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Analysis of a Quality Evaluation Model for VR Contents

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Abstract

Recently, virtual reality (VR) industry is growing explosively as one of new business that may lead ICT industry of next generation. Owing to box office success of VR contents, supplier's market spreads to buyer's market and sustained ecosystem of industrial growth would be provided. Under this background, now is the time to require test guide of VR contents that could be played by the users safely and comfortably. VR environment based on purchasable head mounted display (HMD) has a common problem of cognition unconformity and uncomfortable VR experience arousing motion sickness and vomiting seriously discourages diversified consumption desire of VR contents of the users. Therefore, in this study, evaluation model case of VR contents was surveyed based on theses at home and abroad. This paper proposes quality evaluation method that follows the current widely accepted approach for user interface evaluation that extend it specifically for VEs. This also attempts to unify the quality evaluation with presence assessment in VR specifically the quality evaluation method for VR has been applied. As early stage of market, it could be confirmed that relevant research would be required and as a future research, deduction of quality evaluation model of VR contents was suggested by analyzing and linking evaluation methodology of international standard and 3D game contents.

Keywords: *Virtual Reality, Quality Evaluation Model, Test Guide*

1. Introduction

Recently, virtual reality (VR) industry is growing explosively as one of new business that may lead ICT industry of next generation. Virtual reality refers to a computer-generated environment which provides viewers with visual illusion and sensation of being inside an artificial world that exists only in the computer. It is also referred to as immersion technology and the extent of immersion may vary based on the system characteristics and context of virtual model. Immersion creates a level of sensory fidelity which depends on measurable system attributes such as field of view (FOV), display size, stereoscopy, display resolution, head-tracking, or input devices [1]. VR system types can be categorized as non-immersive systems such as desktop computer systems, semi-immersive with large, multiple screens or monitors that provide a medium to high level of immersion, and fully immersive systems such as head-mounted displays.

It is expected that the virtual reality market will grow into gigantic market having scale of tens of billions of dollars for the couple of years to come even though its detailed scale is different depending on each institution [2]. Deloitte Global predicted that virtual reality have its first billion dollar year in 2016 onward with about $700 million in hardware sales,

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and the remainder from content. The estimated sales is about 2.5 million VR headsets and 10 million game copies sold. VR have multiple applications both consumer and enterprise where the vast majority of commercial activity focuses on video games. As expected, the majority of spending on VR to be by core rather than casual gamers. This implies that while anyone with a smartphone could try out a variant of VR, the majority of VR's revenues will likely be driven by a base of tens of millions of core gamers rather than the hundreds of millions of occasional console or PC gamers, or the billions who play casual games. In addition, diversified VR technology and hardware device have been rapidly developing under convergence with cultural contents including military, medical service, fire fighting, and games. However, due to its lack of killer contents, VR still remains at supplier's market.

Supplier's market means a market led by manufacturers of various VR device and computer graphic card, communication companies that are required to sell more network based on minor early adaptor for creating new growth engine. Eventually, conversion to buyer's market is required based on general public awareness and it could be developed continuously only when an ecosystem of virtuous cycle among investors, manufacturers, developers, platform companies, sellers and consumers is constructed. At present, VR environment based on purchasable head mounted display (HMD) has a common problem of cognition unconformity and uncomfortable VR experience arousing motion sickness and vomiting seriously discourages diversified consumption desire of VR contents of the users.

In order to solve this problem, it shall be overcome through improvement of software quality and in order to ensure safe and comfortable VR environment experience of the users, test guide of contents is required. This paper proposes quality evaluation method that follows the current widely accepted approach for user interface evaluation that extend it specifically for VEs. This also attempts to unify the quality evaluation with presence assessment in VR specifically the quality evaluation method for VR has been applied.

The paper is organized as follows. First, the case study of quality evaluation method is discussed and applied. This is followed by evaluation of the method to assess the reliability of the utility of the method itself and the cause that give rise to cognition unconformity and goal of quality improvement were discussed. The paper concludes with a discussion of future research on evaluating virtual environments.

