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Contents

WaterHCI: Water in Human-Computer Interaction

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ABSTRACT

Over recent years, there has been an increase in the coming together of interactive technology and water, leading to the emergence of WaterHCI, a distinct subfield of human-computer interaction (HCI). However, there is little work that aims to paint a comprehensive picture of the work around WaterHCI experiences so far, limiting the opportunity to identify directions for future research. This monograph aims to address this through an articulation of prior WaterHCI works structured using two frameworks that aim to offer a better understanding of the design of aquatic experiences through four key user experiences across six different degrees of contact with water. This articulation allows us to

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highlight underexplored areas that could guide WaterHCI researchers in identifying what to research next in order to bring the field forward as a whole. Ultimately, our work aims to help so that more people can profit from the many benefits that combining interactive technology and water affords.

Keywords: Water; aqua; aquatic interfaces.

1

Introduction

Over recent years, there has been an increase in attempts to place interactive technologies into aquatic settings (Oppermann *et al.*, 2013, 2016; Pell and Mueller, 2013a), not least in the human-computer interaction (HCI) field (Clashing *et al.*, 2022a). For example, there have been developments to place augmented reality goggles into public pools (Oppermann *et al.*, 2013, 2016), interactive water projections into bathtubs (Koike *et al.*, 2013), virtual reality headsets into water-based rehabilitation exercise settings (Quarles, 2015), and robots to interact with into the ocean (Novitzky *et al.*, 2019). In the HCI field, these efforts have been called WaterHCI (Clashing *et al.*, 2022a; Mann, 2021, 2022) and a set of grand challenges have been proposed (Mueller *et al.*, 2024). However, these water-human-technology interactions have not yet been formally collated, even though there is work emerging that goes beyond technical implementation and also considers the associated user experience. In particular, there is work that not only considers instrumental, but also experiential aspects of being in, on and around water, such as the enjoyment that being in bodies of water can facilitate (highlighted in many recreational water activities) that can now be supported by interactive technology (Clashing *et al.*, 2022b; Mann, 2022; Pell and

Mueller, 2013b). In response, in this monograph, we align with a general trend that appreciates a heightened experiential focus in HCI and hence go beyond instrumental systems to also consider the experiential aspects of WaterHCI. In particular, we review systems by employing a user experience framework (Clashing *et al.*, 2022a) in combination with a water contact framework (Raffe *et al.*, 2015). With this, we can identify gaps in the WaterHCI design space. This articulation is hopefully inspiring as it can show what the underexplored opportunities are in the coming together of water and interactive technology.

We hope that our monograph can assist researchers in identifying what to research next. Similarly, we hope that for academics not working in the field of WaterHCI our monograph offers guidance and orientation on how to get into the WaterHCI field. For people within HCI, we hope that our monograph can shed light on discussions around WaterHCI. We also hope that developers can learn about the various technologies employed in WaterHCI and be inspired to push beyond what has already been achieved. Furthermore, aquatic educators might also benefit from our work as they may gain awareness of the different kinds of interactive systems that exist and be inspired to collaborate with WaterHCI experts.

To achieve our objectives, we examined prior work that looked at the WaterHCI field more holistically, as well as individual projects that made use of water properties (hence we excluded projects that solely focused on waterproofing existing systems). We believe that these water properties are important to consider because aquatic activities are subject to properties that are less pronounced or not even present in land-based activities, resulting in very different experiences. Shmeis (2018) listed a set of water properties, namely: depth, temperature, pressure, visibility, light, sound, water flow, non-open water environment, and open water environment. When compared in land-based activities, these water properties affect our sensory perception, physical movement, and physical abilities (Pell and Mueller, 2013a). Previous research positioned these effects as potential constraints for the human body during aquatic activity (Li *et al.*, 2016). However, prior work also advocated viewing these water properties as opportunities (Kajastila *et al.*, 2016; Kosmalla *et al.*, 2016; Mueller and Young, 2018) and we similarly believe that they provide opportunities for interaction design (our framework described

below frames water as both a problem and an opportunity). Furthermore, we note that, without the necessary skills, such as the ability to swim, many aquatic environments can be dangerous (e.g., participants can drown). We, therefore, believe that designers must consider how to harness or mitigate the impact of water's properties through informed risk assessment and the establishment of acceptable margins of safety.

