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A New Approach of Virtual Reality Systems Evaluation and Quality Standards

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Abstract

At the present time, many virtual systems are being built and these systems need to be evaluated. The evaluation process is very important because it reveals the weaknesses and strengths of these systems and the possibility of developing them later. Evaluating VR systems is also crucial for ensuring their continued development, improving the user experience, and demonstrating the technology's value and impact. This paper reviews the current methods of evaluating VR systems and suggests a scientific method for evaluating VR systems. In addition, this study enters a new standard for evaluating an aspect of VR which is rarely mentioned in VR studies: security. The relationship between VR and security is complex, and there are many potential risks and challenges to consider. As with any new technology, it is important for individuals, organizations, and policymakers to carefully consider the security implications of VR as it becomes more widespread. Results show that most evaluation methods depend on people's personal opinions, which differ from one person to another (user experience). Thus, the proposed method and current evaluation methods are useful. This report also addresses VR quality studies, which will enable scientists, designers, and developers to begin human-centered research and product development.

Keywords: *virtual reality standards, virtual reality quality, virtual reality evaluation, virtual reality design, virtual reality planning.*

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1. Introduction

Virtual reality (VR) simulates a world that may be similar or distinct from the real world. It uses a headset or goggles to display virtual visuals and may integrate sound or touch. VR immerses users in a virtual world, making digital exploration more compelling. Gaming, entertainment, teaching, and other applications that require a realistic and dynamic virtual experience employ VR [1].

VR has become a popular topic in the field of information technology in recent years. Basic VR technology has been available as an idea since the 1960s [2] but its spread has been limited by the low specifications of devices, such as processors, as well as their small memory and high prices. A VR system consists of hardware and software, which affects the system in general. The VR system shown in Figure 1 illustrates the design and tracking of a VR system. Where this system is evaluated in terms of aesthetic design and the details of this design, the tracking system is accurate. This is called the degree of immersion, the higher the degree of immersion the better the system. The degree of immersion is also affected by the additions, sounds, and haptic.

Evaluation is an essential process that is of great benefit to the software industry. It identifies the strengths and weaknesses of software programs and, thus, the possibility of developing these programs in the future. Evaluation involves checking whether a program and the project it develops conform to different characteristics and display the different qualities expected of sustainable programs. More satisfying attributes mean a more sustainable pro- gram [3]. Software applications and systems are evaluated for performance, capability, and efficacy [4, 5]. Software functionality, features, usability, performance, dependability, and security are measured and compared. As well as determining software's robustness and shortcomings, evaluation helps identify opportunities for improvement, and make educated decisions about adoption, deployment, or development. It is crucial to guarantee software's solution quality, efficiency, and applicability for specific demands [6].

VR systems should be evaluated for numerous reasons; such as for assurance they are high quality and pro- vide a good user experience [7]. This can boost technological adoption and confidence. Users can also submit comments on the VR system during evaluation, which can help developers, construct more interesting and productive experiences. It can also identify VR system improvements such hardware constraints, software issues, and unsuitable content. Additionally, evaluation can quantify a VR system's efficacy in boosting education, lowering medical symptoms, or promoting brand or product engagement [7–9]. Finally, evaluation can inform future VR system development by revealing systems' strengths and flaws and users' needs for more functionality or better experiences [10, 11, 53].