2. Related Research

Numerous researches has formed the basis of virtual reality as it appears today such as the use of head-mounted displays [3], and projection-based virtual reality [4]. The display technology evolved from the usual panel-mounted to the head-mounted. VR applications emerged from the 1960s but it is recently that the technological advances enabled the applications to gain momentum within the industry. Different technologies that enabled the development of virtual reality converged to create the first true VR systems. Despite the development of virtual reality technology over a long period, VR has just begun to shift away from the purely theoretical and towards the practical [5]. VR system are starting to demonstrate practical effectiveness in real industrial settings [6]. However, current VR system designs encounter many issues that are needed to be resolved.

Problem recognition and problem definition in the early conceptualizing stages are vital to virtual reality design. Several studies have identified problems associated with the use of virtual environments [7]. The design principles have been applied to evaluate desktop VR applications [8] and checklist evaluation methods have been adapted for VR [9] where it shows that VR designers have demonstrated the need for HCI knowledge and methods [10]. As in the case, VR designs cannot rely solely on the methods developed for standard graphical user interfaces (GUIs) since their interaction styles are radically different from standard user interfaces [11], numerous studies have followed observation and expert interpretation of user errors [12] or experimental studies reporting performance data and problems in a range of virtual environment technologies [13].

Quality evaluation of virtual environments has also focused on evaluation of presence, which involves if how real or natural the user's experience was when immersed in the environment. Presence can be evaluated through the application of questionnaires which ask users to rate various qualities of the virtual environment ranging from perceptions of being there [14] to more detailed inventories ranking controls, feedback, perception of realism and user engagement [15]. While presence measures can benchmark virtual environment designs in terms of their realism and overall user experience, they do not help to diagnose design flaws for quality evaluation.

3. Virtual Reality Contents Quality Evaluation

Virtual reality contents quality evaluation is essential to resolving the relevant issues in VR. In real world, the VR problems encountered are classified and assigned for evaluation. By establishing a set of representative tasks, quality evaluation can be done with the classification of problems and interpretation of values.

3.1. Quality Evaluation Method

The quality evaluation method to be employed in this case study is based on recommendations for quality evaluation. Since virtual environments are constructed to represent the real world, user tasks should ideally mirror real world action. However, in real scenarios, limitations of technology mean that some compromises have to be accepted. Even when the virtual environments represent an artificial world such as a complex information space, the users' ability to move in the VE will necessitate mapping real world actions to VR technology. As such, an additional step to quality evaluation method for virtual reality contents is introduced. This technology evaluation method establishes the baseline of what the virtual environment can reasonably be expected to deliver based on the interactive devices present in the applications and is carried out in the familiarization period.

3.2. Virtual Reality Evaluation Guide

The baseline guide to evaluate the quality of the virtual reality design and diagnose design features responsible for the problems encountered is presented. The following evaluation guide attributing to problems of classes of design features. See Table 1 below.

Table 1. Class of Design Features

Class of Design Feature	Description
Graphical display	Identify the poor resolution of image in graphical display, 3D depth or perspective distortion as indicated by perceptual difficulties
User presence	Determine if able to move and manipulate user presence and if there is representation of the user as indicated by navigation and manipulation difficulties.
Interaction with objects and tools	Check the interaction with objects and tools as indicated by unsuccessful attempts to act or there is poor feedback which misleads users
Environmental features	Identify parts of the environment which created unexpected effects such as moving through walls and floating objects
Interaction with other controls	Determine if there is interaction with other controls, such as floating menus and palettes
Other hardware problems	Inspect other hardware problems, such as with head-mounted display and shutter glasses

Through the design features of virtual reality allows the contents evaluator to identify and diagnose the classes of problems by assigning them with values. This can be done by ranking the severity of the problems. Indications of the severity of the identified problems are given, ranging from poor design with a severe impact likely to result in task failure to a minor problem which are fixable by training. The severity ranking reflects the number of errors assigned to each value using four-point scale [16] shown in the Table 2 below.

