

The experiment was conducted in a laboratory setup during a period of working hours in a single day. Twenty random participants were chosen to play the VR-based application. From whom 5 were females and 15 males. The participants were mostly the academic staff members of the IT faculty. Also, some students were included. The participants received no form of compensation for their input. The author of the given thesis was the conductor of the experiment.

The following is a sequence of activities conductor, and single participant went through to complete an experiment. At first, the participant was directed to fill in the fill-form in UI. After completion, partaker was given brief directions of how to use the motion controllers and what is his goal during the two-minute game session. Then the conductor started the python script on the same computer. Next, the participant proceeded to complete the first game session. During which instructions were given only if the partaker asked for help. After the first session form fill UI was loaded again, the fill-form was completed once again, and the second game session was started. After completing the second game session conductor stopped the python script and instructed the participant to fill in the survey on a different computer. The experiment was finished for the given participant after completing the survey, and the conductor repeated the steps with the next contributor.

Since the fault tolerance of given real-time data collection system was unknown, some of the steps of the experiment were unnecessary but were conducted as precautions to prevent data loss in case of errors. Therefore, the python script was stopped after every participant and restarted with each new participant. Partaker was required to complete the fill-form twice for the same reason. It also provided the participant with a short break between the game session. Additionally, conductor frequently checked whether new data is correctly saved into SQL database. Conducting the experiment in safe-mode, allowed to make important observations and to draw conclusions whether such a system is a viable solution for data collection and if yes how to automate it.

4.3. Technical requirements

Due to being part of a larger project of VRBACC, there were requirements imposed by the aims of the project. The data communication solution needed to provide real-time communication. It would create an opportunity to objectively and better understand user's behavior via real-time visualization as this is one of the desired results of the project. There were already existing components within the project that partly facilitated real-time data communication. It needs to be noted that the existing solution only included data communication of HMD's locomotion. Also, the data often included a considerable amount of noise.

The three preexisting components were the following:

- UDP communication plug-in for UE4
- Python script that saves incoming UDP data to the SQL database
- SQL database that facilitates incoming data

Taking into account the given components the proposed real-time data communication needed to integrate and utilize the benefits provided by those ready-made parts. The following is a short description of the components and how they were edited to fit the needs of described real-time data communication implementation.

Before describing the UE4 data communication plug-in the technical background of UDP [37] is given. UDP is designed to work in the set of interconnected computer networks and is not fit for operations that require reliability. Since there is no connection between sender and receiver, the delivery of the message is not guaranteed. Instead, UDP provides the broadcasting possibility, meaning that every device in the subnet can receive sent data. Broadcasting enables to use of UDP in real-time applications. Additionally, UDP performance proves to be fair in comparison with other data communication protocols [38]. Considering that the suggested communication was to be real-time and communication reliability is not at utmost importance, using UDP based data transfer is justified. In a setup described in the given thesis the broadcasting and data receiving takes place within a single personal computer.

UDP plug-in for UE4 is C++ class based UDP socket implementation developed by the Center for Intelligent Systems. It is in charge of UDP packet communication between Unreal Engine 4 based VR game. The plug-in has to be installed separately and is required to be updated to the same version as the Unreal Engine to work. UDP plug-in employs the UE4's visual node-based scripting system for easy game logic integration. UDP plug-in allows transferring 20 float and three integer parameters, meaning that only numerical values can be transferred using in a given implementation.

Python script captured, sorted and saved the UDP data into SQL database. The purpose of the Python script was to capture the UDP data from the local host network and save it into the SQL database. The script was constructed in a way that allows it to read bytes in the header of UDP packet. Every four bytes marked a single input of data that was sent from the game. Script saved the captured information to the designated SQL column and added a variable of delta time. A Ph.D. student Ahmet Kose developed the initial python script and SQL database setup. It was later modified to fit the needs of collectible data Table 2. Input names and byte extracting was defined by order of the data that were sent via UDP plug-in from the game engine.

SQL table is used to facilitate user behavior data. There existed previously configured table that needed to be edited to fit the data presented in Tables 1 and 2. HeidiSQL [39]was used as a database client.

Described technological requirements and experiment enabled to derive the basic functionality that a VE software needed to accommodate experiment. The VR-based application needed to support the following functionality:

- Participants had to be able to insert primary personal properties before they were directed into the game session by the application.
- During the game sessions, the application had to collect and transmit data regarding player locomotion and interactions to the SQL database via UDP plug-in.
- During the game session, data transmission needed to be as close to real-time as possible.

4.4. The implementation of real-time data communication

The modifications made to the VR-based application are described in three parts. Firstly, visual changes that included adding and eliminating menu pages in UI. Secondly, creating and integrating a real-time data communication component to the game. Thirdly, the game level sequence was changed.

4.4.1. User Interface modifications and creation of fill-form

The UI of the previous game version consisted of 5 menu pages: main menu, tutorial or game level selection menu, high scores menu, and credits menu. All the pages were navigable through the main menu. For the new version, only the main menu page from previous versions was preserved. Other pages were disabled for navigation. Form menu page was designed and connected with the menu page.

The additional fill form menu page would still be part of a holistic game. Therefore, it was essential to keep the visual consistency of the pages and use only the visual assets provided by the client for the VR-based application described in Section 3. An additional benefit for keeping the similar design lies in the opportunity to use the same menu page in the future, where the experiment can be implemented outside the laboratory environments in an automated self-sustaining manner. First, a sketch of the future menu page was developed. The design could be created in any digital artwork creation software, however, in the given case, Photoshop CC was used. The visual assets were later finalized in Photoshop CC and then exported as .png image files. Image files were then imported into UE4 as game objects. After completing the visual creation of the UI page in the interface editor, blueprint scripting followed. Since the UDP plug-in only allows to communicate numerical values, all the multiple-choice options in fill form were index. 0 is the first index of a first option. The index would then be cast and saved into a variable inside the Game Instance using "get index" and "cast" blueprint blocks. UI blueprint scripts also checked two conditions before the proceeding to the game was made available for the player. First, has a choice been made for all the given questions. Second, has the agreement to share data checkbox been checked. If both of the conditions were true, the participant could start the game level.

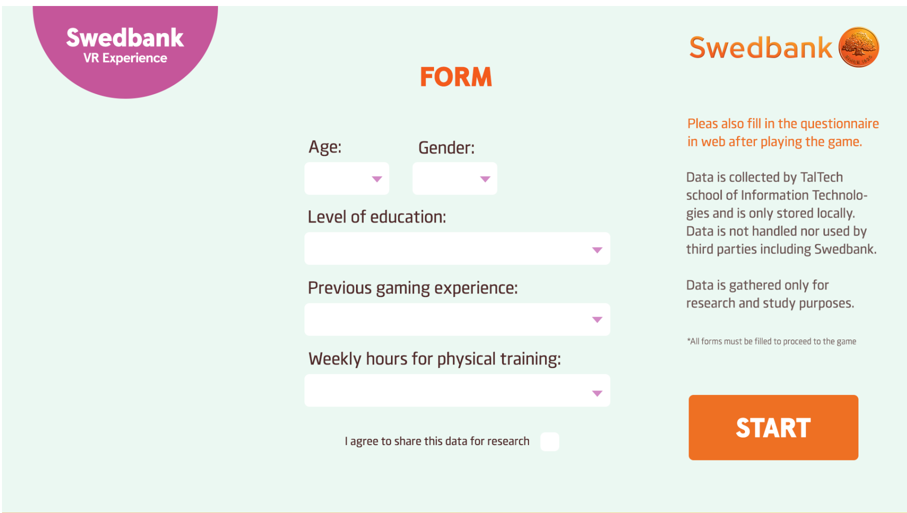

Figure 5. *Multi choice fill-form*

4.4.2. UDP data communication in UE4

UDP communication is initiated through the level blueprint and game level. UDP plug-in requires placing UDP data blueprint blocks into level blueprints and a blueprint class actor of the given plug-in into a visual virtual environment. In a given manner, a UDP data blueprint block in level blueprint acts as a reference to UDP actor in visual level. The reference can only be made to corresponding level blueprint and a level.