We also learned from prior work around technology supporting water experiences more generally. These previous research endeavors highlighted that water is a difficult medium to design for because it often requires the waterproofing of electronics (Bellarbi *et al.*, 2013; Cejka *et al.*, 2021; Lin and Xie, 2010; Quarles, 2015). Therefore, based on the high electrical conductivity of the impurities in water, interactive technologies can be seen as not really suitable for aquatic environments (McCleskey *et al.*, 2011). As a result, recreational interactive systems are typically unsafe or impractical in wet environments while wireless components face interference challenges when trying to communicate through water (Niu *et al.*, 2019; Verzijlenberg and Jenkin, 2010). Furthermore, water's dynamic movement adds complexity to the use of technology in relation to bodily activity when compared to the relative predictability of moving through lower-density air (Ranson *et al.*, 1996). In this regard, we note that prior investigations around the use of technology to support aquatic activities have typically taken the form of technical papers detailing sensor deployment in the aquatic domain (Davey *et al.*, 2008; Reyes *et al.*, 2016). In addition, given that these deployments historically required extensive technical knowledge and resources, they were predominantly focused on supporting elite sporting performances (Delgado-Gonzalo *et al.*, 2016; Hagema *et al.*, 2013; Stamm *et al.*, 2012).

While these prior works showed that technology can support people in the aquatic domain, we believe that recreational activity participants should also be supported, not just elite athletes, especially now that technological advances make low-cost prototyping more feasible. Taken together, we found that prior work mostly focused on technical challenges (and how to address them) when it comes to combining interactive technology and water. The resulting developments have advanced the WaterHCI field by mostly showcasing that interactive systems can work

within water settings. Furthermore, we note that much of the prior work in WaterHCI does not mention user experiences, and even if they do, they do not offer much insight through, for example, a study. This is a shortcoming within the WaterHCI field that future work should address. As such, it seems imperative to note that we believe what the field is still missing is a comprehensive overview of the field and, in particular, an investigation into the experiences of such interactive systems in water settings. Without such an investigation, we believe that the field will continue to simply waterproof existing land-based systems, missing out on the opportunities that water offers to human experiences. With such an investigation, however, we hope that the field can delve deeper into utilizing the many affordances water brings to our lives. Furthermore, such an investigation could extend our understanding of experiences with technology more broadly as it moves from land-based HCI to a more comprehensive perspective to also consider interactive experiences in oceans, lakes, pools etc.

1.1 Contribution and Benefit Statement

Our work makes the following contributions:

- We present an overview of the WaterHCI field that is concerned with the coming together of interactive technology and water. This overview might be useful for people aiming to get into the field and would like to gain a broad impression of what the field has achieved so far and what the current status quo is. The overview might also be useful for researchers interested in other sub-fields of HCI, such as SportsHCI (Elvitigala *et al.*, 2024), FoodHCI (Khot and Mueller, 2019), and NatureHCI, as it allows to compare the state of their sub-field to other sub-fields in HCI in order to assess progress and inspire next steps (Mueller *et al.*, 2020).
- Our work presents a comprehensive structured analysis of prior WaterHCI projects based on the consolidation of two existing frameworks. This analysis could be useful for WaterHCI researchers aiming to identify where their own work sits in relation to prior work in order to gain guidance on what to work on next. It could

also be useful for junior researchers who would like to venture into the field but do not want to repeat investigations already being conducted. It could also be useful for researchers in other areas that look for inspiration about how one can structure an analysis of prior works. Finally, our consolidation of the two existing frameworks could also be helpful for researchers who are looking for examples on how to combine existing theory to structure survey works.

- We also present a table with underexplored areas within WaterHCI based on our aforementioned analysis. This table highlights opportunities for future work, which could be useful for PhD candidates looking for dissertation topics. Furthermore, these underexplored areas could be useful for funding agencies who are looking to support "the next big thing". Also, they could be useful for researchers who aim to direct larger research endeavors and hence can use them to structure such endeavors around WaterHCI. Lastly, these underexplored areas can be useful for industry practitioners already working on WaterHCI development projects to guide them in what to work on next to facilitate innovation and to advance the field as a whole.

With our work, we aim to provide the WaterHCI field with an overview of what has been achieved so far to highlight what has been underexplored and, hence, might deserve further attention. With this articulation, we can prevent the field from repeating existing work and consequently stagnating. Instead, we aim to advance the field as a whole by providing a structured understanding of what the underexplored areas are and hence guide what opportunities researchers and practitioners might want to focus on next so that more people can profit from the many benefits that combining interactive technology and water affords.

In the next section, we discuss the two aquatic frameworks from which we drew (Section 2). We discuss each (Sections 3 and 4) and then, in the subsequent section (Section 5), combine the two; the result is a table that allows us to place prior WaterHCI systems (Section 6). We go through the table, column by column, to detail these prior

WaterHCI systems. In the following section (Section 7), we present design gaps identified through the frameworks and what this can mean for future work (Section 8), before we present the limitations of our work (Section 9) and our conclusion (Section 10).

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