Table 2. Virtual Reality Evaluation Ranking

Severity Ranking	Description
Severe	The problem encountered would make it impossible to complete the task successfully
Annoying	The problem would disrupt the user's task but most users would learn how to cure the error given an explanation, and some might find a work-around with time
Distracting	The problem would disrupt the user's tasks but most users would discover the fix relatively quickly given a hint
Inconvenient	The problem could disrupt the user's task but most users would discover the fix unaided.

The severity rankings provide a summary of quality evaluation of the virtual reality contents by prioritizing areas for design improvement in the future version.

3.3. Cognition Unconformity and Goal of Quality Improvement

As experience of VR environment is based on technology of transition period, software supporting such tool has various problems [17]. As a typical problem, cognition unconformity is taking place as immediate background screen conversion is not made depending on viewpoint change of users and this is major common cause arousing motion sickness and vomiting even though there is level difference depending on each user. This problem could be solved by maintaining scanning rate and quality evaluation team of Oculus that is a typical company initiating VR times said that what's most important besides fun of contents is scanning rate and guide contents of such team at 2016, April 'United 2016 Seoul' lecture is summarized and cited as follows.

Scanning rate shows how many sheets of screen is displayed per second and as the more its rate is high, displayed image looks soft and realistic, users could enjoy game comfortably. Scanning rate supported by Oculus' HMD Oculus lift is max. 90Hz. Therefore, 90fps, that is, 90 sheets of screen per second could be shown to the users as shown in Figure 1. Contents launched in 'Oculus share' that is Oculus lift exclusive store is required to receive Oculus QA team check in advance and QA team decides launching status by determining whether contents are appropriate for commercialization. As VR market is at its early stage, Oculus' policy is to raise completeness of contents by strictly applying evaluation standard. Launched contents are required to support 90fps entirely and if frame is lowered during use, sale of contents is not permitted. If game lower than 90fps is provided, user will feel dizzy and resultantly, VR experience will end up with failure. If game performance under production is unable to be improved, it is important to provide 'full frame' even at the sacrifice of game resolution [18].

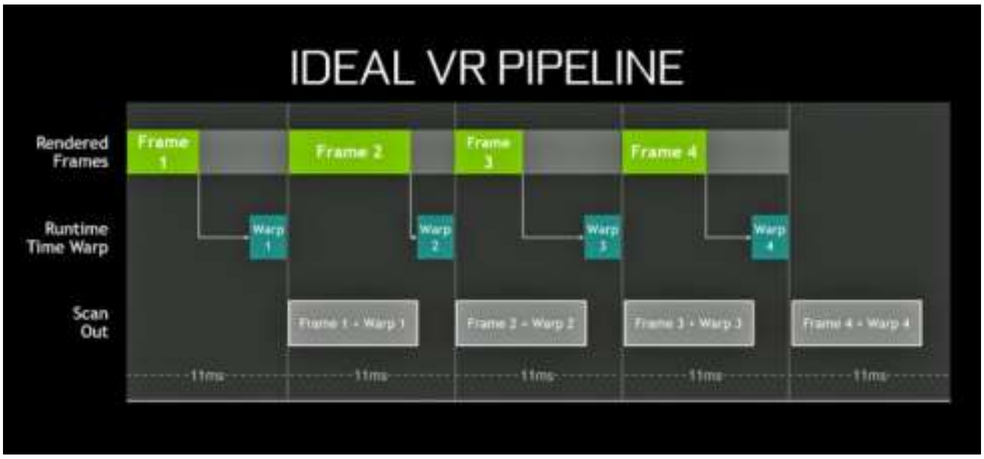

Figure 1. Ideal VR Pipeline

Users exist in VR environment but if surrounding environment fails to come along with fast time conversion, our body experiences big confusion and as cognition unconformity like sea sickness is taken place, user may encounter uncomfortable experience. Therefore, in real time 3D environment, while displaying data object on screen, maintaining frame consistently even under fast time change becomes the most important contents evaluation standard. In case of development of VR software utilizing head mounted display, its goal of quality improvement shall be focused on increasing user convenience and immersion through improvement of picture quality and delayed time and it is expected that through this, motion sickness or vomiting symptom that is indicated as the biggest problem by VR device users would be relieved.