The UDP plug-in consists of three different blueprint blocks, which need to be correctly integrated into level logic. The three blueprint blocks:

- Start UDPSender - Is a blueprint logic element is responsible for defining the IP, port number and socket name. The function needs to be initiated with target reference from the persistent game level and sequenced by the event of begin play.
- Make UDPData – Is a blueprint logic element that gathers together all the inputs that are chosen to be transmitted via UDP and packs them into an array. The array is then ready to be inserted into the sending function.
- UDPSendArray – Is a blueprint logic element responsible for packing the array of data into UDP packet and sending the packet into the local host network. As an UDPSender component, it needs to be initiated with target reference from the persistent game level and sequenced event. In the given case the sequenced event is Event tick which is called out on every frame of gameplay.

The C++ class based UDP socket communication is only accessible through the persistent level and its level blueprint. This restriction created a challenge where only HDM locomotion was directly available within the game level. Data and blueprint scripts concerning fill form, teleportation and interactions are all located in different specified blueprint classes. Therefore, it was required to convert all the defined variables into global variables, which could be accessed by any other blueprint. In UE4 intermediate Game Instance blueprint class, which acts as a variable facilitator and has no other functions, is needed to tackle a given challenge. Game Instance blueprint class is defined at the initiation of the project. The name of it cannot be changed later, and single such blueprint class can be expended throughout the entire project. In given VR-based application, the game instance class was named as *GameInstanceIO*. As a collection of global variables, the class can communicate values of global variables to all the blueprints within the project via the "Get" function.

Furthermore, new values can be written into global variables by other blueprints via the "Set" function.

"Get" and "Set" functions also require "Cast To" blueprint node to function. "Cast To" node checks whether the specified location facilitates the stated variable that is being cast to and casts them if possible. "Cast To" node also requires specified location from where to get the variables. The location is specified with "Get Game Instance" function which turns to *GameInstanceIO*. To ensure a smooth experience with minimum latency UDP socket is employed to collect data with delay. The sampling rate was set to f*s*=1Hz, which also benefited in noise-free data sets.

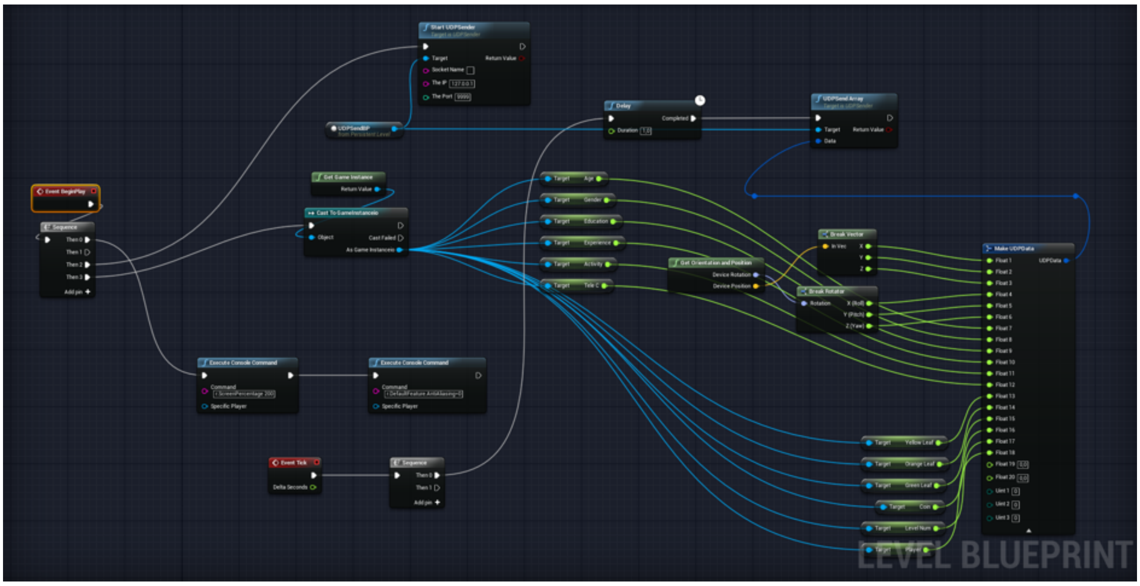

Figure 6. *Blueprint scripting for game level UDP communication*

"Set" functions were used across different blueprints, since all the four objects, user interface and teleportation blueprints need the addition to their game logic. Simple incremental counters for teleportation and pick-up interactions were implemented in the VRpawn and items blueprint classes. On Figure 7 is the blueprint logic of coin pickup is presented.

4.4.3. Level sequence modifications

In the original game, a player was directed into tutorial level he needed to complete to continue to the main level of the game. An introduction would warm-up and acquaint the player with the visuals, rules, and mechanics of the game. Inversely, the experiment

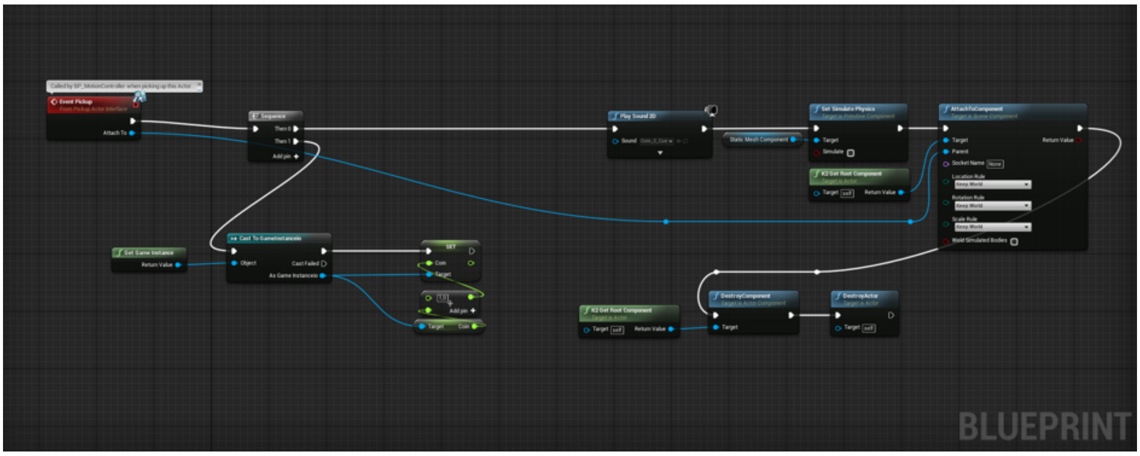

Figure 7. *Coin pick-up blueprint logic*

was designed not to give any in-game experience to a player before the main game level, thus creating a self-educational situation. The participant needs to get used to the virtual environment and figure out how to complete the task efficiently in the simulated world — given set-up also allowed to keep the experiment shorter and measure the improvements between the first and the second game session. Therefore, the tutorial level was eliminated from the game sequence, and the participants were directed into the main game level after completing the filled form.

4.5. Collectable data inputs

Structure of the collected data plays a significant role in the current thesis. Data were collected using two methods in three distinct stages: (a) via UDP sockets, (b) participant survey, (1) first stage is represented by a graphical user interface inside the game itself, (2) second stage is conducted during the game sessions as the player was interacting in the virtual environment, (3) third stage takes place right after a player had finished the second game session. At that stage, the player is required to fill in a questionnaire on a separate computer. Three stages are best portrayed through how the data collection was conducted in each step.

1. Form data - Data that participants provided before the game sessions
2. Generated data – Data that was generated during the game sessions
3. Questionnaire data – Data that was provided by the participants after the game sessions

Each stage provided a block of data that can be sorted by the type of data they are containing:

- Static data – Data retrieved via fill from
- Generated data – Relative data to the individual game session
- Subjective data – Subjective evaluation of the personal experience

4.5.1. Static data

Static data was collected via multiple choice UI form before the game session. Form data is considered to be static since it can only change over a substantial time frame. Static data categorizes the participants by their background. The parameters participants had to fill in form were: age, gender, level of education, previous VR gaming experience, weekly hours for physical training. Given data allows to separate the test participants into general groups by standard parameters and make available human behavior modeling in the future.