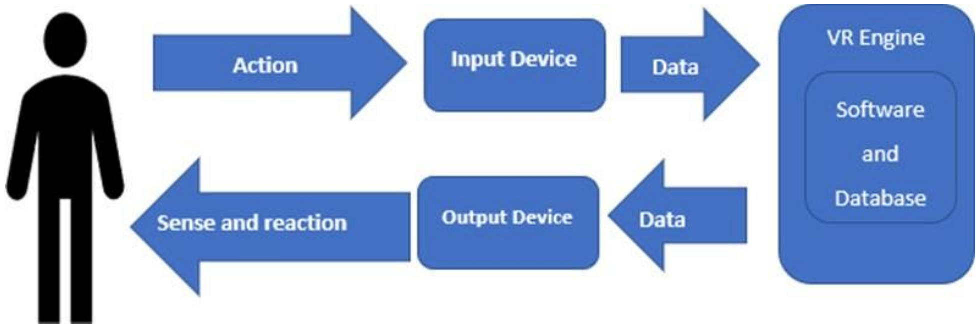

Figure 1: Virtual reality system

There are a number of typical VR system components. The user sees the virtual world on a head-mounted display (HMD). HMD shave two displays–one for each eye—and may have head phones. There is also a tracking system that tracks the HMD and other input devices like hand-held controllers. This information updates the virtual world in real time, allowing users to move and interact. Controlling the virtual world requires input devices including gloves, controllers, and body suits. Another component of the VR system is a powerful computer that runs the VR software and creates the virtual world [12, 54]. VR requires strong computers for real-time rendering and tracking. Virtual environment graphics are generated and shown by a graphics card. The VR experience creation and operation software is another typical VC system component. Examples of this software include game engines, VR platforms, and development tools. Sensors such as accelerometers and gyroscopes can improve VR tracking and interactivity. Power and data cables are also important VR system components. The cables are used to connect the various components of the VR system and provide power and data transmission. While the main components of a VR system have been identified here, different VR systems may include additional oral tentative components, depending on the specific needs and requirements of the application [13–15, 54].

There are several other concepts related to the concept of virtual reality, including augmented reality (AR) that is adding digital objects to the real physical environment to enhance this environment with these digital objects, which allow the user to interact with these digital objects. There is also mixed reality (MR). MR is a combination of the two previous terms while allowing the user to interact with the virtual environment and the real environment [16, 17, 55]. In this study, we refer to these three terms as virtual reality, with an emphasis on the immersive environment of this term (VR).

In this paper, the first contribution is that we reviewed several important studies that built VR systems and methods of evaluation. Also, we reviewed some of the components of VR and the standards upon which VR systems are built, including technical standards called quality of service and personal standards called user experience. The second contribution is that we suggested some important criteria for evaluating VR systems, which were presented to a group of virtual reality specialists, including academics and developers.

2. Related Work

In this section, author should provide the latest related work of the subject matter and critical analyze them. Substantial literatures are expected in this section to ensure the novelty of the proposed work. In this part, we reviewed some studies that built VR systems and the methods used to evaluate them. Table 1 provides a summary of the various VR systems that are discussed in this paper. Some of the key aspects of these systems are highlighted in the following review of the relevant literature.

In [18], the author conducted a comprehensive comparison of various VR HMD technologies and designs. To do this, they established a new set of metrics specifically relevant to medical VR solutions that were critical to VR- based education and training. They assessed 10 technologies based on factors such as neck strain, heat generation, ease of cleaning, and color accuracy. They also evaluated text readability, comfort, and contrast perception through a multi-participant study that focused on the Oculus Rift S, HTCVIVE Pro, and Samsung Odyssey+ technologies. The results showed that the HTC VIVE Pro offers the best experience in terms of comfort, display quality, and compatibility with glasses.

Study [19] reviewed human factors/erg anomic studies on VR headsets and discussed ways to improve human- centered product development. It examined VR human aspects, performance, pressure, tiredness, and motion sickness. The study discussed both subjective and objective evaluation methods and indicators. VR's future evelopment was also examined, boosting the sector. Both domestic and international research on VR headset human factors/ergonomics was explored. Correspondingly, [9] tackles how different haptic feedback kinds affect manual VR presence and performance. User research with 14 individuals used visual, vibrotactile, or force feedback for throwing, stacking, and item recognition. Vibrotactile feedback outperformed haptic and visual feedback in presence. Force feedback reduced throwing and stacking execution time, while vibrotactile feedback boosted item identification detection rates but increased identification time. Despite consumer technological limitations, the study linked haptic feedback kind, presence, and task performance. In a similar manner, in [20], three methods were compared in relation to performance, illness, presence, usefulness, and comfort in 75 users. Teleportation performed better and caused less nausea than the other methods. Leaning outperformed joystick. No significant presence differences were found. Teleportation had a higher usability score than the other approaches, and the study studied the comfort effects of each technique, which were varied and explained in detail.

