HCI RESEARCH IN VIRTUAL REALITY: A DISCUSSION OF PROBLEM-SOLVING

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ABSTRACT

Recent advances in Virtual Reality (VR) systems have revived interest in the field and strongly affected Human-Computer Interaction (HCI) research. The problem-solving capacity of HCI research in VR is examined and discussed in this paper. A literature review of 62 publications is utilised to examine the type of research problems that have been addressed by HCI research in VR over the last three years. The results show that recent HCI research in VR mainly addresses constructive problems. The underrepresentation of empirical and conceptual problems shows that the research may have lower problem-solving capacity than desired. We address the findings by arguing for the field's need to investigate more empirical problems, formulate more conceptual work, re-examine past research questions under the new prism, and improve its dissemination process.

KEYWORDS

Human-Computer Interaction; problem solving; Virtual Reality;

1. INTRODUCTION

Over the last few years, major advances in Virtual Reality (VR) systems have revived the interest of the Human-Computer Interaction (HCI) research community in the field of VR (Sun et al., 2015, Olszewski et al., 2016). It is not surprising that the number of research publications with "Virtual Reality" and "Human-Computer Interaction" in their author-originated and/or indexed keywords, more than doubled between 2012 and 2015, according to the Scopus database by Elsevier (2012: 169 publications, 2015: 463 publications).

At the same time, a variety of HCI aspects of VR environments, interfaces, and interaction techniques are currently discussed in VR-related forum threads and analysed in several popular tech articles by members outside the academic community, such as bloggers, forum users, and tech journalists. With a quick search, one can find several popular articles and threads addressing concerns, opinions, and examinations of HCI issues in VR, such as: *"Typing in VR: the unsolved problem of input*" (Staub, 2015), "*How should we move around in VR? Nobody has figured it out yet"* (Martindale, 2016), *"How will we be doing text input in the future in VR?"* (Reddit thread, 2016), *"First Rule of VR: Don't Break the Presence"* (Marinkovic, 2015), and *"I spent 2 weeks socializing in VR, and I saw the future"* (Strange, 2017).

On the one hand, the public interest around VR is indicative of how popular the technology has become over the last few years, the need of the public to improve their VR experience, and the potential of VR for social impact. On the other hand, the investigative nature of the non-academic community's published material and the technology gaps addressed may reveal a significant disconnect between HCI research in VR and the public's real research needs. This potential disconnect may be caused by the fact that HCI research in VR has not reached high levels of problem-solving capacity (Oulasvirta and Hornbæk, 2016) and/or by the problematic dissemination of information between the HCI community and the public (Oulasvirta, 2016). This hypothesis triggers us to research and discuss the subject.

The current work paper reflects on the problem-solving capacity of HCI research in VR, highlighting and proposing directions for improved research outcomes and solutions. It documents changes in the VR field that have affected HCI research (Section 2), utilises a literature review to examine the problem-solving capacity of HCI research in VR (Section 3), and presents the authors' argument about how to advance HCI

research in VR (Section 4). The ultimate purpose of the paper is to generate a new debate about the HCI community's position on recent VR advances, as well as to generate ideas for research in the field.

2. THE REVIVAL OF VIRTUAL REALITY

Recently, VR has undergone a hardware-driven revival, which has had massive effects on the ways users experience and use VR compared to a few years ago (Olszewski et al., 2016, Grebner et al., 2016, Zhang et al., 2015). The introduction of the Oculus Rift Development Kit 1 (mid-2013) can be considered a turning point for VR, indicating when VR became accessible, up-to-date, and relevant again (Riva and Wiederhold, 2015, Hilfert and König, 2016, Kapoor and Sharma, 2016, Olszewski et al., 2016). Devices like the HTC Vive and the Sony PlayStation VR headsets followed, along with open-source software development kits, such as OpenVR and the Open Source Virtual Reality project (Kapoor and Sharma, 2016, Barnes, 2017, Olszewski et al., 2016). Low-cost VR solutions, which can turn a regular smartphone to a VR headset, were also implemented, such as Google Cardboard, and Samsung Gear VR (Barnes, 2017, Kesselman and Kesselman, 2016).

With recent advancements, the hardware costs for VR systems dropped due to such systems gaining traction in the mainstream gaming community (Hilfert and König, 2016, Olszewski et al., 2016). The low acquisition cost of VR hardware made VR a widely-accessible and popular technology over the last few years (Moreira et al., 2016). Regular users can now acquire VR systems at low cost, use them in the comfort of their home, and develop VR applications for the application domain of their choice.