Table 1. *Indexed answers to multi-choice questions*

Index	Age	Gender	Education	Experience	Activity level
0	3-7	Female	Still in primary school	None	None
1	7-14	Male	Highschool education	Little	1-2h
2	15-24		Bachelor's degree or obtaining	Somewhat	3-4h
3	25-49		Master's degree	A lot	4-7h
4	50-65		Ph.D		more than 7h
5	65+				

4.5.2. Generated data

Generated data is generated during the 120-second game session by the participant movements and interactions inside the virtual environment that are continuously captured and transmitted via UDP sockets. Generated data is captured by the programmed game logic element described in Section 4.4.2. Data is generated and sent even if the player is not making any interactions. Thus the data is actively collected during the whole game session. Each set of the generated data is only relative to the single game session. The probability of having matching data for two separate game sessions is slim considering fact that all the collectable objects are spawned randomly in each game session forcing the player to interact contrarily every time. Secondly, every participant was limited to two game sessions, reducing the probability even more drastically. The collection of generative data was restricted by the number of possible inputs in UDP plug-in. The data passed to the server can be categorized into three groups. First, movement data of HMD is collected as the user is interacting with the VR-based application. The HMD's x, y, z coordinates and roll (x-axis rotation), pitch (y-axis rotation), yaw (z-axis rotation) sequences are collected. The rotation sequences are made available via an integrated gyro sensor in HMD. Second, user action and interaction data: occurrence time and count of teleportation, occurrence time and count of item pick-ups per each of 4 items. Third, the level number and random player identifier were transmitted to the database. The purpose of the additional id is to assure that the different game session data is nor mixed up.

Table 2. *Generated data inputs to UDP plug-in*

Variable	Type
X coordinate	Coordinate relative to launch point
Y coordinate	Coordinate relative to launch point
Z coordinate	Coordinate relative to launch point
Yaw	Degrees range of 180 to -180
Pitch	Degrees range of 180 to -180
Roll	Degrees range of 180 to -180
Teleportation	Incremental counter
Yellow leaf	Incremental counter
Orange leaf	Incremental counter
Green leaf	Incremental counter
Coin	Incremental counter
Player identifier	Random number between 0 – 10 000
Level number	1 or 2

4.5.3. Subjective data

The subjective data type is the only type that cannot be integrated into the system in real-time. The reason for being that the user only fills the survey in the last sequential event. Another aggravating cause is that the user has no imposed time limit for filling in the questionnaire and has the opportunity to reconsider the given answers before submission.

This stage is aimed to gather the subjective feelings and emotions that participants experienced during the experiment. It was crucial to include this part since this method is widely expended in the field of VE and presence research. The personal data collection was implemented using Google Forms [40]. Being the last stage of data collections, the participants had the change how they individually felt about the various aspects of the VR-based application. Questions are targeted to gather data about the physical and mental demands that completing designated tasks in VR-based application required. Players also needed to give a rating of how the experience made them feel.

The questionnaire was deliberately constructed in a manner that directs the participant to give a rating about his/her apprehensions in a free and easy way. Thus, partakers had seven questions where they were able to provide answers in a five-level Likert scale from 1 being very low to 5 being very high [41]. The scale is widely used for measuring attitudes. However, the semantic meanings of numbers were modified to fit the characteristics of the given survey. Linear scale provided the participant with a limited range of subjectivity they had to choose from but greatly simplified the questionnaire filling process. Questions 2 to 5 were derived from the NASA-TLX [42]. The test was explicitly developed for NASA as a universal tool to evaluate workload across disciplines. Given test has been used across numerous fields for subjective measurement of human performance. It has also proven itself beneficial in previous VR researches [43, 44]. As it was initial to keep the experiment period short the most relevant questions were chosen from NASA-TLX into the questionnaire. Questions 1, 6 and seven were generated by the author as these questions potentially seemed to be able to reflect the participant's feelings of the VE experience.

Table 3. *Subjective survey questions*

No	Question
1	Did you enjoy the VR application?
2	How much mental and perceptual activity was required?
3	How much physical activity was required?
4	How satisfied were you with your performance?
5	If you played for the second time, were you more satisfied with your performance?
6	Did you have the immerse feeling while experiencing the application?
7	Would you like to try the VR application again?

4.6. Data flow

Data is generated by the player who interacts with the UI and VE in the VR-based application. The VR-based application runs with HTC Vive HMD in UE4 editor. The data is then transmitted through UE4 facilitating game instances into UDP plug-in blueprint script. UDP plug-in then packs the data into UDP packets and broadcasts them into local host network. The network address is 127.0.0.1, and the port number is 9999. The port number can be different, but 9999 is used as a default. Simultaneously at the same computer is running Python script in Spyder programming environment. The python script scans the local host network and captures the data from UDP sockets. The script then extracts the UDP data into distinct blocks and identifies them by order of specified inputs. Python script saves the captured and sorted data into SQL database. The order of the columns needs to be matching within the script and the data table, otherwise, the script runs into error.

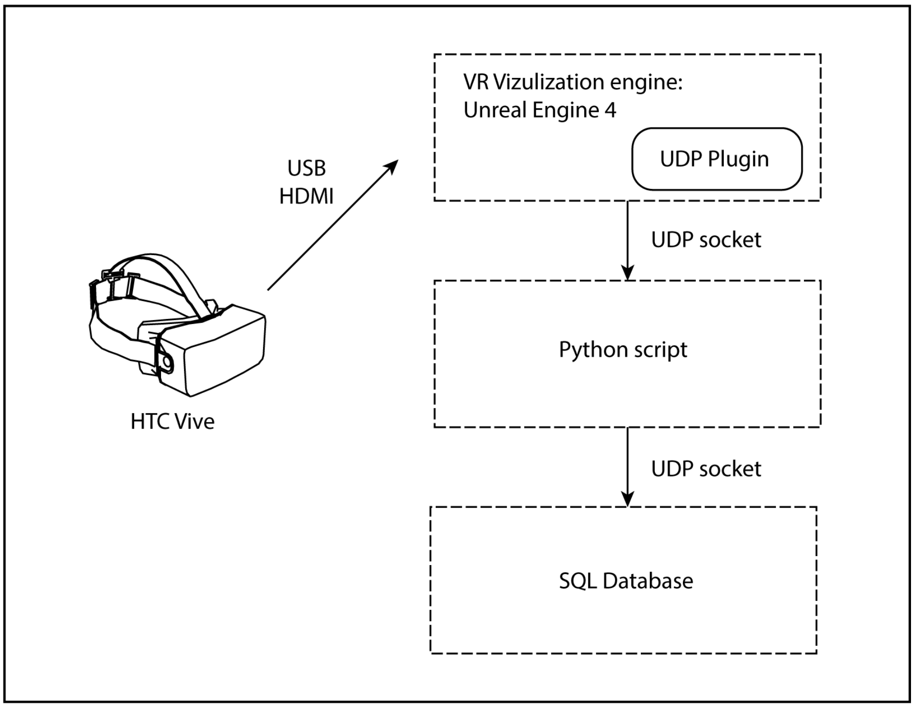

Figure 8. *Data flow*

5. Collected data

This section focuses on presenting the gathered data and analysis.

In total 5173 lines, each covering 19 rows of data was collected during the 40 game sessions in the experiment conducted in a single day period described in the Section 4.2.1. The current average participant was 25-49 years old male having at least a master's degree and who have low to the moderate previous gaming experience and works out as a minimum 1-2 hours per week. It is necessary to point out that the experiment is still continual on-going process and the number of participants is increasing. Currently, the state of art solution is used while an upgraded version is being developed. Given approach provides agility to the system development while not halting the data gathering process. Bearing in mind that the current quantity of data is small and sample undiversified it makes it impossible to draw any significant conclusions between on participants background characteristics and their interactions and movements in VR-based application. Only general preliminary trends can be suggested at that point. Therefore, analysis regarding the current sample and data relevance is done, and recommendations for superior sample composition are made. The more extensive data collection is planned to take place in an automated form in Mektory VR demo room.