Several features of virtual reality contents where problems or issues can arise are user presence, interactive techniques and realistic graphics. In user presence, the feature allows the user to be represented in the virtual world by a simple cursor or more commonly by a hand or a whole body avatar. The presence may be controlled by a variety of devices ranging from 3D mouse, space ball, joystick to pinch gloves and less frequently whole body immersion suits.

Interactive techniques create numerous virtual environments implement controls that allow users to fly through the virtual environment to reach and select distant objects by ray-casting. This can be taken further by providing magic 'snap-to' effects so nearby objects automatically jump into the user's hand. Also, realistic graphics is important for information displays and for tasks when the system environment is visually complex despite the fact that virtual environments do not provide realistic presentation of the prototype since most applications are not rendered in photorealistic detail.

3.4. Requirement Analysis of Virtual Reality System

In virtual reality, user is placed in a real-time simulation and immersed in a world that can be both autonomous and responsive to its actions. The requirements for virtual reality applications are defined in terms of input and output channels for the virtual world simulation as shown in Figure 2.

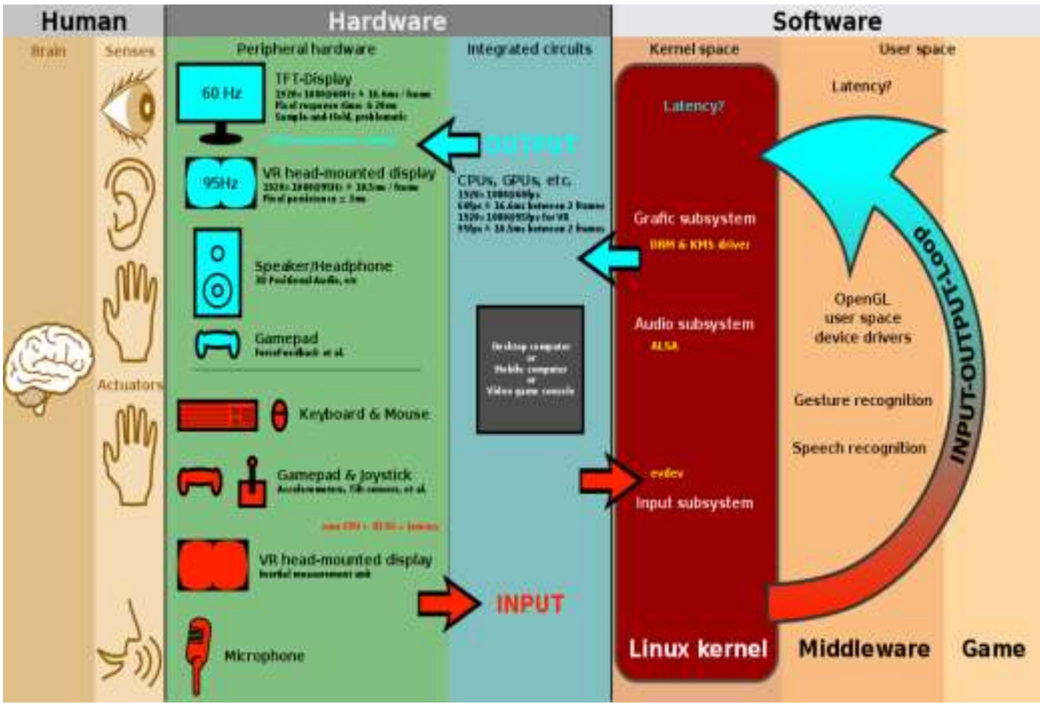

Figure 2. Paramount for the Sensation of Immersion into Virtual Reality (source: Wikipedia)