Moreover, the quality of virtual environments has increased rapidly, while supporting full immersion. Recently introduced VR systems have taken advantage of rapid advancements in the Graphics Processing Unit (GPU) field to produce high-quality graphics and perform high-fidelity rendering of complex scenes in fully immersive settings (Reinert et al., 2016, Kim et al., 2017).

Finally, multi-user VR environments have become technically robust, surpassing the lack of intuitive multi-user capabilities of the past, and have begun pushing the boundaries of next-generation social platforms (Olszewski et al., 2016). Current VR systems easily connect distant users, immerse them in multi-user virtual environments, and provide them with all the communication tools (text input, audio chat, collaborative GUI, etc.) necessary for multi-user collaboration and interaction (Olszewski et al., 2016).

The changes mentioned above have revived the potential of VR. The interest of the public and HCI researchers in the VR field has reached high levels. To examine the role of HCI research in the revived VR field, we turn to the evaluation of one of HCI research's main qualities, that of problem-solving (Oulasvirta and Hornbæk, 2016).

3. HCI RESEARCH AS PROBLEM-SOLVING IN VR

HCI research is about solving problems related to the human use of computing (Oulasvirta and Hornbæk, 2016). The field's problem-solving capacity refers to researchers' ability to solve important research problems effectively, efficiently, and with high confidence in the solutions' validity (Oulasvirta and Hornbæk, 2016). To address the problem-solving capacity of HCI research in VR, we turn to the typology of contribution in HCI from Oulasvirta and Hornbæk (2016), which was based on the work of Laudan (1978). We investigate the types of problems that HCI research addresses in the VR field, attempting to evaluate potential gaps in current research.

According to Oulasvirta and Hornbæk (2016), HCI research problems can be of three types: *empirical*, *conceptual*, and/or *constructive*. *Empirical* research is aimed at creating or elaborating descriptions of real-world phenomena related to human use of computing. Work on a *conceptual* research problem is aimed at explaining previously unconnected phenomena occurring in interaction. *Constructive* research is aimed at producing understanding about the construction of an interactive artefact for some purpose in the human use of computing (Oulasvirta and Hornbæk, 2016).

3.1 A Literature Review of HCI Research Problems in VR

To examine the type of research problems that the HCI research addresses when it comes to VR design and interaction, we conduct a literature review. For the search process the Scopus database was used due to its wide coverage of the examined field and its flexible filtering capabilities (cf. Falagas et al., 2008, Jacso, 2005). The study examined publication years after the VR's "turning point" until the most recent (complete) publication year, i.e. from 2014-2016. For the retrieval of the publications' online versions (.pdf or .html), the publishers' websites (using institutional subscription access), the Google search engine, and Google Scholar were used. The accessibility of the publications was also investigated as it relates to dissemination.

During the first search stage, 1120 publications were retrieved using the terms "Virtual Reality" and "Human-Computer Interaction" as author-originated or indexed keywords[1]. For the second search stage, we used the same terms only as author-originated keywords[1] to address the high volume of first stage publications, while maintaining a representative sample that would allow us to reach safe conclusions. The search query produced *N = 68* publications, which were then reviewed by all three authors separately[2].

Since an HCI paper can often involve two research problem types, the categorisation of each publication's research problems and their possible pairwise combinations was discussed and agreed upon by the authors based on the definitions of Oulasvirta and Hornbæk (2016). The publications that were considered by the authors as irrelevant to the field were manually removed.

Table 1. The number and percentage of HCI in VR research problems based on the publications reviewed.

	Year				
Problem Type	**2014**	**2015**	**2016**	**Total**	**Percentage**
Empirical	6	11	9	**26**	**31 %**
Conceptual	1	5	6	**12**	**14 %**
Constructive	15	16	16	**47**	**55 %**

Six publications were excluded from the literature review as irrelevant to the examined theme. One publication related to a book about teaching; two articles presented Augmented Reality systems; and three articles were written in languages other than English. A review of the remaining 62 publications led to the documentation of 85 research problems and showed that the majority of the problems addressed were constructive (47 out of 85), whereas empirical and conceptual problems were less frequently addressed, as shown in Table 1. A significant observation is that a number of publications presented constructive research without any form of evaluation or contribution to the understanding of relevant phenomena.

As for the accessibility of the publications, 9 of them were open-access articles, whereas 53 of them were only available behind paywalls. Of these 53 paywalled articles, 19 were freely accessible as archived copies at the time of the search. In total, 28 out of 62 publications (45%) were publicly accessible without subscription/payment.

Without empirical solutions and integrative concepts, theories, and models to link empirical and constructive knowledge, there is a gap in HCI research for VR and the existing research has lower problem-solving capacity than desired (Oulasvirta and Hornbæk, 2016, Laudan, 1978). This conclusion verifies the hypothesis that triggered this reflection paper and leads us to suggestions for improving the problem-solving capacity of HCI research in VR.

