論 文 内 容 の 要 旨

1. Background and Motivation

Since the inception of computers, the relationship between humans and computers has been a significant debate within the Human-Computer Interaction (HCI) community. The field of HCI has long explored symbiotic/synergistic relationships between humans and computers, especially as technological threats to humanity increase within interactive systems. The earliest discussions can be traced back to Licklider's proposition of "Man-Computer Symbiosis" in the 1960s. Over time, the focus of the debate has evolved through four waves of HCI. The progression from the first wave to the third wave marked a gradual shift from a purely technological point of view in the context of industrial engineering and ergonomics to an emphasis on human-centered computing for addressing some of the social and emotional aspects of HCI. In the current fourth wave, particularly with recent advances in artificial intelligence, there has been a widespread focus on an even more human-centered perspective, within a renewed focus on human capabilities. However, previous research has yet to fully explore an ideal relationship aimed at fully developing and enhancing human capabilities through the utilization of promising technologies.

In this context, the concept of synergized interactions has been proposed in the theory of Human-Engaged Computing (Ren, 2016), aiming to achieve seamless integration with the appropriate allocation of resources in interactions, emphasizing on human soft skills such as creativity, mindfulness, and design. With the rapid development of information technology, the concept of synergized interactions advocates for addressing both the threats posed by technology and enhancing human capabilities to tackle current challenges in the field of HCI, such as dependency on the internet or gaming addiction. However, there exists a gap between theoretical understanding and practical design in the pursuit of synergized interactions, as this concept remains primarily theoretical level.

1. Research Questions

To address this gap, the fundamental goal of this dissertation is to explore the theoretical foundations and empirical research of synergized interactions, as well as to investigate their potential for enhancing human capability. More specifically, our aim is to address the following three overarching Research Questions (RQ):

- RQ1: How can we construct a theoretical framework for synergized

interactions in general?

- RQ2: How can we develop promising synergized interaction technologies to enhance human capability?
- RQ3: How can we understand and extend the investigation of synergized interactions and provide general knowledge to the HCI community?

2. Solutions

To address Q1, in Part I, we dive into theoretical studies on synergized interactions. In Chapter 2, (1) We analyze the issues with existing interaction patterns and adopt a rhythm perspective to understand and expand the interaction process. (2) We review the importance of rhythm and rhythm regulation in the HCI community. (3) Furthermore, we define the scope of synergized interactions from a rhythmic perspective for this dissertation. In Chapter 3, we propose a framework for synergized interactions. This framework comprises three components: (1) defining the states of synergized interactions, (2) proposing protocols for rhythmic regulation mechanisms toward synergized interactions, and (3) introducing general procedures and design principles for these mechanisms.

To address Q2, in Part II, we explore three design cases on synergized interactions. These three studies represent empirical explorations following theoretical reflections on synergized interactions, with the goal of enhancing human capabilities. In Chapter 4, we investigate the effects of three general rhythmic interaction patterns on enhancing creativity while walking. This foundational study highlights the value of synergized interactions. In Chapter 5, we develop a synergized interaction system and explore, through empirical studies, the positive effects of seven pairs of enhancing mindfulness meditation while running. In Chapter 6}, we explore a teaching framework to enhance students' design capacity while developing synergized rhythm game.

To address Q3, in Part II - Chapter 7, we further extend the guiding significance of synergized interactions in the field of digital heritage education. Our overarching goal is to continually enrich the concept of synergized interactions, fostering cross-disciplinary empowerment and insights across different fields and disciplines. Furthermore, in Chapter 8, we summarize the key findings of theoretical and empirical studies on synergized interactions, compare differences in existing studies, and present insights in six aspects (perspective, methodology, design, system development, user study, and evaluation). In Chapter 9, we present general conclusions on main findings, contributions, significance, and future agendas and remarks to contribute new knowledge to the HCI community.

3. Main Findings

This subsection has succinctly summarized the findings of this doctoral dissertation, which are distributed across the following chapters.

Chapter 2 indicate that （1）rhythm, as a significant analytical approach, holds substantial importance for observing interaction states; (2) a promising hypothesis suggests that adjusting interaction rhythms can facilitate the transition towards synergized rhythms between human rhythms and computer rhythms, thus offering a practical approach for realizing this synergized interaction.

Chapter 3 contribute to the following aspects: (1) We define states of synergized interactions by adjusting interaction rhythms to achieve synergized rhythms; (2) We establish interaction protocols by proposing computational methods of rhythm adjustment to implement synergized interactions; (3) We design promising interaction mechanisms by identifying the interaction procedure and five design principles based on FSIRA.