3.4.1. Input Channels

The input channels of a virtual reality application are categorized as something which enables humans to emit information and interact with the environment. They interact with the world mainly through locomotion and manipulation and convey information by means of voice, gestures, and facial expressions [19]. Communication using gestures as well as locomotion make full body motion analysis desirable, while verbal communication with the computer or other users makes voice input an important option. It is possible to limit user input to a few selected channels. As the hand offers many more degrees of freedom concentrated in a small area than any other part of the body, hand motion tracking is sufficient for most applications. Moreover, the fact that the hand is our privileged manipulation tool makes hand motion tracking a critical input for interacting with virtual worlds. Viewpoint specification requires real time motion tracking of the user's head, and possibly eyes, in order to update displayed stereo images in coordination with user movements.

3.4.2. Output Channels

The output channels of a virtual reality application correspond to human senses namely: vision, touch and force perception, hearing, smell and taste. As such, sensory simulation is at the heart of virtual reality technology.

1. Visual Perception. Vision is generally considered the most dominant sense, and there is evidence that human cognition is oriented around vision [20]. High quality visual representation is thus critical for virtual environments. The major aspects of the visual perception that have an impact on display requirements are the depth perception, accuracy and field-of-view and critical fusion frequency.
2. Sound Perception. Hearing is mainly used for verbal communication in order to get information from invisible parts of the world or when vision does not provide enough

information. Audio feedback must be able to synthesize sound, to position sound sources in 3D space and can be linked to a speech generator for verbal communication with the computer. In humans, the auditory apparatus is most efficient between 1000 and 4000 Hz, with a drop in efficiency as the sound frequency becomes higher or lower [6].

3. Position, Touch and Force Perception. The haptic sense is capable of both sensing what it is happening around the human being and acting on the environment. This makes it an indispensable part of many human activities and thus, in order to provide the realism needed for effective applications, VR systems need to provide inputs to, and mirror the outputs of, the haptic system. The primary input/output variables for the haptic sense are displacements and forces.
4. Olfactory Perception. Specialized applications exist where olfactory perception is of importance. One of these is surgical simulation, which need to provide the proper olfactory stimuli at the appropriate moments during the procedure. Similarly, the training of emergency medical personnel operating in the field should bring them into contact with the odors that would make the simulated environment seem more real and which might provide diagnostic information about the injuries that simulated casualty is supposed to have incurred [21]. A VR environment giving olfactory cues should provide the possibility to diffuse the odors when needed and purify and filter the air when the cue is no longer required.

The analysis of the requirements in terms of input and output channels has highlighted performance requirements for the simulation of existence of synthetic objects. Successful virtual reality applications must combine new input and output devices in ways that provide not only such an illusion of existence of synthetic objects, but also the interaction metaphors for interacting with them.

4. Analysis of Quality Evaluation Case of VR Contents

Quality evaluation case based on qualitative indicator for VR contents is rare as its quality and quantity based on software and hardware technology being developed at present are at an early market stage and quality evaluation model is also at an early research stage.

4.1. Development of VR Software Quality Features

As demand for VR software is increased suddenly, quality features of software in a perspective of users and developers was explained based on international standard defining quality determinant and features of software and matrix of its quality features and evaluation after dividing evaluation procedure into quality requirement definition stage, evaluation preparation stage, evaluation stage by using international standard, ISO/IEC 9126 as shown on Figure 3 that was mainly used for quality evaluation of existing software.

Figure 3. ISO/IEC 9126 Quality Evaluation Model

In this study, major quality features being applied to VR software was divided into functionality, reliability, efficiency, maintainability and matrix of mutual operability, fault tolerance, operability, time behavior, changeability was deduced and it was digitized and quality determination is suggested by applying deduced matrix to scenario matching with VR software.
One method to improve the information representation is through the development of virtual prototypes that can be experienced in virtual reality (VR) environments. The following evaluation procedure in Table 3 comprises the tasks to be done in evaluating the quality of VR systems.