4. ADVANCING HCI IN VR

Considering the previous discussion, we now focus on the implications for the HCI in VR field by addressing the question: "How can we improve HCI research in VR?"

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[1] The Scopus database query string for the first stage was: `(KEY("virtual reality") AND KEY("human computer interaction")) AND (LIMIT-TO(PUBYEAR,2016) OR LIMIT-TO(PUBYEAR,2015) OR LIMIT-TO(PUBYEAR,2014))`. At the second stage the `KEY` command was replaced with `AUTHKEY`. The searches took place between February 22nd and 24th, 2017. The number of retrieved documents is subject to change over time, depending on the number of online-first, published articles that are printed at a later date and the number of withdrawn publications.

[2] A list of the reviewed publications and the examined parameters is presented at: http://boletsis.net/ihci2017/TABLE.pdf

HCI puts strong emphasis on construction (Oulasvirta and Hornbæk, 2016), and the literature review showed that this is also the case with HCI research in VR. However, the VR-related empirical and conceptual HCI work over the last few years may not have been powerful enough to drive the field. To address the recent developments, improve HCI's problem-solving capacity in VR, and advance the field, we strongly recommend putting more effort in investigating empirical problems and formulating more conceptual work. HCI researchers can carry out ever more new designs based on the updated VR technology. However, without grounding the contributions in empirical and conceptual research, the results will have low impact and problem-solving capacity. Empirical research should be done in such a way that its hypotheses inform design. Designs (constructive work) should embody and be driven by empirically validated hypotheses. Integrative concepts, theories, methods, and models should act as the connecting link between constructive solutions and empirical work (Oulasvirta and Hornbæk, 2016).

Another suggestion to address the need for more empirical and conceptual work and to plan the future of HCI research in VR is to visit its past. By that we mean, that – even though the VR field has a long HCI research history – some research questions of the past may need to be re-examined under the new prism. The hardware-driven revival of VR has produced new and updated metaphors, which affect the HCI research of the field and the empirical work around it. Several VR-related topics, e.g. text input and locomotion in VR, should be re-examined from empirical and conceptual perspectives. Even though most of these HCI aspects have been presented and covered in the past (e.g. for text input and locomotion cf. Bowman et al., 2002, Arns, 2002), recent VR developments have generated interest in new designs and constructive work (cf. Pick et al., 2016, Bozgeyikli et al., 2016). Nevertheless, HCI research should also empirically evaluate these metaphors and "build" concepts and models that would facilitate communication between hypotheses and designs. Naturally, there are steps taken in the right direction (such as the empirical works of Porta, 2015, Kitson et al., 2017 for text input and locomotion, respectively), but more effort is needed to cover the rapidly changing field of VR.

Finally, the problematic dissemination of information between the HCI community and the public is a general HCI issue that can lead to a disconnect between HCI research in VR and the public's real research needs. The fact that research is locked behind paywalls, as also shown in Section 3.1, limits public access to important research results (Oulasvirta, 2016). Moreover, it has been stated that the HCI field's writing culture does not support the problem-solving view, since HCI papers usually put aside the description of the problem they are tackling (Oulasvirta and Hornbæk, 2016). The dissemination and presentation of research can be a "vehicle" for the problem-solving capacity of HCI research in VR on the road to social impact. Therefore, we also support previous recommendations on the topic (cf. Oulasvirta and Hornbæk, 2016, Oulasvirta, 2016) that i) the writing culture of the HCI community should be improved by including clear descriptions of the addressed problems and ii) HCI researchers should freely disseminate their works through multiple archiving and/or open-access channels. This suggestion is of broad scope; however, its application to the examined field could positively affect the way users experience and use VR.

5. CONCLUSION

Even though problem-solving may not apply to all HCI research, it provides some great first questions for any HCI paper or research programme: "Which problems does it tackle, and how does it increase our capacity to solve them?" (Oulasvirta and Hornbæk, 2016). After the revival of VR technology, a discussion of the problem-solving capacity and social impact of HCI research in VR is important. The direction of future HCI research in VR will define the degree to which expert and non-expert users understand and utilise VR for the greater good. By reviewing the recent state-of-the-art in the field and documenting the research problem types it addresses, we consider that HCI in VR can benefit from conducting more empirical and conceptual research, examining past, related research questions in a new light, and improving its writing quality and dissemination.

ACKNOWLEDGEMENT

This research is funded by the Norwegian Research Council through the Centre for Service Innovation.

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