The data analysis section thus focuses on the objectives presented previously. Firstly, to validate the sufficiency of the collectible data to proceed with through analysis in the future. Secondly, to verify if the data collection method proves itself capable. Additionally, it aims to explain why chosen data inputs were collected and included in the experiment. Although given analysis is mainly presenting the characteristics of the data, some preliminary conclusions can be assumed based on basic statistical methods. As described in chapter 5 gathered data was divided into three types. The structure of the given data chapter is following. First, each collected data type is analyzed separately. Then possible interconnecting trends are presented which is followed by preliminary conclusions.

5.1. Static data and background analysis of the participants

Static data was collected via fill-form in the user interface. Five types of data with free choice answers were provided. Inputs with all the answer options are provided in Table 1. Preliminary analysis solely based on participants background did not reveal any apparent trends or relationships to performance nor behavior in the VR-based application.

Wide-ranging data was collected by previous experience of games as shown on the Figure 9. As VR gaming is not yet as widespread as other forms of videogames, acquaintance with VR-based applications was expected to be low. Although the results raised in all categories, they met expectations - a two-thirds of participants evaluated their level of VR gaming experience as none or low. Given data would help to understand whether previous VR gaming experience provides itself beneficial on succeeding in VR-based applications.

Only a quarter of the participants were under 25 years of age, and all the rest fell into the range of 25 to 49 years of age. Since all the participants had some form of higher education, no partaker was younger than 22. Also, no elderly individuals were included. Consequently, large demographic groups are completely excluded from the current data. Those two groups, however, represent the extremes of the general populations and their behavior in VR-based applications might occur to be non-standard.

Education level proportions were relatively similar to one another. All the participants hold at least a bachelor's degree. Both, Master's degree and Ph.D. were held by 35% of the partakers. The results were anticipated since the experiment was conducted in an academic environment. Results may become different if participants, who have not acquired any university degree, are included.

The most diversified data was collected by weekly physical activity level where all the possible answers were chosen at least once. The aim of the question being included was the underlying reason for the use of VR-based application requiring some degree of physical activity. It is being proposed that people who exercise more often are bound to move more. Therefore, they might be more successful in using VR-based applications that require physical agility.

5.2. Generated data

Generated data is dived into two subcategories to simplify the analysis. Firstly, the data generated by the user interactions to the VR-based application. Interactions, in turn, consist of two possible types: teleportation or item pick-up. Secondly, data generated from HMD motion and movement. The second category is not further analyzed nor discussed since the author chose to focus more on the research of interactions in VR-based applications.

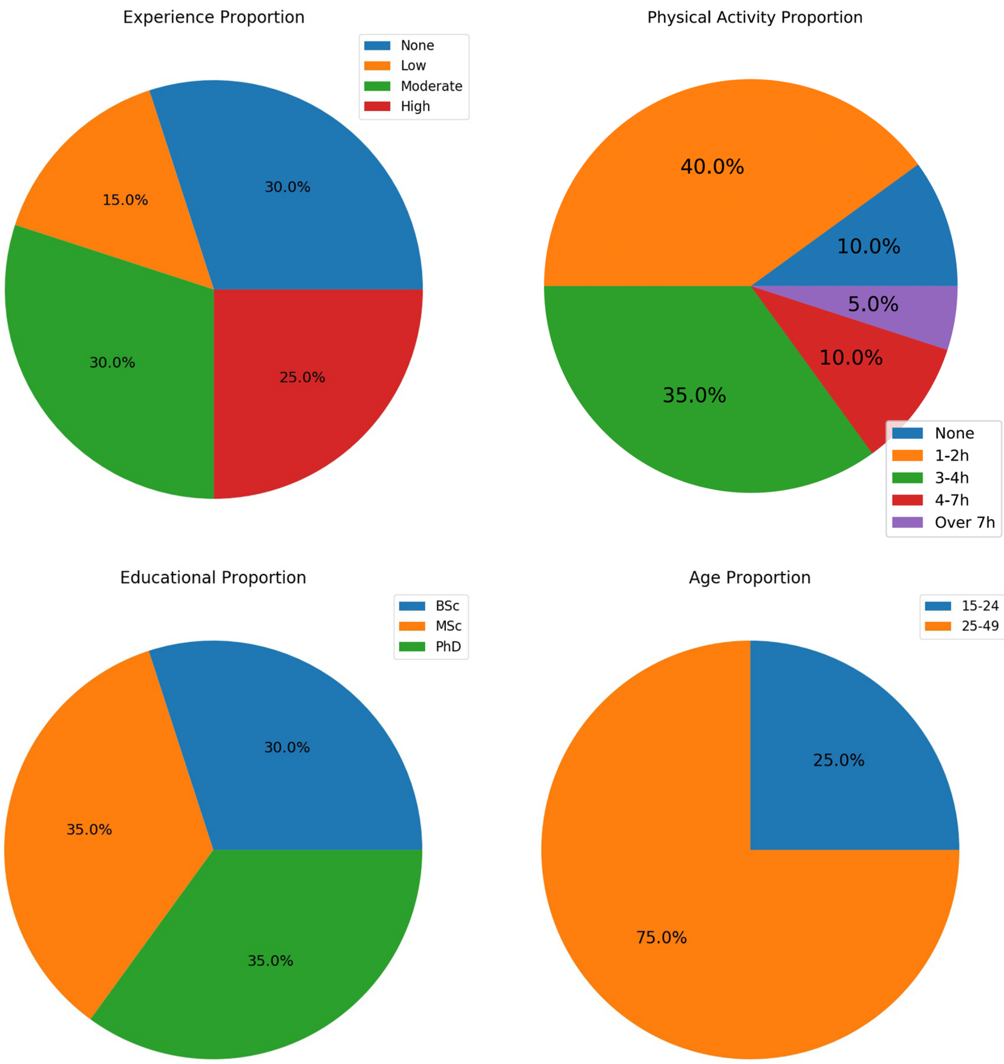

Figure 9. *Background data of Experience, Gender, Education and Age*

Additionally, the second type of generated data is missing vital components of motion controller movement data. Therefore, HDM movement data is ignored in the scope of the given thesis.

5.2.1. Interaction data

During the development and testing phase of VR-based application the challenge, for first-time users, to adapt to interaction mechanics was inadvertently observed by the development team. Thus, tracking teleportation and pick-ups data were relevant to include within collectable data. Because all of the collectable items were colored differently there exists a possibility that some people are more biased to particular colors than to others. Aspect becomes even more remarkable when considering the high pace of the game, during which the human brain has to make rapid, unconscious decisions. Teleportation is a well-recognized locomotion method featured in VR-based applications today. In the VR-based application described in a given thesis the jump frame teleportation method is used. The technique features illuminating hologram like blue indication box and a line. The line starts from the player's robot hands and ends in the box. The box serves as an indicator to a final teleportation destination. The seemingly simple solution proves to be challenging to grasp at first. The hardship to adapt might occur for the reason that such features are not performable in real-world situations, therefore, being alien to people. There do exist possible alternatives, but the above mention solution is widely used and default in VR-based application development in UE4.

Collected data confirms previous observations - interactions prove to be hard to grasp for some users. Phenomena are well illustrated by the Figures 10 and 11 representing the results of teleportations and collected items respectively for both game session. Some of the participants only managed to perform teleportation seven times during the first game session whereas the average number of teleportation was 26.5 as provided in Table 5. Results were even worse concerning the second type of interaction. Some of the participants failed to perform any pick-up interactions during the initial game session. The failure can be expected since game design required a first to approach the collectable item using teleportation.

