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リハビリテーション応用へ向けた触覚デバイスのコンテクストに基づく最適化：LevioPole を事例として

Context-based optimization of a haptic device toward application to rehabilitation: A case study of LevioPole

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概要: In this study, we thoroughly document and explain the process of applying activity theory and contextual inquiry to bring LevioPole, an existing propeller-based haptic device used in virtual reality environment, to the use case of rehabilitation for elders.

キーワード： Design-oriented Research, Rehabilitation, Haptic Device, VR, Elders

1. Introduction

Human-Computer Interaction (HCI) is an interdisciplinary domain, which allows every researcher from diverse backgrounds to contribute freely to the community with their expertise. Hence, there are always encouraging results that worth researchers to reapply from a scenario to another. Among these cases, one common situation nowadays is how to bring haptic devices into other contexts in the real world apart from gaming applications, such as telehealth or the rehabilitation field.

Haptic devices can generally refer to the device with mechanical and electrical integration for the enhancement of interacting in a simulation environment. A group of HCI researchers aims at utilizing various combinations of mechanisms to lively simulating force feedback in the virtual reality environment. Force feedback provided by haptic devices can roughly be categorized into active and passive feedback. Passive force feedback often used to present the surface of objects or resistance in the environment. For example, Wireality [1] attaches strings on the fingers of users and controls movement of fingers to enable users to feel complex tangible geometries in the virtual world. ElasticOscillator [2] employs damped oscillation effects to simulate the complicated force feedback of shaking elastic objects or liquid-swirling in one's hand. As for active force feedback, it can be applied to

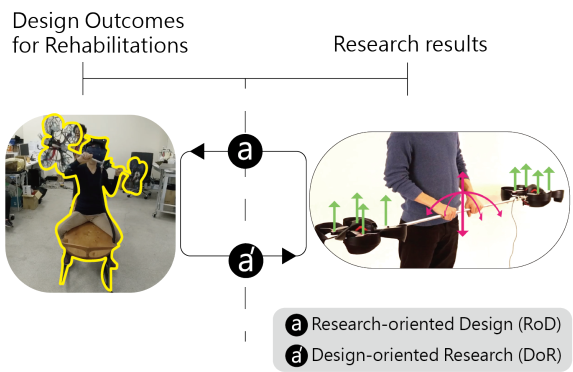

図 1: LevioPole provides directional force via propellers mounted on each end.

simulate outdoor activities or extreme sports. For instance, LevioPole [3], a rod-like haptic device that both ends with two pairs of a propeller mounted on it, takes advantage of the generated wind to present the lifting power of virtual super-leaping [4] and the resistance force of the water of virtual kayaking [5].

A noteworthy viewpoint from the cognitive science domain is "Mental Models [6, 7]." The concept of mental models indicates that people behave by following their mental models. Furthermore, all kinds of researchers, engineers, and designers who deliver products and services to people can be called "Cognitive Designer" because, in other words, we actually deal with mental models mapping to our target users.

We can wrap up similar mental models by reviewing of the mentioned project. A novel concept of haptic device usually starts from yearning for simulating a variety of haptic feedback, mostly feedback from a single movement in a scenario, such as casting with a fish-pole. Then, the HCI researchers will realize it via different integration of mechanisms, such as vibration-based, wind-driven, and magnetic principles. Therefore, the mental models of haptic devices remain some room for investigation if we aim at deploying the research results of haptic devices to the real world. Luckily, we now benefit from some developed models, such as activity theory and contextual inquiry, for analyzing complicated systems. Hence, in this paper, we will explain the process of how we apply LevioPole, a haptic device, to rehabilitation usage by optimizing it according to the context of the healthcare system.

2. Literature Review

2.1 Activity Theory

Activity theory [8] was first proposed by Russian psychologists. It provides a complete framework to analyze the context of individual and group activities, and emphasize on how humans interact with each other through artifacts. To understand the meaning of an activity, we supposed to consider environmental factors such as environment, rules, and social context and focus on observing people's active implementation. This research adopts the development framework of Engeström [9] to find out the critical elements in the rehabilitation process as the references for designing the LevioPole interactive model.