Table 3. Division of Evaluation Procedure of International Standard into Quality Requirement Definition Stage, Evaluation Preparation Stage and Evaluation Stage

Evaluation Procedure	Contents
Definition stage of quality requirement	Define quality requirement by preferably using sub-ordinate quality features
Evaluation preparation stage	Set grade standard and define determination standard by preparing matrix that could measure quality requirement and express it quantitatively
Evaluation stage	Determination by assigning grade after actual measurement

The fact that virtual reality software is intrinsically difficult to design and implement emphasizes the importance of user interface tools, such as toolkits, frameworks, user interface management systems, or graphical user interface builders.

Current systems supporting virtual reality software construction are toolkits and authoring systems. Toolkits are programming libraries that provide a set of functions for supporting the creation of a virtual reality application. Authoring systems are complete programs with graphical interfaces for creating worlds without resorting to detailed programming. These usually include some sort of scripting language in which to describe complex actions such as VRML. While simpler to use, current authoring system do not offer all the functionalities of toolkits.

A typical VR toolkit provides supports for high-speed rendering, low-level interfacing with a variety of input devices, a few built-in interaction metaphors, graphical database support with converters to/from a variety of formats, and an event model for interactive application programming as shown in Figure 4[22]. The increased power of parallel processing is essential to meet timing constraints in real applications.

User interfaces software is intrinsically difficult to design and implemented, and there are reasons why this type of software will always be among the most complex to create. Developing virtual reality applications is an even harder challenge, since it involves the creation of a software system with strict quality and timing constraints dictated by the needs of sensory simulation and direct 3D interaction.

In addition to the quality evaluation model, some quality features of VR software in this study are described as follows.

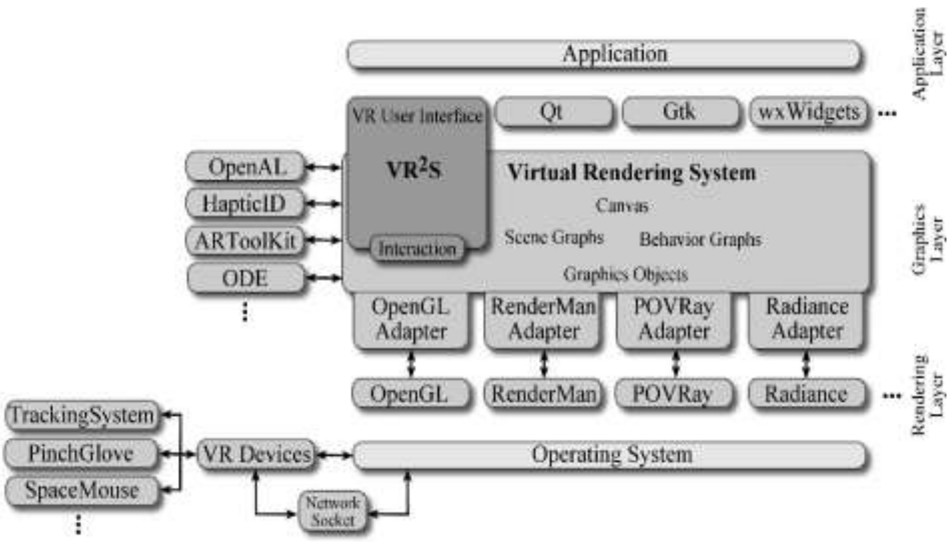

Figure 4. A Generic Virtual Reality Software Systems Architecture

4.1.1. Modularization

The ease of creation and maintenance of a piece of software is improved by decoupling it in units with very weak coupling, so as to develop and test them in isolation. Unfortunately, a complete separation between user interface and application is very difficult to obtain. In particular, the need of semantic feedback associated to the different operation tends to increase the coupling among application and interface components. This fact often forces a change in application parts because of changes in the user interface.