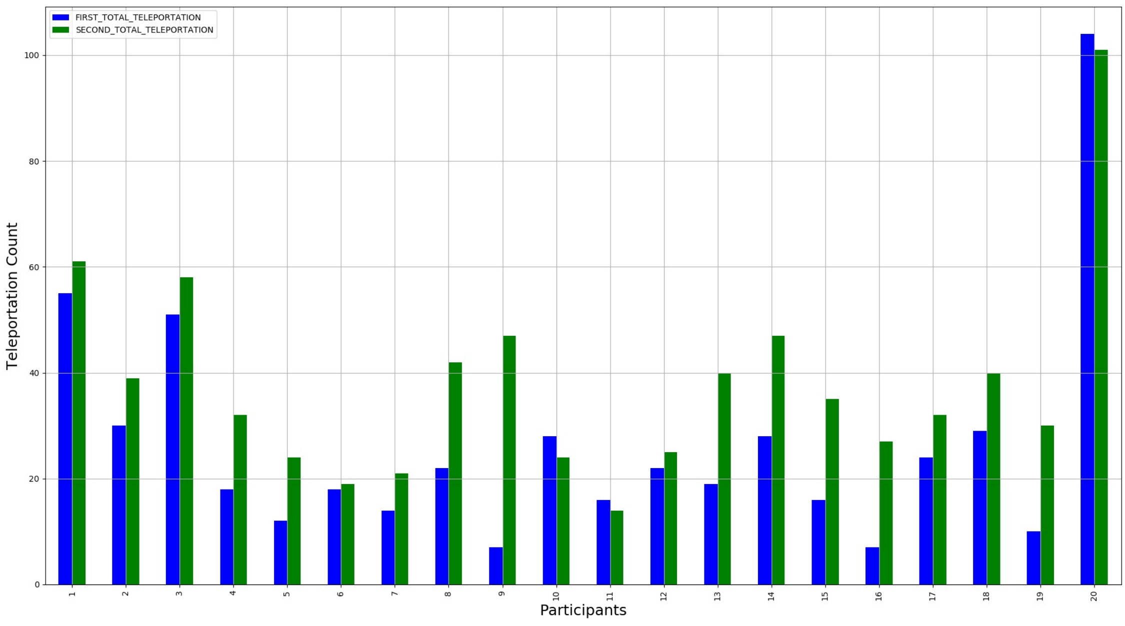

Figure 10. *Number of teleportations by the participant in both sessions*

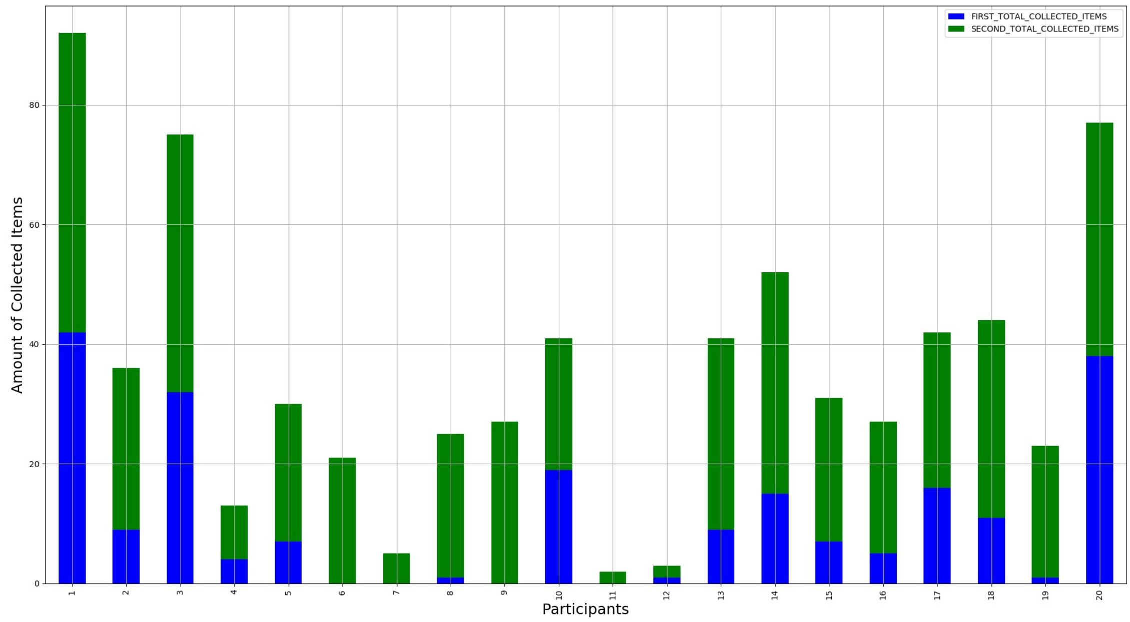

Figure 11. *Collected items by the participant in both sessions*

It is evident from the data that the first and second type of interactions is in correlations. It can be said that the second type of interactions is dependent on the first type of interaction. Participants who did not succeed in performing the first type of interaction also failed to complete the second type. Participants who reported to possess none to low previous VR gaming experience performed worse during both game sessions compared to those participants who reported to have moderate to high previous exposure to the gaming experience. Also, the performance of those participants increased more during the second game session compared to all as shown in Table 4.

Table 4. *Analysis of participants with previous experience*

Comparison parameter	Previous Experience	Session	Mean
Teleportation number	All	First	26.5
Collected Items number	All	First	10.85
Teleportation number	None to Low	First	16.5
Collected Items number	None to Low	First	4.875
Teleportation number	All	Second	37.9
Collected Items number	All	Second	24.5
Teleportation number	None to Low	Second	27.75
Collected Items number	None to Low	Second	18.875

Almost every participant was more successful with both types of interactions on the second game session as the mean number for collectable items was one and a quarter times higher than during the first game session. Considering the correlation mentioned above, a 40 percent increase in the first type of interaction-induced more than three times higher yield in the second type of interaction Table 6. It can be preliminary concluded that previous experience with VR simulations plays some role of user's success in adapting into interactions in VR-based application. The participant who had none to little previous gaming experience demonstrated the higher educational impact of the first game session to their performance in the second game session as shown in Table 4. Mean values were used instead of the median values due to the small sample size.

Table 5. *Number of teleportations*

Number of teleportations			
	Mean	Lowest	Highest
First session	26.5	7	104
Second session	37.9	14	101
Change (%)	+40.7	+100	-2.9

Table 6. *Number of picked up items*

Number of item pick ups			
	Mean	Lowest	Highest
First session	10.85	0	42
Second session	24.5	2	50
Change (%)	+125.8	+200	+19

5.3. Subjective data

Personal data has been part of every more extensive research in a given field since the technological capabilities for gathering objective data have become available only recently. The survey is also an only viable solution possible today that enables to collect data regarding human emotional experience. Therefore, collecting the subjective type of data was relevant and necessary. All the participants also answered to the questionnaire, the composition of which is presented on the Table 3. The questions were presented with linear answer scale from 1 being very low to 5 being very high. Intermediate values of 2, 3, and 4 can be interpreted as low, moderate and high respectively. The data gathered from the survey was not automatically transferred to the SQL database but was manually bound with the UDP data using timestamps in both data sheets. Since every participant filled the study once, the subjective data amount is even smaller compared to other types.

5.3.1. Breakdown of the subjective data

The most diversified data was gathered by evaluation of the physical activity required, where the answers were distributed somewhat equally, the highest difference being 10 percent, compared to other questions which had one or two most favored answers. Similarities to weekly physical activity question via fill form gathered data are noticeable as the given question's responses were also most diversified in static data type. It might become evident that VR-based application is more comfortable to use for people who are in better physical shape but the data is not consistent enough to draw conclusions. Therefore, those two inputs to data prove themselves necessary and relevant.

Given VR-based application succeeds to deliver immersion as 65 percent of the participants reported feeling involved inside the game during the experiment. Given results can be higher since one third rated the immersion feeling moderate. Participants who rated their feeling of immersion moderate performed 34.5 percent fewer teleportations in average compared to the overall average. It might point to the fact that the immersive atmosphere in VR-based application also benefits from the successful adaptation of interactions.

When combining multiple subjective data inputs enjoyable impact of the experience and personal improvement can be seen. Eighty percent of the participants were more satisfied with their performance during the second game session, meaning they felt some improvement in skills. Also, 85 percent of the participants rated the enjoyment level of the VR-based application as high or very high. The same amount partakers also are likely or very likely open for trying VR-based application again. The results demonstrate an enjoyable skill improvement factor complimented in the VR-based application. What is more, participants are open to such experiences in the future again.