2.2 Contextual Inquiry

Context inquiry (CI) [10] can assist researchers to observe and interview in the user's workplace. Acquiring context through five working models of CI can help us have a comprehensive understanding of target activities. Furthermore, we are enabled to find details and difficulties in the user's work via different models of CI [11]: the cultural model, the flow model, the sequence model, the artifact model, and the physical model.

3. Process of Context-based Optimization

This section thoroughly documents the action plan we take in the process of context-based optimization LevioPole. The process of context-based optimation goes back and forth on the spectrum of design and research [12], which is literally under the process of research-oriented design (RoD) and design-oriented research (DoR), as shown in fig. 1. The following passages explain the details of revising LevioPole in the RoD and DoR stage.

3.1 Research-oriented Design Direction

Since LevioPole is initially designed for simulating somatic experience, we firstly begin from RoD direction and picture its default mental models.

3.1.1 Understanding the Context of rehabilitation

Then, two experts (one physiatrist and one occupational therapist were invited (fig. 2) to experience three contents of LevioPole, then interview them with questions from the six perspectives of activity theory: subject, object, community, tools, rules, and division of labor. The decision to apply virtual kayaking experience (VKE)

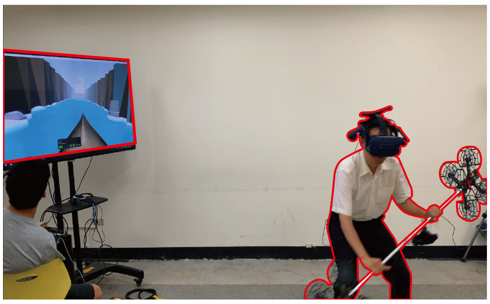

図 2: A physiatrist is invited to experience the original version of virtual kayaking.

rather than virtual super-leaping or virtual weight-lifting to rehabilitation is because the paddling movement is more doable and can repeatedly exercise shoulder for everyone. Besides, our fieldwork based on five working models of contextual inquiry and feedback from experts shows the following vital problems: (1) the invited experiencers try to keep lower posture when experiencing VKE; (2) the default paddling movement of VKE to trigger haptic feedback can not extend shoulder enough; (3) it lacks the richness of visual content; (4) it is better to minimize the range of users movement; (5) the time of rehabilitation program per person in the hospital is around 30 minutes.

Therefore, the revised VKE utilizes a 360-degree recorded real scene (fig. 3(a)) as visual content and a rocking chair (fig. 3(b)) to present feedback of wave, let users sit on it, and effectively minimize the range of user's movement. Then, the triggering condition is modified to inserting paddle into the virtual water surface (fig. 3(c)) rather than rotating the Vive tracker.

3.2 Design-oriented Research Direction

After revising the VKE in RoD stage, we crave for understanding is our designed mental model similar to users' or not. Therefore, for exploring the possible issues at the phase of upfront research, two formative user stud-

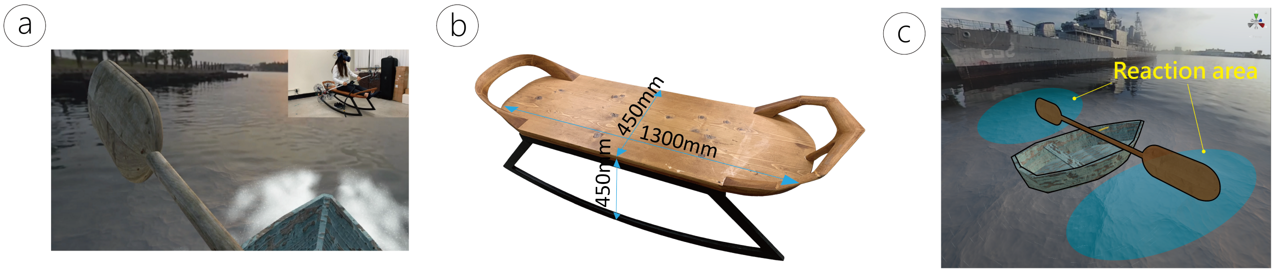

図 3: **The revised parts of LevioPole for rehabilitation purpose.**

ies were conducted to collect first-hand information from the random experiencers and elders.

3.2.1 Formative User Study

Participants. Nine participants with an average age of 72.5 years were recruited through friends, three males aged 72∼86 years, and six females aged 66∼73 years. And, 30 random users experienced VKE as well.