4.1.2. Robustness

The contract model of software programming [23] is a way to specify and understand the behavior of software units. With this model, precondition and postcondition describe the benefits and obligation in the software contract that relates the software unit supplier to its clients. User interface software units is forced to have weak preconditions, since few assumptions can be made on the behavior of the external world. This makes its realization and verification more difficult.

4.1.3. Parallel Programming

Interactive applications have to model user interaction with a dynamically changing world. In order for this to be possible, it is necessary for applications to handle within a short time real-world events that are generated in an order that is not known before the simulation is run. Thus, user interface software is inherently parallel, and some form of parallelism, from quasi-parallelism, to pseudo-parallelism to real parallelism has to be used for its development.

All problems inherent to parallel programming have thus to be solved such as synchronization, maintenance of consistency, and protection of shared data. Furthermore, the multimodal aspect of virtual environment applications imposes the use of true parallelism [24], as the various components of an applications have to receive input and produce output at considerably variable rates such as 10 Hz for visual feedback and 1 KHz for haptic feedback.

4.2. VR Contents Test Guide

Quality evaluation model of VR being linked with empirical test knowhow of game contents in which real time 3D environment build-up technology that may borrow methodology defining requirement of major features at quality requirement definition stage based on international standard and matrix that could be expressed at evaluation preparation stage. See Table 4 for the test types in evaluation virtual reality contents.

Table 4. Quality Evaluation Test Guides of Korean Game Contents

Test type	Contents
Operation (progress) test	Installation, U.X. usability
Environmental test	Smooth drive and response speed under diversified hardware environments
Load test	Number of concurrent connected user and network stability test based on contents suitable for large scaled on-line access contents
User test	Verification of original contents objective and balancing

Testing VR systems enable the checking whether users are able to fully feel the presence effect of VR contents that serve as the basis for positive user experience as shown in Figure 5. VR systems are applied to PC games developed for VR such as HTC Vive, mobile VR applications and games, console VR games, and specific equipment for data input / output including base stations, controllers and headsets.

Performing functional testing of VR not only assess system core functionality, but also check the effectiveness of the VR content system by conducting basic usability checking, verify accessibility for end users, and determine and test error conditions. To make functional testing more efficient, requirements-based checking is performed under the design features and start testing the most critical design features. Functional tests apply black box methodology. In testing, a satisfied user means a success for software. Useful functionality, strong security level, and high performance of the product cannot overpass poor usability that causes negative user experience. Even excellent design will not prevent the users of a system leaving it immediately. Design features should support and ensure the achievement of users' goals without any inconveniences.

Usability distinguishes a solution out from the ocean of available similar ones. Based on requirements, and personal experience, a configuration list is formed and suitable methodologies to define common configuration combinations and evaluate system compatibility under different conditions are selected. In order not to miss software logical issues and avoid redundant checking, the specifications and system requirements are thoroughly examined. By prioritizing the product features and tests, evaluations of critical functionality first are provided. This methodology allows executed tests and recheck system functions in order to be always aware of the current quality of the VR solutions.

Conducting usability testing enables analysis of different product characteristics from the perspective of beginners and experienced users according to the developed checklists. In addition, ease of learning, product efficiency, system accuracy, and failure rate are evaluated in order to provide our customers with objective measurement of product usability. The gathering and analyzing of the user experience in real conditions allows the performance of usability tests on-site and examine user working environment. In order to check whether the solution satisfies user expectations, approaches for usability testing are applied which comprises of qualitative in order to detect major issues on the basis of product nature, and quantitative in order to check the consequences of changes and product redesign.