5.4. The visual observations of user behavior in VR-based application

As the author was conducting the experiment, there was a chance for him to visually witness how 20 different people manage to adapt VE and complete tasks. As a result of this are highlighted some of the most commonly appeared challenges encountered by the participants. The list of following problems is by no means definitive and is based on subjective observations of the author.

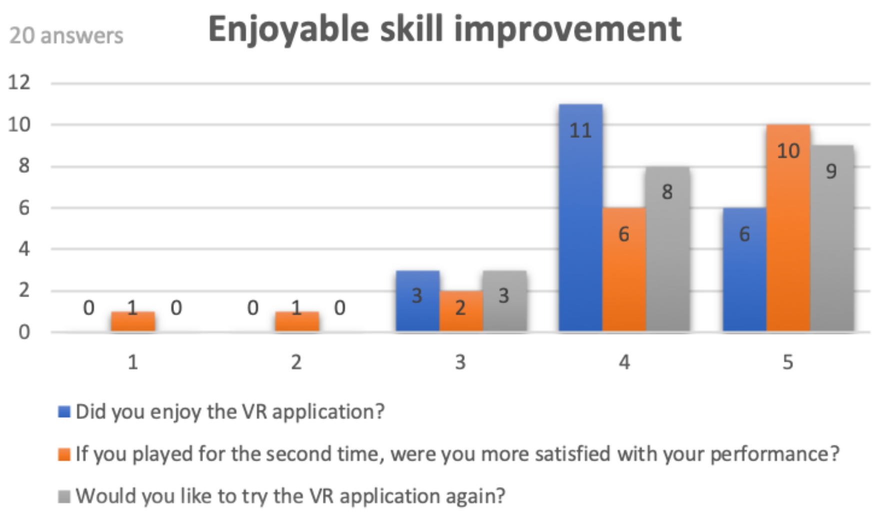

Figure 12. *Enjoyable skill improvement*

Observation 1

Some players were struggling to perform teleportation. The reason behind that lied in their body posture and head movement. Participants held their hands in a relatively low position, elbows almost fixed to the chest. They rotated their head to sides and minimally up and down directions. Posing in such manner restricts the player to see the virtual robot hands since they are left out of the range of view. Players who failed to detect their virtual hands in VE performed visibly weaker. It can be ventured that virtual hands may enhance the phenomena of immersion in a way that player is then able to identify some parts of the VE as himself or part of himself.

Observation 2

Some players had confusion grasping the sole functionalities of the HTC Vive motion controller buttons. In given VR-based application only two of the buttons were used: trigger button underneath the controller for picking up objects and circular touch-sensitive button on the top for teleportation- participants tend to press both of the buttons simultaneously, causing chaotic results like teleporting when trying to collect an item and vice versa. Participants who failed to exploit physical controllers likewise performed visibly more inferior in VE.

Observation 3

Some players failed to apprehend boundaries of the game area. Meaning the players might have lost a sense of boundaries or was unable to perceive them at all. The phenomena occurred in situations when a player had teleported to the edge of the navigation area to interact with a collectible item. After the interaction, those players kept trying to perform teleportation to the outside of the area. Likewise, they kept visually searching for collectable items from further parts of the level where none was to be found. Fortunately, most of the players were busy focusing on the task of collecting vibrant colored items and did not encounter moments of being lost.

6. Determinations

Given section presents the various findings and fully automated real-time data communication system. The primary data analysis results are also presented.

6.1. Deficiencies of implemented technical solution

A Potential automated solution that aims to diminish manual setup and labor related to data collection is described in the Section 6.2. However, it is relevant to point out the technological shortcomings of a given system. The drawbacks of the defined state of the art real-time data collection implementation lay in UDP plug-in. Specifically, there are two ways the plug-in could to be improved. Firstly, the number of inputs is currently restricted to 20 floats and 3 integers. Shortcomings limit to gather all desired data. In a given experiment locomotion data of motion, controllers were not collected, also locomotion data of virtual positioning of the player was left out. Both, former and latter data may prove itself to be crucial in future research and should not be considered obsolete. Therefore, at least 18 additional float inputs would be needed in UDP make an array node. Secondly, the data sampling rate is required to be higher than 1Hz — the reason being that during a one second period player can go through multiple consecutive actions. For example, a player can collect more than one similar object or teleport numerous times during the 1 second period. Keeping data sampling rate low results in gradual data, which might complicate data analysis and visualization in the future. Using a higher sampling rate with the current system would result in noise enriched data. The first described issue is solvable through rewriting and compiling the plug-in source code. Same cannot be stated concerning the second challenge, as the author has not researched this matter. It might become evident that some other data communication solution besides UDP plug-in might become necessary to achieve higher sample rates.

6.2. Fully automated real-time data communication system

During the experiment, no technical errors occurred and given system proved itself to be reliable in given condition of low data sampling rate. Therefore, the system which consists of current components can be automated. The level of automation possible with the present method is still unclear since the scope and amount of data determined to collect is not defined. Using an automated system, however, would diminish the need for the conductor's labor. Therefore, it enables to gather a large amount of data with less effort. The author suggests three possible complexity levels of the real-time data communication system can be automated.

Level 1 automation

Local network solution where data is collected in a single computer. The filled form is needed to be completed only in once, and game sessions are sequenced in series. The Python script is running in the background at all times in idle mode and is ready to communicate UDP data to the SQL at all times.

Level 2 automation

All of the described features in level 1 is applicable. Additionally, a python script is compiled into an executable program file and starts up with the game. Thus, running only during the times the game is used. In level 2 automation the collectible data properties should be editable through the executable program.

Level 3 automation

Network solution with all of the described features of previous levels being applicable. Level 3 is characterized by employing the system simultaneously in multiple computers that run a VR-based application. This requires building an online SQL database and using multiple SQL data tables. In given level, python script and UDP plug-in can be discarded and Unreal Engine 4 multiplayer and server communication classes could be used. Level 3 might require building online version update system for the application.

6.2.1. Additional requirements

As there would be no conductor to assist the players all the VR-based applications using various level of automated real-time data collection systems require a great tutorial level or other forms of guidance. Secondly, all the complexity levels need to communicate with an internet browser to open web-based questionnaire after game sessions. Given aspects consequently require the computer to be connected to the internet. The implementation of game and browser communication can be developed using UE4 blueprint scripting. Additionally, the questionnaire data can automatically be communicated to the SQL database. Automation can be implemented through Google apps scripts form service. It allows requesting data from Google Forms and saves it for processing into the database. In any level of automation, however, the data inputs from the survey cannot be provided in real-time for the reasons described at the beginning of Section 4.5.3.

Level 1 and Level 2 automation would still require some form of human labor. Bearing in mind, in those automation levels the data would be collected into a local database, so it involves data retrieving from the computer. Therefore, it is prudent to implement these levels of automation also with online SQL database. Storing data exclusively online allows exploiting the data both in time and location independent and enables to develop and apply real-time data analysis and visualization.

Any level of the automation should be developed into some form of UE4 plug-in where the current functionality of UDP plug-in is also included. Additional standalone UDP socket capture software would be needed if considering level 1 and 2 automated versions. Developing a plug-in solution would detach the system from defined VR-based application and make it independent. Thus, it can be used with a range of various VR applications and benefit in a more significant amount of data.

Automation of the suggested, currently in state-of-the-art, real-time data communication system level should be considered in regard to the end goal in mind. Level 3 automation is only justified if it is desired to be included in third-party commercial VR-based applications. Otherwise, the time required for developing a system with such complexity is unreasonable.

6.3. Experiment

The experiment and its methods can be considered as a viable solution. It can be further automated and integrated into the real-time data communication system for VR-based applications. However, the sample of the on-going experiment needs further diversification and increase in size. Additionally, some determinations regarding the results and observations are presented in the given section.

6.3.1. The results of the experiment

The experiment can be considered a success. Important observations regarding the solutions viability and user behavior were made and Given data collection method proved to be viable. So, all the presented goals for the experiment were reached. In total, data of 40 game sessions and 20 participants were gathered. The analysis of the data and participant diversification was presented in the Section 5.