Findings. Six interesting findings were observed from the user study of the elderly people: (1) Cultural Engagement from Local Scene. It was an active atmosphere of discussing the history of the real scene in Tainan while one experienced VKE. Participants shared their personal memories related to what they saw with others; (2) Priorities of Multimodal Feedback. We found that all participants were focused on what they saw rather than how long they repeatedly paddled; (3) Various Types of Paddling Behavior. An important issue in the VKE interaction process is how a user paddles using a hand-held haptic device. To observe the real behavior patterns of the user, we do not restrict the frequency of paddling, direction, and any other way of using the haptic device.Therefore, we found that most of the elderly participants had incoordination problem while paddling. Therefore, it is necessary to fix the hand-held device if the users are required to complete a certain movement perfectly in the rehabilitation scenario; (4) users from the Tainan city curiously look around from the viewpoint on virtual canoe although they are familiar with this area; (5) some users try to move backwards by reverse stroke; (6) bystanders can interact with user through appropriate human-scale hardware design.

4. Results and Discussions

Through the process of context-based optimization of LevioPole, we learned that anchoring the direction based on the state of development is the priority before adopting any method. Additionally, the mindset of focusing on the mental model of haptic devices helps us to find a cut-in point to a complex field, such as the rehabilitation field.

On the other hand, our results of exploration reveal three aspects of applying the VKE system to rehabilitation usage, which is usability, engagement, and feasibility. First, in terms of usability, we found that the hardware part requires a solid handle rather than just a bare rod to prevent elders from rotating the haptic device in the wrong direction or gripping an inappropriate width of the rod fig. 4(b) because they are not familiar with kayaking. Furthermore, participants also shrug fig. 4(c) while kayaking, which leads to improper posture during rehabilitating. As for user engagement, the obser-

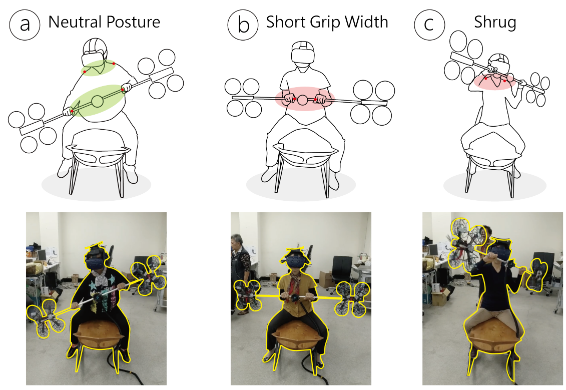

図 4: **Improper movement of elders when doing VKE**

vation is positive that elders often forgot how long they were experiencing it since they immerse in the virtual environment and show high acceptability and interests towards our VKE system. Nevertheless, the vision deterioration of elders affects their experience a lot. Thus, different types of media to represent vision content are necessary. In the aspect of the feasibility, the users show high acceptance of the integration of 360-degree recorded real scenes and the haptic device in the virtual environment. However, in the whole experience process, the staff usually spends lots of attention to the user's conditions, which needs to improve to ease the loading of staff.

5. Conclusions

In this study, we thoroughly document and explain the process of applying activity theory and contextual inquiry to bring LevioPole, an existing propeller-based haptic device used in the virtual environment, to the rehabilitation usage for patients and elders, and the differences from original VKE to revised VKE. We introduce the methods we adopted and describe the reasons behind the decision making for improving the appropriateness of applying to rehabilitation.

We conducted two formative user studies to evaluate the feedback of users after experiencing the revised VKE system and observe the behavior pattern of older adults who are the future target group of the VKE system. The findings were reported, and some phenomena from observation were discussed. In future work, we propose some perspectives for improvements: (1) utilize computer graphics-related techniques to enrich the visual content for the historical perspective to evoke more emotional connections; (2) to simplify the manipulation process, the haptic device and rocking chair can be integrated into an arcade game machine form. On the other hand, as for the older people, the fixed position of the seat and handle of the haptic device helps them to maintain the correct posture while experiencing, such that they can perform the designed rehabilitation movements much more precisely; (3) some elders have vision or hearing problems. Hence, different media of presenting vision and hearing content are necessary.

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