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Poster

Study of Pseudoresistance during Water Walking in Augmented Reality

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Abstract

Lack of exercise affects health and the quality of life. Walking is a suitable remedy for sedentary lifestyles. Therefore, in this study, we developed a walking exercise system that employs augmented reality technology and pseudoresistance sensations to mimic walking in water. The system includes an application with adjustable water-level features, making it suitable for everyday use in environments such as homes and gymnasiums. Our preliminary experiments reveal that variations in the water level can affect walking speed, demonstrating the potential of the system for inducing pseudoresistance and walking assistance.

CCS Concepts

• ***Human-centered computing*** $\rightarrow$ ***Mixed / augmented reality;***

1. Introduction

Walking is considered a suitable exercise for mitigating sedentary lifestyles and maintaining health because it can be performed without causing excessive stress on the body. Recent advances in computer technology have facilitated research on walking-assistance systems for rehabilitation using virtual reality (VR) technology [HNAL22]. However, VR systems that require the attachment of additional devices, such as actuators or controllers, can be cumbersome to set up and adjust, potentially becoming obtrusive during movement and lowering the motivation to continue using the system. Therefore, walking assistance that avoids the need for such peripheral devices is desirable. The application of a pseudoforce sensation can help achieve this. The illusion that arises from inconsistencies between visual feedback and proprioception (ability of the body to sense position, movement, resistance, and weight) is a result of brain adjustments during visual information and self-motion mismatch. This sensation may be harnessed to aid walking by providing the impression of resistance or guidance during movement. In this study, we developed a system using augmented reality (AR) technology that enables walking within computer-generated (CG) water visuals in an everyday environment, to examine induced pseudoresistance sensations. Using this system, we conducted a preliminary experiment in which participants wore a smartphone-compatible head-mounted display (HMD), and their walking speed was measured as the water level was altered.

2. Related work

Li *et al.* proposed a low-cost pseudoforce feedback method for upper limb rehabilitation using VR technology. Changes in cursor speed are used to create the illusion of virtual assistance or resistance to arm movements [LGH*19]. Aoki suggested the possibility of inducing pseudoforce sensation through the ratio of hand movement to the movement of a floating sphere in a virtual environment during swimming exercises [Aok20]. In this study, we explored pseudoresistance sensation related to walking motions, which has not been studied previously, specifically through variations in the water level. Utilizing AR technology, we simulated water surfaces to develop a system for walking in water and conducted a preliminary experiment to study the sensation of pseudoresistance associated with different water levels.

3. System description

In this study, real-world imagery and position estimation technology were used to investigate whether pseudoresistance sensations could occur during walking movements in an everyday environment. Furthermore, enhancing the sense of immersion is essential to make users feel as if they are walking in water. However, optical see-through goggles such as HoloLens and Nreal have gaps between the area where the image is displayed and the body of the goggles, rendering it challenging to convey the sensation of being underwater to the user. To address this issue, we used a smartphone-compatible HMD in the developed system. Additionally, considering the device performance, we adopted the Dynamic Water System that utilizes the wave equation to calculate the mesh height information for simulating the water surface. We utilized the position estimation technology of ARKit to accurately generate ripples at the location of the user. Finally, to investigate the pseudoresistance sensation caused by differences in water levels, we developed a water-content application (Fig.1) that enables users to experience

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various water levels (water level 0: no water; water level 1: waist height; water level 2: chest height, featuring a higher viscosity).