6.3.2. Conclusions of the observations

Given challenges point out the deficiencies of the VR-based application used for the experiment. Through user testing, which was lacking during the given VR-based application development phase, would reveal such deficiencies early. Discussed shortcomings that challenge a user are avoidable through better level design and profound user guidance in the tutorial level.

6.4. Data

Based on acquired data through experiment three conclusions can be drawn. Each determination is only preliminary and is intended to show potential future directions of how further data analysis based on more extensive data quantity can be employed.

6.4.1. Suitability of Current data inputs

It appears that the data collected in the frame of this experience is relevant and none of the inputs can be considered obsolete based on the given thesis. Inversely, there should be additional inputs from motion controllers and player's locomotion regarding virtual environments coordinates. As there exist two types of generated data, locomotion and interaction data, all the data regarding interactions should be considered as a possible input when the data collection system is employed on some other VR-based application. The reason for that is that the locomotion data inputs are common to all VR-based application, but interactions can be diverse. Data gathering method proves itself capable, and all the collected data was analyzable. Therefore, any additional modifications that are imposed by data are not required.

6.4.2. A necessity for user guidance

The need for user guidance in VR experience seems apparent and various data presented in the given thesis express a necessity for introductory instructions or tutorial level in VR-based applications. Firstly, shown by generated data in the Section 5.2.1 participants who possessed previous experience in virtual gaming were more successful in completing tasks in VR-based application than participants who did not have any. Secondly, illustrated by the subjective data, the participants who were more successful in completing tasks in VR-based applications were experienced a higher degree of immersion. Taking above into consideration alongside with interaction type dependencies the need for introductory tutorial levels in VR-based applications can be confirmed. This instructional level, however, should first and foremost focus on the first type of interactions that prove themselves vital for completing the dependent second type of interactions.

6.4.3. Joyful learning experience

VR-based applications are often developed for educational purposes since they have proven to be an engaging way of learning. VR-based educational applications have also shown to deliver learning within higher pace [6]. Meaning that students acquire and improve their skills faster compared to conventional methods. This way of learning can also be confirmed by the data presented on Table 4 as the participants, some of whom had no previous VR experience, were able to improve their performance notably with just single game session. Although tasks in a given VR-based application were rather simple, the results serve as a proof-of-concept. Since most of the participants had no previous experience with given VR-based application, we can state that during the first game session participants learned to use them, and during the second session they improved their skills. Therefore, the experience can be counted as educational towards acquiring behaviors for using this particular VR-based application. Based on subjective data collected via questionnaire the experience was also considered enjoyable by the participants and most of the participants would like to use VR-based applications again which confirms the enjoyable part of the experience. The reasons of why VR-based learning might be providing such educational benefits are further discussed in the Section 7.

7. VR as a facilitative way for behavior acquirement

The purpose of the given thesis is to pave the way to a framework for the analysis of human behavior in VR-based applications. The data-based analysis allows explaining dependencies between stimuli or NULL stimuli and response. Data about relations enables to design VR-based applications where a user would always produce prescribed reactions to stimuli in a VE. However, the author believes it is vital to provide a complete toolset which, besides dependencies, would also describe requirements for successfully passing new behaviors on to the user. Therefore, the framework is also meant to give directions on how to influence a VR user to acquire or improve skills. Skills taught by VR should translate practicable in real-world at the same time being achieved with less time and higher performance rate. The taught behaviors can be considered as an education mediated through VR. Consequently, prominent learning theories [45, 46] can be used to provide hypothetical reasoning how VR can be utilized as an education method and why it shows positive results on this behalf already today [47, 6].

The following section focuses on finding the base on why VR is an excellent way for education and how the technology can be used for teaching new behaviors. The author was led to writing this section by the gathered data which showed VR as a swift way to obtain new skills. Research in the field of VR as an education method is also well researched in the scientific field [48, 49, 50, 51, 52].

7.1. Experiential learning

The idea of experiential learning originated from the writings of Dewey, Lewin, and Piaget and conceptualized into a complete model by [53]. The idea places experience in the center of learning rather than an accumulation of scholarly facts. Compared to conventional education method Experiential Learning Theory (ELT) suggest that new knowledge is acquired not by remembering facts but by transforming personal experience into insight. By [53] this is achieved by cycling through the four-step cycle of (1) *concrete experiences* which are a basis to (2) *observations* which are then gathered into (3) *abstract concepts* from which updated form of action can be (4) *actively tested.* The theory based teaching has been tested and researched in various fields from computer science to law. Although more research and data is needed, the approach shows the promising result as stated by [46].

7.1.1. ELT and VR

The aim of a VR-based application can be one of various discussed in the given thesis. However, no matter how the VE is directed the centric goal of VR can always be considered to provide an experience. The experience of which the user cannot undergo in a real-world environment. Or the recreation requires an unreasonable amount of resources to establish. Considering that VE is naturally experience-based, experiential learning can be mediated. A custom immersive virtual world can be created to provide the learner an experience to train a skill which would then translates into relevant real-world knowledge. Skill, however, should be considered as a set of behaviors and as stated by Skinner: „To acquire behavior the student must engage in behavior" [54]. Today, VR provides a superb opportunity to engage students in a range of behaviors which can set by characteristics of the scenario, level design, and interactions. What is more, the learner is available to train the same behavior an infinite number of times. Various studies have already shown positive results of utilization of ELT in VR [55], however, some of which replace VR with more conventional desktop simulation environments [56, 57].

7.1.2. Examples of ELT in VR

Although VR provides opportunity through immersive virtual simulation to facilitate educational components in an interactive experience, it is still considered new technology in the field of education. Thus research in the given area is usually conducted using a control group which receives a conventional type of education and experimental group receiving VR-based teaching. Employing VE as a training ground is proven to be an accelerated manner for skill acquisition as determined by [6]. The conducted research found that residents who practiced laparoscopic cholecystectomy using VR-based application significantly improved their performance to those who used conventional ways. Later, performing given procedure on patients, the residents who received VR-based training exhibited a smaller margin of error and concluded the operation faster. In [44] VR-based construction safety collaboration platform was proposed. As the VR-based application allowed the users to experience situations expensive to recreate in real-world conditions the need for such systems were confirmed. The study resulted in a prototype system, which showed great potentiality to reduce possible accidents proactively. Another relevant research [56] which ventured on harnessing the benefits ELT and 3D virtual worlds found that experiential based environment cultivated experiential development of interdisciplinary communication apprehension and tactics.

The determination presented in the Section 6.4.3 shows that even the VR-based application used in the given thesis can be considered as an example for experiential learning. As the tutorial level was removed for the experiment, the participants needed to learn the new behaviors through their actions, from which they were able to get instant feedback to make observations. They were then able to translate the observations into abstract concepts, which they were able to test immediately. Therefore, the participants learned through experiencing their behaviors.

7.1.3. Benefits of ELT in non-virtual simulations

A trend toward the use of simulations in classroom setup was already described in 1969 by [58]. Although the simulations were physical and often complex, they demonstrated a way of experiential learning. Rogers describes the simulations a means through which a learner becomes deeply involved and not only has to act but also assume responsibility for his actions and running the simulation — thus serving as a way of self-initiated learning. He also discusses the rise and potential of programmed instructions as an experiential learning method. Although mechanical, this method can be considered as a very early predecessor of computer and VR-based learning. Rogers found programmed learning as a leap forward for meeting the huge need for functional education. The method, however, provides immediate knowledge via feedback about the correctness of the behavior. Therefore, the student learns rapidly to be right and feels free from the uncertainty of his success or failure [54]. The instant feedback loop is also a feature which benefits VR-based learning.

7.2. Person-centered education

Another learning theory that seems to have characteristics similar to what VR can provide is learner/student/person-centered education theory. The approach utilizes most of the attributes of ELT but compliments it with humanistic components such as empathy, unconditional positive-regard, elimination of external grading and encouragement to critical thinking. Although the models of the theory vary throughout the years from the 1950s to 2000s, the results of the use of the method show above-average associations with positive learner results [59]. The principles presented by the theory are meant to create a fertile psychological climate in which student archives higher quality learnings. Some of the psychological aspects are already native to VR-based applications, and others can be consciously implemented during the development. Therefore, the theory and its possible use are presented.