More simply in [7], an augmented reality system was built to help diagnose autistic children and it was evaluated by four caregivers according to comprehensive points that were used as a basis in the study. This system was evaluated using five main criteria; safety, ease of use, valuable, efficiency, and consistency. For each main criterion there are sub-criteria, which indicate that virtual and augmented reality systems are advanced systems. However, the evaluation process in this study was very complicated. Similarly, [21] investigated VR usage, problems, and performance. The text covered group testing, comparative analysis, formative evaluation, and user analysis. This study also assessed virtual performance, considering delay, latency, gender, presence, and technical van cements. Surveying virtual environment usability and performance studies was the major goal of the study. In [22], the re- searchers compared the cognitive and emotional effects of VR and traditional two-dimensional (2D) films. Approximately 60 volunteers were divided into two groups, with one group attending a film shown using 2D technology and the other a film shown using VR. In this study, the researchers tried to use multiple methods for analyzing the influence of the technology on the audience, such as electroencephalograms (EEG) to measure heart rate as well as self-reporting, interviews, and brain activity statements. They found VR had a greater effect on audiences than traditional movies. However, we note here that the researchers were trying to measure digitally but from one side (the influence of the technology on the audience).

Interestingly, [23,56] conducted a literature review and provided an overview of VR assessment tools released from 2010 to 2019, identifying 38 relevant records and 31 unique tools. Of these, 16 assessed executive functions and prospective memory, while 15 assessed visuospatial abilities. The analysis revealed that half of the tools lacked real-world applicability, limiting their usefulness. Additionally, methodological issues related to study validity were identified, which made it difficult to make definitive recommendations for tool selection. These limitations highlight the need for continued efforts to improve or develop VR tools for patients with acquired brain injury, given their potential for research and clinical purposes. [24, 57] examined a VR simulator of a forestry crane, which loads logs onto trucks. The study focused on quality of experience (QoE) relevant to task completion and discomfort-related symptoms. The QoE experiments examined task performance and the simulator's overall subjective experience. The main focus was on how latency affects subjective experience, specifically crane control interface delays. Subjective experiments with controlled delays to display update and joystick signals achieved this. Display update delays were 0–30 ms and hand controller delays were 0–800 ms. Latency had a severe effect on display update and a negative effect of 800 ms on hand controller latency (totaling 880 ms, including system delay). The simulator sickness questionnaire showed considerably higher scores after the experiment, but most individuals reported only moderate symptoms. Due to their symptoms, particularly display update slowness, some test subjects stopped the test early.

In[17] study, there searchers studied the effect of realism in virtual reality systems on the user experience. They concluded that realism plays an important role, almost the most important, in influencing the user experience. It studied 1,300 primary documents and found that 79 documents paid attention to the standards of realism in a way. In [25] this study the usability and impact on stress evaluation, management and reduction were used to evaluate VR system and almost all studies implicitly used this method and its impact on stress levels. This study concluded that there is a need for another method of evaluation, this because of the difficult definition, detection and evaluation of stress.

This study [26] divided the evaluation into two types: the first type is objective and the second type is subjective type is personal. The objective evaluation consists of several factors, including the time to complete the task, the accuracy of the task, and the training time, while the subjective evaluation consists of several criteria, perceived usability, feeling of presence, and ease of use.

Accordingly, we notice that in these studies the researchers focused on a few or specific tools and compared them based on feedback from the users who used this tool and thus the evaluations in these studies were not inclusive of all elements of VR. The studies did not consider, for example, the degree of image purity, but rather relied on the user's experience in general and on the user's comfort. There are also some criteria that were not mentioned in the evaluations and that are difficult to evaluate, such as the degree of security of these systems. We also note that the focus was on the equipment rather than the software. The rating also depends on the VR system type. Games are evaluated differently to educational and training programs. Table 1 summarizes previous studies, the criteria used in the evaluation, and the number of people who evaluated these systems.

3. Evaluation of the virtual reality environment

There are two types of evaluation: objective evaluation and subjective evaluation. Objective evaluation is based on measurable and unbiased observations, while subjective evaluation is an evaluation that depends on people's opinions, which may be influenced by several factors, including a person's psychology and the irbeliefs, culture, and age, which are difficult to verify. AVR developing team uses both objective and subjective evaluation, considering the environment based on their experience and user feedback, which include shareware, software, and network configurations necessary to execute the evaluation. This ensures that the testing environment closely resembles the real environment. In this section, we will review the most important criteria that affect the VR systems environment.

