A Systematic Review of Extended Reality (XR)’s Head-Mounted Display (HMD) Hardware Design Factors from the Perspective of Usability

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Abstract
The study on XR’s; a superset of augmented reality (AR), virtual reality (VR), and mixed reality (MR), headsets was found to be sporadic and decentralized especially with regards to studies on the hardware of the virtual environment system. However, as the interest on artificial reality such as XR is increasingly on the rise, there is lack of study and consensus on the hardware aspect of XR. This is especially true in terms of the usability of XR’s hardware. The paper aims to identify the major properties of the hardware design factors of XR’s HMD that affects the usability in the virtual environment. Conducting a systematic review, this paper applied an adjusted Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) review protocol. 7 scientific and engineering related journal databases were selected to collect research papers. The collection of research papers used keyword combinations of “reality”, “head mounted display”, and “usability”. The papers were collected from the period year of 2000 till 2018. From the databases a total of 2,136 articles were collected first, and 35 articles are reviewed after the final screening. The screening criteria for the full-text review are hardware design factors on usability issues. It was discovered that critical features from the results have pointed the following hardware design factors such as “head fit”, “field of view (FOV)”, “weight”, “occlusive design”, “resolution”, and “wires” cause usability issues. This highlights future research focus through commonly occurring properties such as degrees of FOV, ideal weight, and matters such connectivity freedom. Such research focus also leads to opportunity in verifying, identifying, and applying of future HMD hardware design parameters, thus improving the current standards that are available out there in the market.

Keywords: Extended reality, Head-mounted display, Usability, Design factor, Systematic review

Introduction
Extended reality or XR as the name implies is an extension of reality or according Charles Wyckoff in his patent for his XR film which allowed people to visually experience nuclear explosions and other events beyond the range of standard human vision. Mann and Wyckoff together built XR vision devices into wearable computer armaments or equipment such as AR/VR headsets for augmentation and outer sensory experience through imaging technology and virtual/augmented reality [36]. Hardware collaboration with XR and its subsets of AR, VR, and MR counterparts are available but unfortunately have been found to be sporadic and decentralized [37, 38, 39].

The myriad taxonomies that accompany XR and the others such as VR, AR and so on, have hindered the focus on hardware equipment due to presence of duplicates and research mainly on hardware is sidelined. Besides that, usability studies on the virtual environment hardware equipment itself is scarce and limited or is censored by the usability studies of the whole system rendering the focus on hardware to become a background matter instead of a research focus. This paper aims to reignite the focus on hardware design research for future reference in consideration for usability and also for applications towards user experience in virtual environment.

Review Objectives
This review study is designed to identify the major properties of hardware design factors of XR HMD that affects usability of extended virtual reality system environment. In order to achieve this goal, we categorized extended virtual reality system environment’s HMD usage studies according to keyword combination screenings and full reviews on hardware design factors on usability issues. From the categorization process done, critical features were discovered with relation to usability issues.

Search Methodology
For the systematic literature review, PRISMA method was used. A total of 35 articles dating from the period year of 2000 till 2018 were obtained and reviewed. Articles were found via computerized search. Figure 1 demonstrates the methodology used in this study.

In the identification and collection phase, the articles were collected from 7 science and engineering research and journal databases. These databases are ACM Digital Library, IEEE Xplore, PLOS One, PubMed, ScienceDirect, Scopus, and Web of Science database. In the computerized search within these databases there were 3 pre-screening criteria imposed to the database sources. The first criteria were articles obtained be in the medium of the English language. Secondly, the...
articles are from the period year of 2000 till the period year of 2018. Third and the final pre-screening criteria in which the articles were searched using the combination of the following keywords of “reality”, “head mounted display”, and “usability”. The keyword of “reality” is to cover all the sections on extended reality be it in virtual reality context, or augmented reality context, or other reality context except any non-bending reality concept such as real-life. “Head mounted display” keyword was chosen instead of abbreviations of HMD or hyphenation of head mounted, was to cover a more general and wide scope of search range for the articles. “Usability” keyword is used to limit the range of the other two keywords to be within the boundary of ergonomics concept of usability. The whole identification and collection process yielded a collection of 2,136 articles.

The next phase, which is the 1st relevance screening process resulted in 251 articles to remain and further refined with the next phase of duplicate removals which resulted in 168 articles. The 2nd relevance screening phase involved detail screening on the abstracts of the article papers collected and finally for the full text evaluation process 35 articles were collected for a full paper review and evaluation process on HMD hardware design factors on usability issues.

Figure 1. PRISMA flow diagram systematic review on HMD hardware design factors on usability issues.