The most recent framework of the theory was concluded by the American Psychological Association (APA) [45]. The framework was developed for schooling. Therefore the well-regarded theoretical model of the necessary features presented by [58] is used in the given thesis. However, only principles relevant to VR-based education are presented.

1. the principles about learner:
    (a) Much significant learning is acquired through doing.
    (b) Significant learning takes place when the subject matter is perceived by the student as having relevance for his/her own purposes, when the individual has a goal he/she wishes to achieve and sees the material presented to him/her as relevant to the goal, learning takes place with great rapidity.
    (c) Learning which involves a change in self-organization in the perception of oneself is threatening and tends to be resisted.
    (d) Those learnings which are threatening to the self are more easily perceived and assimilated when external threats are at a minimum.
    (e) When the threat to the self is low, the experience can be perceived in differentiated fashion and learning can proceed.
    (f) Learning is facilitated when the student participates responsibly in the learning process.
    (g) Self-initiated learning which involves the whole person of the learner feeling as well as intellect is the most lasting and pervasive.
    (h) Independence, creativity, and self-reliance are all facilitated when self-criticism and self-evaluation are basic and evaluation by others is of secondary importance.
2. the principles about the facilitator:
    (a) It is very important for the facilitator to set the initial mood or climate of the group or class experience.
    (b) The facilitator helps to elicit and clarify the purposes of the individuals in the class as well as the more general purposes of the group.
    (c) The facilitator endeavors to organize and make easily available the widest possible range of resources for learning.

(d) The facilitator regards himself/herself as a flexible resource to be utilized by the group.

(e) In responding to expressions in the classroom group, the facilitator accepts both the intellectual content and the emotionalized attitudes, endeavouring to give each aspect the approximate degree of emphasis which it has for the individual or the group.

Given principles are described in a classroom setup manner. At that time no modern forms of technology-based learning were yet developed. Principles are still applicable to VR. However, some modifications in wording are needed.

7.2.1. Student-centered learning mediated by VR

The principles mentioned above in the Section 7.2 are now regarded through the perspective of VR. The following description, however, is a conceptual idea of how VR-based applications full-fill the principles. Thus, ground reasoning of why VR is already today providing promising educational and training results. The term of facilitation is replaced with mediation since the former instead refers to a person, but VR is considered a medium.

1. the principles about learner through the perspective of VR:

   (a) The principles of learning by doing and its benefits are covered in the Section 7.1.

   (b) Relevance for purposes acts as a prerequisite for learning. Once fulfilled, however, mediating goal-driven learning through VR can have a tremendously positive effect. It can be illustrated by [6] where the resident was motivated to obtain the skill for performing a procedure.

   (c) The user is not judged nor evaluated by the VR-based application. He does not have to change his appearance nor values to fit the user requirement opposed by VE since there is none.

   (d) A VR-based application provides an opportunity to practice skills privately without observing group. Therefore eliminating potential social pressure and judgments which is especially crucial if the user is already inadequate in his abilities. On contractionary VE can provide a supportive and understanding environment at all times. What is more, the user can train according to his current skill level independent from the group.

(e) VR inherently is repeatable. Thus, the user is free to try out various scenarios for completing the simulation. The risk for failure is minimal since the user can restart the simulation. Additionally, actions in VE have no impacts in real-world. The feature is also considered as the main attribute of games by [60].

(f) VR simulations provide an opportunity for the user to choose his own set and sequence of the actions. Therefore, a user is solely responsible for the outcome. Freedom to choose a desirable simulation path is already well known in the gaming industry.

(g) VR-based learning is also self-initiated since it takes the user to start and use the application. User is therefore responsible for starting and running the simulation. Thus it can be considered as a self-initiated.

(h) VR-based application can be configured in such manner that it assigns no final grade to a learner but leaves the grade to be decided by a learner himself. One possible implementation for that can be leaderboard based. The learner can compare his result with others and decided to rerun the simulation or accept his outcome of the learning.

2. the principles about facilitator through the perspective of VR:

   (a) VE can be programmed to provide a variety of initial moods or climates. By [61], the VR-based application has the potentiality to improve emotional conditioning.

   (b) Multi-purposed VE can be developed, to provide a range of choice on how to train a skill. Simulation can ask a set of questions to determine the purpose of the user.

   (c) A VR-based application can be programmed in a manner to provide, materials and animated tutorial to aid learning. Additional artificial intelligence and internet-based extras should be considered

   (d) If programmed in assistance providing manner the simulation can be utilized by the user in an advisory way.

   (e) A VR-based application can be programmed to act accordingly to a particular set of user behaviors. Thus, they accept the attitudes and possible emotions od the user.

7.3. VR as a mediator of learning

VR proves itself to be an excellent medium through which learning can be mediated. The VR-based simulation should not be considered solely as a teacher or a resource for education since they can provide the functionality of both. However, the partition of the features is dependent on the complexity of VE. VR-based applications remove human bias and judgments from the equation of education and can be programmed to provide unconditional positive regard. Judgments are considered to be a significant threat and source of stress for many learners [58]. Using simulations have also become more noticeable in fields where real-world simulations are expensive to conduct or might result in hazardous outcomes when mistakes are made by learners [6, 44]. Potential adverse consequences undoubtedly increase stress levels of the learner as he ought to be successful at all cost. Considering that making errors in VR simulations does not have negative consequences compared to real-world training, the fear of failure is minimized. In contradiction, the freedom to learn correct behavior through misbehavior is encouraged via experience. Providing the user with freedom, responsibility, and experience while removing fear, negative consequences and judgments appear to be the keys why VR is a powerful medium for learning and behavior acquirement.

8. Conclusion

In the given thesis, a system and method for user behavior analysis for VR were suggested. Initial motivation and benefits were presented. Next, a development including tools, concepts, components, and workflow, of a complete and fully functional VR-based application was described. A UDP based real-time data collection system was developed for a VR-based application. The system was tested and validated through custom designed experiment. The experiment and data analyzation prove collectable data inputs relevant. Although the experiment is still an on-going process, the need for the instructional level was already confirmed. Finally, analysis exposed a tendency of the VR towards acting as a mediator of learning. The educational behavior acquirement aspect was then further researched and hypothetical reasoning provided.

Considering the presented work regarding the research questions of this thesis we can provide answers to all of them. A UDP based data transmission system proves itself viable. The real-time data gathering system was tested on a VR-based application of which development workflow was presented. The data inputs, collected from the VR-based application were all relevant. Moreover, additional data inputs, such as the player's location in VE should be collected. Analyzed data showed that the user experience in VR-based applications would be better with tutorial level and the introductory level should be focusing on teaching the user the interactions of the VE. Using the previous studies and learning theories reasons were presented why and how VR can be utilized educationally were given. Taking into account the outcomes, we can say that all the goals of the thesis were achieved and the first step towards a framework for the analysis of human behavior in VR-based applications has been made.

8.1. Future works

From the practical side, the real-time data communication system for VR-based application needs to be improved. Notably, the data sampling rate should be adjusted. Improvements would result in more accurate data, based on which accurate predictions and models can be developed — the suggested automation of the system would reduce a time for data collection and analysis processes in total. Additionally, the automated system would make the data collection more convenient as the sample size is expected to grow exponentially. A future sample of experiment participants should be more diversified. It should also include selection individuals who have not yet been able to achieve a higher level of education due to their young age and those who have not desired to do so. Also, participants from various age and education groups need to be included. To make significant conclusions the demographic diversification of the sample should imitate one represented in real society.

From the theoretical perspective, the hypothetical explanation of why VR appears to be a mediator for the learning needs further research. Although some aspects of the suggested principles are already backed by research, more studies have to be conducted to validate the explanation. Additionally, the relations between presence feeling and VR-based education efficiency need clarification. The presented method and tool for real-time data communication can be employed to conduct future theoretical work.

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