Table 1: Summary of previous studies

Study	Hardware/software	Criteria used	Number of evaluators
[19]	Hardware (virtual reality headsets)	Human aspects, performance, pressure, tiredness, and motion sickness.	-
[7]	Software	Safety, ease of use, valuable, efficiency, and consistency, and, for each main criterion there are sub-criteria.	4

[21]	Hardware/software	Virtual reality usage, problems, and performance.	-
[9]	Hardware	Haptic feedback kind, presence, and task performance.	16
[20]	Hardware	Performance, illness, presence, usefulness, and comfort.	75
[23]	Hardware/software	The effect on cognitive functions	15
[22]	Software	Analyzed heart rate using an electroencephalogram (EEG) self-reports, interviews, and brain activity.	60
[24]	Hardware	Quality of experience and discomfort-related symptoms.	18
[17]	Hardware/software	Realism	< 6 per group get one point 6 << 11 get two points > 11 get three points
[8]	Hardware/software	Flexibility, adaptively, and extensibility	-
[27]	Hardware/software	13 questions about the visual and haptic aspects	8
[25]	Hardware/software	stress evaluation, management and reduction	97 studies
[26]	Hardware/software	Objective evaluation: including the time to complete the task, the accuracy of the task, and the training time. Subjective evaluation: consists of several criteria, perceived usability, feeling of presence, and ease of use.	24 articles

VR system evaluation entails as sassing the system's pieces and their harmonious integration to create a seamless and engaging virtual experience. Many things must be considered while assessing a VR system. These include:

Visual Fidelity: VR systems should have great image quality, including resolution and refresh rate, for a seamless and immersive experience. For an immersive viewing experience, 360-degree image content (omnidirectional image content) must have a high spatial resolution, such as 4K or 8K [28].

Low latency is crucial for an immersive experience. Any time difference between the user's bodily actions and the virtual environment's changes might cause pain and disrupt immersion [24, 29, 30].

Interactivity: The VR system should provide intuitive and responsive controls for the user to interact with the virtual environment.

Sound Quality: Good spatial audio can greatly enhance the immersion in a VR experience [31].

Content: The VR system should have a good selection of high-quality content that is engaging and diverse.

User Comfort: The VR system should be designed to minimize motion sickness and other types of discomfort for users.

Usability: The virtual reality (VR) system should possess a high level of user-friendliness in terms of instal- lation, operation, and upkeep.

Affordability: The VR system should provide good value for the price, considering the hardware, content, and other factors.

Support: The VR system should have good customer support and a strong community of developers and users.

The most essential tracking performance criteria are static accuracy, dynamic accuracy, latency, update rate, tracking jitter, signal-to-noise ratio, and tracking drift [32–34].

Static Accuracy: ability to maintain and determine a fixed position during a specified time period [35].

Dynamic accuracy: is that which is achieved during active motion between two points within a three- dimensional space [35].

Latency: The time between the change in object pose and the time sensor detects the change [29].

Update rate: Number of measurements per second usually improve the accuracy, while demanding more computational power [36].

Jitter: Change in track measurement when tracked object is fixed. Low latency is a fundamental requirement for Virtual Reality (VR) systems [30]. Jitter can be caused by various factors, such as tracking noise, signal interference, or hardware limitations.

Drift: Steady rises in tracker error over time [34, 58]. Drift can be caused by various factors, such as mechanical wear, temperature changes, or tracking errors.

One method of evaluation involves users filling out a questionnaire to indicate the weaknesses and strengths of this system. This evaluation depends on personal opinions. Bad VR experiences can cause motion sickness, also known as VR sickness or cyber sickness, which includes symptoms like eye fatigue, disorientation, and nausea. These symptoms can diminish the VR experience for users [37,38].