Review and Search Results

From the full text evaluation of all 35 articles 15 main hardware design factors were identified from a total of 83 hardware design factors attributed towards usability issues on HMD. These main design factors are “display”, “design”, “FOV”, “resolution”, “weight”, “processor”, “external module”, “wires”, “fit”, “camera”, “cost”, “power”, “sensor”, “sound”, and “heat”, in accordance to frequency of mention and in alphabetical order.

The “display” main hardware design factor on usability issues stems from the type of display used with mentions from 12 articles. Upon further exploration on the factor, shows option on see-through display [2, 7, 29, 35], with options on LCD [22], optical [27], mirror/lens based [7, 9], micro-display [9], OLED [15], stereoscopic display [10], and general display [33]. The “design” factor addresses on the physical shape and the direction the HMD is to be produced had 11 mentions. Such as monocular/binocular design [3, 22, 35], helmet design [7, 21], eyeglass/visor design [7, 31], portable design [25, 35], wearable/ removable design [14], and occlusive design [12]. “FOV” design factor is about the limitation and angle view affecting the experience of XR [1, 3, 4, 8, 16, 17, 20, 22, 24, 29, 32] have tied mentions with the previous factor. The “resolution” factor addresses the users’ need on resolution for better viewing experience [4, 6, 8, 15, 16, 18, 21, 22, 29, 32]. “Weight” factor touches on how the factor causes uneasiness when using HMD [3, 5, 10, 13, 22, 25, 29, 31, 32, 33]. Both “resolution” and “weight” factors have 10 mentions each. Meanwhile “processor” with 7 mentions, is the internal capability and performance overall [8, 15, 16, 19] of the HMD, in terms of latency [17, 24], and frame rate [6]. The “external module” is the factor which requires and external accessory or additional input mechanism to aid in the operation of HMD generally overall [3, 11, 15, 23] and through haptic system too [6].

In addition to the previously most frequently mentioned (more than 5 mentions) 7 main hardware design factors, the remaining 8 main hardware factors had frequency mentions of less than 3. Such factors are “wires” of 3 mentions, which is about the HMD setup of wired connection [21, 25, 29], “fit” also with 3 mentions, about head fit of user [5, 13] and the size discomfort upon usage [26], except “heat” which has only 1 mention, on temperature discomfort of HMD, the rest of the factors have 2 mentions each. “Camera” factor about the camera hardware [28, 34], “cost” factor on the financial expense to purchase or use HMD [3, 6], “power” factor mentions about inefficient battery on portable HMD [31, 33], “sensor” design factor is about the sensor hardware [31, 34], and “sound” factor touches on the volume control and internal speaker system for the HMD [31, 33].

Discussion

With the ongoing interest on XT and the virtual environment as a whole, the attention towards the hardware system that is part and partial of the whole system has been growing steadily. From the research review that was conducted there are several key findings with regards to the HMD hardware design factors. One such findings are the importance towards visual performance of the HMD, articles have shown
concern and attention towards the type of viewing experience that the HMD can provide. Such example is the attention towards the FOV, non-occlusive design, and high processing capabilities expectation. Besides that, another finding to highlight from this study is the need for attention towards physical comfort that is highly reflected on the concern towards the overall weight of the HMD and also the portability capabilities a HMD should possess. Finally, growing attention towards additional or accessories that aid in the equipment for better operation experience such as the keyboard, mouse, joystick, camera, sensor, and speaker indicates the need for a more overall complete transformation or adaptation towards the current traditional display and other peripherals.

Despite the findings mentioned before, there are limitations that were also touched upon the ongoing of the study. One such limitation is the concern with cost. Mainly because for the dissemination of the technology, the matter of cost for the accessibility of the general population is essential to ensure the HMD becomes a common staple technology on par with staple traditional technology such as the computer, smartphone, and the up and coming streaming service technology. Once accessibility is achieved, another limitation for the technology in which HMDs require prior familiarization for effective utilization can also be resolved. One more concern towards the HMD technology in terms of hardware is how much design variability can the technology achieve before another technology will bypass it? Such concern would make for a research study in terms design and manufacturing in the future.

Conclusion
In conclusion, for this study there are design factors that goes into the operation of the HMD hardware that affects the usability of the hardware system. Such factors are essential as a reference for future hardware usability studies on the subject matter of HMD in the XR virtual environment research. Standards that accompany the factors have yet to achieve uniform standardization as the current presence for the technology is mainly limited to commercially available HMD or specialized equipment for professionals such as surgeon, pilot, and tech companies, guidelines for hardware is needed. Finally, product usability is an essential part on the survival of a product and early identification on causes for a lack of usability will help the development of the product.

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