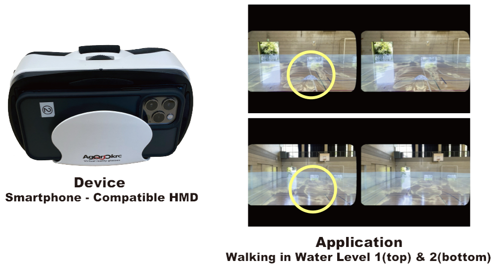

Figure 1: *Water-content application*

4. Preliminary experiment

The preliminary experiment was conducted in a university gymnasium with eight participants in their 20s (six men and two women). Participants wore a smartphone-compatible HMD and followed the instructions of the water-content application to walk on a straight 15-m route with the three water levels mentioned in the system description (Section 3). First, upon hearing the audio cue "Start" from the water-content application, participants walked 5 m in water level 0. Upon reaching the 5-m mark, an audio cue "Stop" was played. Subsequently, the participants waited for 3 s before walking 5 m each in water levels 1 and 2, following the audio cues of the water-content application, similar to that in water level 0. The order of the appearance of water levels 1 and 2 was randomized to avoid bias in the evaluation. Finally, the participants removed the smartphone-compatible HMD and responded to a questionnaire regarding the sensation of water resistance when walking in water levels 1 and 2 using the 7-point Likert scale. During the experiment, the smartphone-compatible HMD was detached for one participant, hindering the concentration of the water surface content; thus, the associated data were excluded from the analysis.

Table 1: *Result of Water Resistance Sensation Questionnaire (7-point Likert scale, Ranging: 0(felt nothing) - 6(very strongly felt))*

ID	Result of Water Level 1	Result of Water Level 2
1	5	2
2	2	4
3	1	4
4	3	5
5	1	1
6	4	1
7	3	1

From the results of the aforementioned questionnaire(Table 1), a trend was observed in which the resistance felt at water level 2 was greater than that at water level 1 (ID2,3,4). This indicates that the sensation of water resistance can be enhanced by adjusting the viscosity of water. From the differences in completion time between water levels 0 and 1 or 0 and 2(Table 2), a pseudoresistance sensation may be experienced owing to water (ID1,3,4,5,6). Additionally, the differences in completion time between water levels 1 and 2(Table 3) revealed that changes in water level might induce pseudoresistance sensation (ID1,2,4,6,7). The analysis of the differences in completion time at varying water levels demonstrated the possibility that disparities in water levels may produce a simulated sense of resistance during everyday-walking activities. Furthermore, because of variations in water level, some participants walked faster to overcome resistance, while others walked slower owing to perceived resistance. This suggests the potential of the system for applications in walking assistance.

Table 2: *Completion Time Difference: Water Level 0 to 1 or 0 to 2*

ID	Order of Water Levels	Completion Time Difference
1	Lv.0, Lv.2	0.88s (Lv.2 - lv.0)
2	Lv.0, Lv.2	0.08s (Lv.2 - lv.0)
3	Lv.0, Lv.1	-0.24s (Lv.1 - lv.0)
4	Lv.0, Lv.1	0.56s (Lv.1 - lv.0)
5	Lv.0, Lv.1	-0.40s (Lv.1 - lv.0)
6	Lv.0, Lv.2	0.94s (Lv.2 - lv.0)
7	Lv.0, Lv.2	-0.02s (Lv.2 - lv.0)

Table 3: *Completion Time Difference: Water Level 1 to 2*

ID	Order of Water Levels	Completion Time Difference
1	Lv.2, Lv.1	2.68s (Lv.1 - lv.2)
2	Lv.2, Lv.1	-0.44s (Lv.1 - lv.2)
3	Lv.1, Lv.2	-0.04s (Lv.2 - lv.1)
4	Lv.1, Lv.2	-0.66s (Lv.2 - lv.1)
5	Lv.1, Lv.2	0.04s (Lv.2 - lv.1)
6	Lv.2, Lv.1	-1.20s (Lv.1 - lv.2)
7	Lv.2, Lv.1	0.14s (Lv.1 - lv.2)

5. Conclusion and future work

In this study, we developed a system for simulating water-walking during everyday-walking motions using AR technology to investigate whether a pseudoresistance sensation occurs owing to the different water levels on CG water surfaces. In addition, we conducted preliminary experiments in a university gymnasium. The results indicated the potential of the system to exhibit a pseudoresistance sensation at various water levels on CG water surfaces. Furthermore, the variations in water level led some participants to walk faster to overcome resistance, and others to walk slower owing to perceived resistance, suggesting potential applications in walking assistance. Future research will focus on enhancing the resistance sensation at water level 2 by studying parameters such as the splash height and ripple spread speed. Furthermore, it is necessary to verify the alterations in muscle activity upon the perception of pseudoresistance.

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