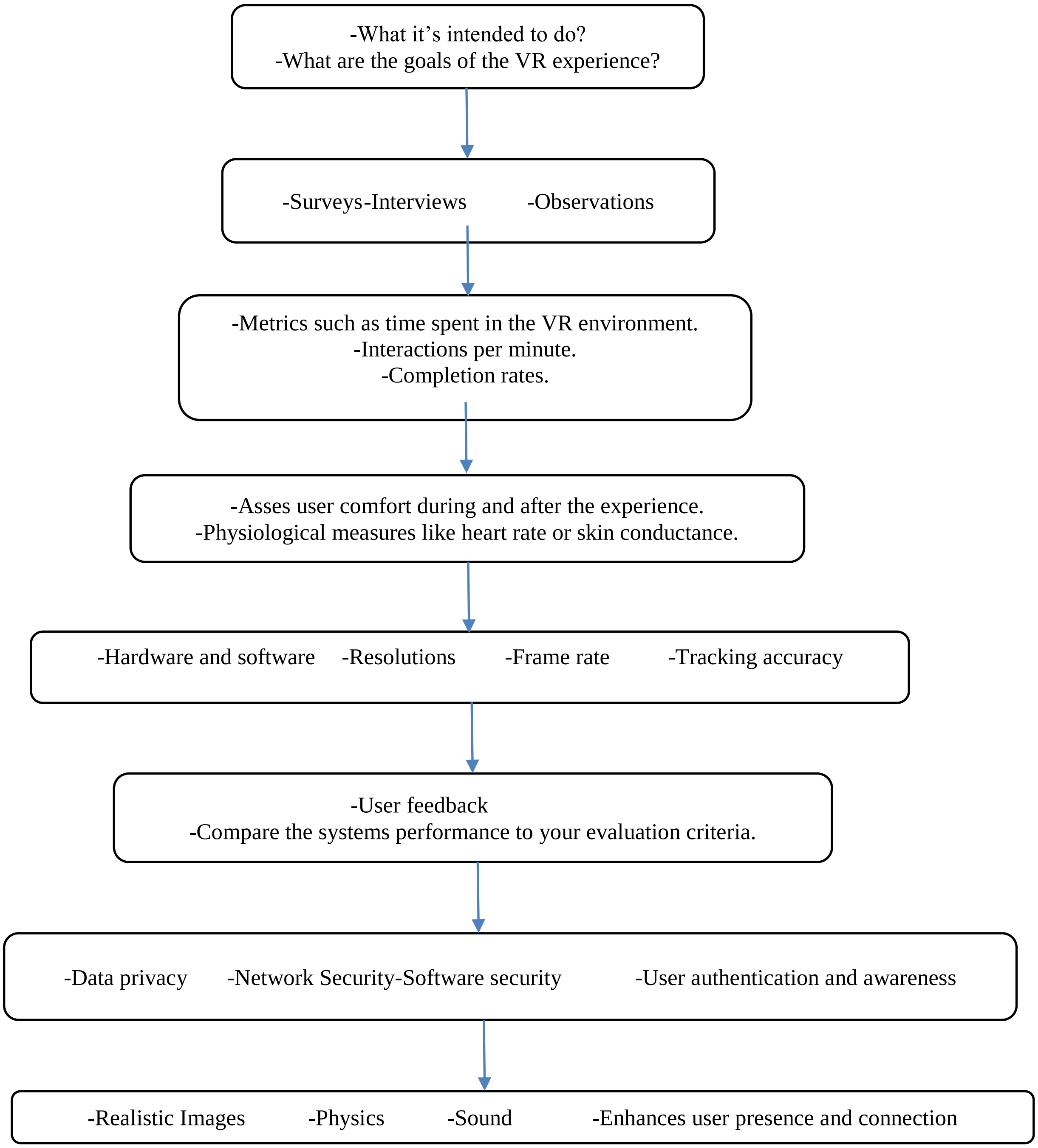

Figure 2: Steps for evaluating virtual reality.

Table 2: Acceptance value for VR system criteria

Criteria	Acceptancevalue
Static accuracy	depends on the specific use case andapplication
Dynamic accuracy	depends on the specific use case and application
Latency	<10ms
Updaterate	typically > 30Hz
Jitter	< 1mm
Drift	Values below a few centimeters or degrees per minute are consideredgood

* All the level of criteria value acceptable for a VR system can depend on the specific use case and application.