Moreover, load testing is the process of putting demand on a software system or computing device and measuring its response. Load testing is performed to determine a system's behavior under both normal and anticipated peak load conditions. It helps to identify the maximum operating capacity of an application as well as any bottlenecks and determine which element is causing degradation. When the load placed on the system is raised beyond normal usage patterns to test the system's response at unusually high or peak loads, it is known as stress testing. The load is usually so great that error conditions are the expected result, but there is no clear boundary when an activity ceases to be a load test and becomes a stress test.

Figure 5. Virtual Reality Testbed

4.3. Case Study of VR Quality Evaluation

A case study was carried out to test the applicability for the quality evaluation method. This study involves evaluation of historical museum tour where a fully immersive application using a HMD and hand-held interactive 3D mouse were used. It depicted a 3D environment of a historical museum. The user is able to explore the museum layout and was able to gather historical facts and history of the place. At several points within the VE application, pictures from the real environment have been inserted to help museum tour. The representative task was to locate and enter the entry points in the museum. The task involved the user walking through the VE several times, inspecting historical details in the rooms adjoining the museum, and finding the photographs embedded in the VE.

4.3. VR Case Study Evaluation Testing Analysis

Most of the problems encountered in the case study of the historical museum tour were caused by poor navigation support and the technological limitation of delays in updating the 3D graphics display when moving and changing viewpoint in the VE. The attribution of the problems and severity rating is given. The potential problems are also classified as requirements where clarification was needed from the user and software problems which could be rectified by the VE application designer and technology problems beyond the designer’s control such as hardware. Refer to Table 5 which shows the design features of a VR system and the problems encountered which includes the severity rating and the recommended improvement.

The graphics rendering problems were an inconvenience which could be fixed by running the application on a faster machine or improving the rendering algorithm. Floating objects were a perceptual distraction caused by poor shadowing. The interaction problem of not being able to move objects to explore the VE depended on interpretation of the user’s requirements. If the VE was intended to support further investigation, then there was a case for supporting such interaction; however, this raises a scope of modelling problem: how many objects should be movable and which hidden objects should then be visible? The user specification has to indicate the extent of the real world to be modelled in the VE, and this will depend on the extent of knowledge of the crime when modelling occurs. Given this limitation, a requirement for a less interactive memory system seems to be acceptable. The disorientation problems encountered when passing through walls and other surfaces could be avoided by adding movement constraints on the user's presence, although some audio feedback might be advisable to signal this limitation to the user.

Table 5. VR Problems Classification and Recommendation

Design Feature	Problem Description	Severity Rating	Recommendation
Interaction	Explore objects	Distracting	Requirement clarification
Graphics	Rendering delays, floating objects	Inconvenient	Hardware upgrade
Environmental features	Pass through surface	Annoying	Add movement constraints in the software
Controls	Incongruent photos	Distracting	Provide photo controls in software

5. Conclusion

Recently, virtual reality (VR) industry is growing explosively as one of new business that may lead ICT industry of next generation. Owing to box office success of VR contents, supplier's market spreads to buyer's market and sustained ecosystem of industrial growth would be provided. Under this background, now is the time to require test guide of VR contents that could be played by the users safely and comfortably. In this study, case of quality evaluation model of VR contents was analyzed. Research on quality evaluation model of VR contents based on quantitative indicator was rare and research on quality evaluation model of software was available but there was no research for indicator setting reflecting contents features. In case of game contents, its methodology of operation test, environmental test, load test, user pleasure element test including UX usability was constructed and game planner, programmer, graphic designers had already possessed know-how for real time 3D environment.

For a large number of application domains, the major limitation is now provided by software since no single system supports satisfactorily all the aspects of creation of a virtual reality application. Most of the time, different packages have to be combined, and ad-hoc solutions implemented to integrate them in a working application. In particular, the creation of appropriate time-critical multimodal VR architectures is an open research topic.

Quality evaluation model of VR being linked with empirical test knowhow of game contents in which real time 3D environment build-up technology that may borrow methodology defining requirement of major features at quality requirement definition stage based on international standard and matrix that could be expressed at evaluation preparation stage and implement VR is accumulated will be researched in the future.

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