4. Virtual reality evaluation steps

Another method of evaluation tests a VR system by examining its ability to achieve its goals and identifying opportunities for improvement. The steps to evaluate a VR system are shown in Figure 2, which depicts the phases and their parts. To view these steps in detail, they are presented as follows:

1. Determine VR system goals: Before evaluating the system, you must understand its purpose. What are VR's objectives? To educate, entertain, or train? After understanding the goals, you can create system evaluation criteria [39].
2. Conduct user testing: Gather feedback from users to evaluate the system. Surveys, interviews, and user behavior observations can provide this input. To observe how the system works for different groups, test it with different users [7, 40].
3. Assess user involvement: VR experiences should be immersive, thus assess user engagement with the sys- tem. Time spent in the VR environment, interactions per minute, and completion rates can indicate engagement [41].
4. Evaluate user comfort: VR experiences may cause discomfort or nausea. User comfort during and after the encounter is crucial. Use a scale to rate users' pain or monitor heart rate and skin conductance [42, 43].
5. Assess the technology: The gear and software utilized in VR creation can impact its effectiveness. Check quality, frame rate, and tracking accuracy to make sure the technology is good [9, 20].
6. Analyze user data and input to find patterns and areas for improvement. Finding recurring themes in user input and comparing the system's performance to your evaluation criteria [7].

7. Assessing cybersecurity for VR systems, consider data privacy, network security, software security, physical security, user authentication, and awareness. You may reduce virtual reality cybersecurity threats by addressing these aspects.
8. Realism simulating real-world scenarios with realistic images, physics, sound, and interactions enhances user presence and connection.

These previous steps can be used to evaluate how well a VR system achieves its goals.

5. Cybersecurity assessment of virtual reality systems

Like any other technology, VR systems must be considered for cybersecurity vulnerabilities. Due to their Internet connectivity, many VR gadgets offer security threats. When analyzing virtual reality cybersecurity, the following aspects should be considered.

1. Data privacy: VR systems typically collect a lot of data from users, including biometric data and personal information. Ensuring data protection by making sure that all data can be accessed solely by authorized users is a highly essential aspect [44–47].
2. Network security: The protection of VR systems against network-based threats can be achieved through implementing various network security measures; for instance, firewalls, intrusion detection systems (IDS), and encryption protocols [48, 49].
3. Software security: Regular verification that VR systems are running up-to-date software, and as soon as certain vulnerabilities are identified they must be patched immediately, thus preventing attackers from exploiting software weakness [3, 45, 50].
4. Physical security: The protection of VR systems against unauthorized physical access can be done by implementing physical security measures including access control and surveillance [46].
5. User authentication: The access to VR systems must be limited to authorized users, which can be accomplished by implementing different authentication mechanisms such as knowledge-based, multi-factor, and biometric authentication [51].
6. User awareness: Users should be trained on cybersecurity best practices, including how to identify phishing attacks and other social engineering tactics [52].

Here you can summarize the criteria used in evaluating virtual reality systems in Table3 and the people responsible for this evaluation, these criteria in Table 3 were extracted from previous studies that were adopted as criteria for evaluating virtual reality systems in this study. In addition to the factors and components of these factors that affect the quality of virtual reality, as in Figure 3. The criteria affecting virtual reality systems can be summarized as in Figure 3, and the sub-criteria of these criteria, which collectively affect virtual reality systems. These criteria were extracted from previous studies and the experience of researchers.

6. Expert feedback

We discussed these standards (criterions) with three experts in information security and cyber space as well as three experts in VR and multimedia from four different universities. We received many valuable comments, and many improvements were made to these standards based on the positive comments received from the experts. These notes and comments include adding new standards and reviewing the standards that have been presented in this paper. In addition to reviewing the information security standards for virtual reality systems by information and cybersecurity experts and their suggestions, they showed vulnerabilities in virtual reality systems and ways to support and protect them. As for multimedia experts, In addition to reviewing these standards, there were different opinions regarding the importance and priority of these standards, and there is a difference in systems, with some standards highlighted in systems and the same standards declining in other systems.

7. Conclusion

Developers often evaluate VR systems using these standards. Developers can assess a VR system’s strengths and flaws and make informed improvements using technical and subjective methods. VR systems immerse users in a computer-generated world and allow realistic interaction, seeking to make users feel like they are in the virtual world. This is done through visual, aural, and tactile feedback. They also enable real-time virtual environment interaction with hand-held controllers or motion-tracking systems. In addition, systems strive to produce are a listic and plausible virtual environment, with high-quality images, realistic physics simulation, and naturalistic movements. These basic VR system needs can only be met by meeting this paper’s specifications.

The rating also depends on the VR system type. Games are evaluated differently to educational and training programs. Some systems require precise evaluation and cannot be complacent about security, like medical and military simulation systems. Ultimately, there are many ways to evaluate VR systems based on the aims and VR system type, including user experience, performance, and usability, effectiveness, and safety evaluations [12].

After studying and reviewing many studies that built virtual and augmented reality systems, the following are the most important conclusions.

- Many researchers agree that evaluation is an important stage in the development of VR systems. However, the researchers evaluated their systems in several different ways.
- VR systems are complex systems that rely heavily on hardware and software, and the performance of these two aspects of VR systems cannot be separated.
- Many researchers did not mention the security of VR systems due to the difficulty of measuring it or because it lacked importance from their point of view [7, 22, 40, 53].
- There are several ways to evaluate VR systems, including objective ones. However, there are few objective methods. Most evaluations used are subjective and depend on the opinions of users, and these opinions are influenced by many factors, such as age, gender, and fatigue [7, 40, 53].
- Evaluation criteria vary depending on the nature of the VR system or the audience for whom this system is intended. For example, if the audience is children, the designer may be more concerned with the safety aspect than the information security aspect.
- Researchers suggest that algorithms will be developed to evaluate virtual reality systems that give numerical results and can be compared with users' opinions. If the algorithms converge with users' opinions, we will be closer to establishing objective standards.
- Some studies compare VR equipment [18, 19], while other studies compare VR software.
- The number of evaluators varies from one study to another. For example, there are fewer than 10 evaluators in [7, 40, 53] and fewer than 50 in [9], while other studies that exceed 50 evaluators [20, 22].
- There is recent research that attempts to make the evaluation of VR systems digital based on heart and brain pulses [22] in addition to the questionnaires that still dominate the evaluation of VR systems.
- There were many criteria used in these studies, including neck strain, heat generation, ease of cleaning, and color accuracy. Additionally, they evaluated text readability, comfort, and contrast perception [18], human aspects, performance, pressure, tiredness, and motion sickness [19]. Other studies considered additional criteria, such as safety, ease of use, valuable, efficiency, and consistency, with sub-criteria for each main criterion [7]; VR usage, problems, and performance [21]; haptic feedback kind, presence, and task performance [9]; performance, illness, presence, usefulness, and comfort [20]; analyzed the EEG heart rate, self- reports, interviews, and brain activity [22]; and quality of experience and discomfort-related symptoms [24].

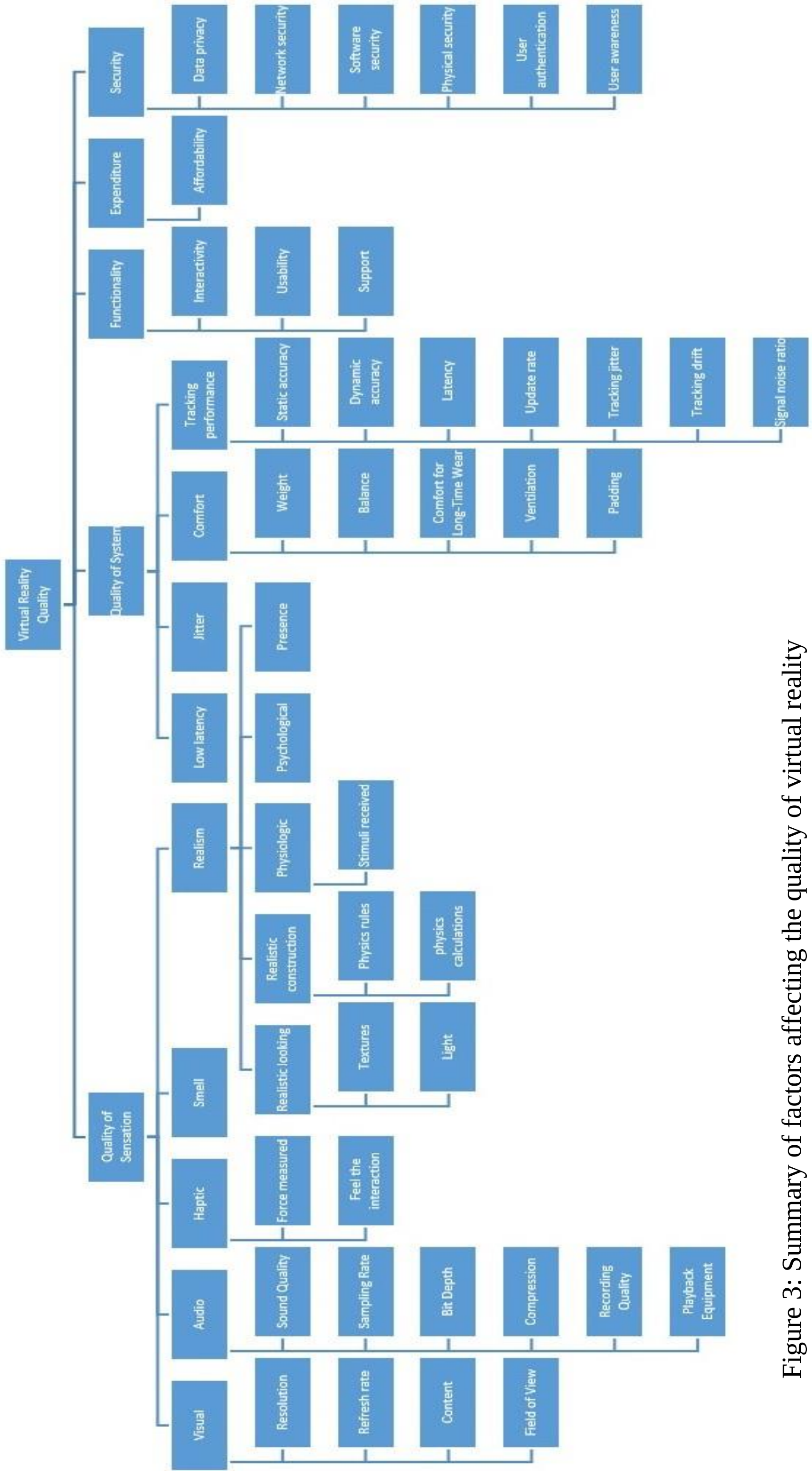

Figure 3: Summary of factors affecting the quality of virtual reality

Table 3: Criteria used in evaluating virtual reality systems.

Criteria	**Casual user**	**VR expert**	**Real system expert**
Image quality	⊂	⊂	
Latency		⊂	
Interactivity		⊂	
Sound quality		⊂	⊂
Content		⊂	⊂
User comfort	⊂		
Ease of use	⊂		⊂
Affordability		⊂	⊂
Support		⊂	
Static accuracy		⊂	
Dynamic accuracy		⊂	
Update rate		⊂	
Jitter		⊂	
Drift		⊂	
Identify the goals of the VR system			⊂
Conduct user testing			⊂
Measure user engagement		⊂	
Assess user comfort	⊂		
Evaluate the technology		⊂	
Analyze data and feedback		⊂	
Realism		⊂	⊂
Assessing cybersecurity		⊂	
Data privacy		⊂	
Network security		⊂	
Software security		⊂	
Physical security		⊂	
User authentication		⊂	
User awareness		⊂	

8. Limitations and future work

Although setting standards is of great importance, as we have reviewed in this paper, it appears when setting any standard for any system, there appear differences in opinions and rulings, and as we mentioned in section number six, when these standards were presented, there were clear differences. What we agreed upon with the experts is that these standards highlight their importance in certain systems, and the same standards decrease when used in other systems.

These standards also remain closely related to each other and affect each other, for example, the delay affects the user experience and realism, even if the image quality and sound quality are within very high standards and makes it a rejected experience by the user because it causes dizziness and headache. Our study did not take into account the ability to determine the importance of each criterion and its impact on the other criteria.

Finally, only studies in English language were studied in this paper, which means that there are many studies in other languages that may be valuable and were not studied.

In the future, we seek to have an arrangement to fall these standards and divide them according to the applicable systems. For example, when talking about military or medical systems, the importance of accuracy as well as the confidentiality of these systems is highlighted here, and when talking about educational systems, other standards are highlighted here. Therefore, this evaluation was shared and general among several systems

The number of experts whose opinions were taken on these criteria was relatively small and in one sector in the academic sector. In the future, the number will be larger and in different fields.

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