Chapter 4 demonstrate that (1) The FSS mode demonstrated higher performance in body awareness and attention regulation in both indoor and outdoor environments; (2) the creativity scores of indoor participants were higher than those of outdoor participants; (3) The indoor FSS mode produced greater creativity compared to the indoor RFSI mode; (4) Participants in the indoor FSS mode showed a significant correlation between heart rate and cadence with creativity compared to other groups; etc.

Chapter 5 show that the RunMe group outperforms the other groups in attention regulation, body awareness, exercise motivation, and mindfulness. Importantly, RunMe allows users to engage in running meditation without specialized equipment, making it accessible for daily practice.

Chapter 6 indicate that (1) there has been a significant improvement in student engagement, with students demonstrating increased collaboration and active engagement in the creative process; (2) the reflective design abilities of students have been enhanced, allowing them to critically evaluate their own work and make informed decisions to improve rhythm game design.

Chapter 7 indicate that (1) the proposed framework effectively guides collaboration between students and digital tools in the understanding and design of Cantonese Porcelain (CP) based on HEC theory; (2) Validation through a five-year creative CP course demonstrates the framework's support for phased student understanding and design of ICH in DHE, marking a pioneering application of HEC theory in education.

4. Contributions

The main contributions of this dissertation fall into the following three categories:

(1) Theoretical Contributions:

In Chapter 2, we unveil the dynamism of interactions through the lens of rhythmic analysis. Additionally, we provide a comprehensive definition of the generalized concept of synergized interactions for the first time.

In Chapter 3, we introduce a practicable framework for synergized interactions, comprising three key contributions. First, the framework delineates the states of synergized interactions, termed synergized rhythms, enabling their observability. Second, the framework proposes rhythm adjustment mechanisms to achieve synergized interactions, consisting of three adaptable computational algorithms. This facilitates the operationalization of states of synergized interactions through actionable protocols. Third, the framework outlines the general procedure and design principles for rhythm adjustment, providing design guidance to future researchers and designers in developing synergized interaction technologies.

(2) Empirical Contributions:

In Chapter 4 - study 1, we design a Footstep Sound Interactions (FSI) framework and develop an interactive system (called WalkMe) that encompasses three FSI modes to support walking creativity. Subsequently, we conduct a user study in indoor and outdoor environments comparing the effects of three FSI modes with a walking-only condition. Based on the findings, we discuss the FSI framework's implications, roles related to attention and creativity in the walking experience context, and implications for design and future work aimed at enhancing walking creativity through interactive technologies.

In Chapter 5 - study 2, we present the design framework and development of the RunMe system, an adaptive sound system specifically designed for running meditation. RunMe integrates stimulation and regulation mechanisms to enhance data interactions between sounds and runners' footsteps and heart rate. We compare the significance of the RunMe group with three other groups: non-adaptive sound, user-favorite music, and no-music/sound groups. The results show that the RunMe group outperforms the others in attention regulation, body awareness, exercise motivation, and mindfulness. Importantly, RunMe allows users to engage in running meditation without specialized equipment, making it accessible for daily practice.

In Chapter 6 - study 3, we propose a Synergized Rhythm Game Teaching Framework (SRGTF) aimed at fostering student engagement and reflective design practices. We conducted a synergized rhythm game design workshop at the university, involving 26 students who engaged in phased game design activities guided by the SRGTF. All

students participated in qualitative and quantitative surveys to collect their subjective feedback. The study identified the effectiveness of the SRGTF in fostering students' engagement and reflective game design skills. This also underpins the framework's potential for sustained research in game design education. These findings underscore the importance of adopting the SRGTF as pedagogical approaches to foster a more effective teaching for rhythm game design education. This study also provides new pedagogical guidelines for future game design education.

In Chapter 7 - study 4, we propose a framework that extends the concept of synergized interactions to improve understanding and design of intangible cultural heritage (ICH) in the field of education. To validate the effectiveness of the proposed framework, we design, implement, and track Cantonese Porcelain Creative Design courses over five years. We discuss the theoretical and practical importance of this framework and outline a future research agenda for digital heritage education in the classroom. Our framework provides researchers and educators with a new approach to explore how digital technology can effectively support students in understanding and designing ICH.

(3) Future Implications:

In Chapter 8, we summarize the theoretical and empirical investigations into synergized interactions that were undertaken previously. Our contributions extend to a comprehensive discourse on the implications of our findings, critically evaluating their significance within the broader context of HCI. We also delineate the limitations encountered during our research, providing a transparent account of potential constraints and areas for improvement. Moreover, we offer a forward-looking perspective by identifying promising avenues for future research and practical design, aiming to guide and inspire HCI researchers and designers.

In Chapter 9, we provide a comprehensive summary of the dissertation, highlighting key findings from Chapters 2 to 7, emphasizing the transition from theoretical to empirical contributions. It underscores the significance of theoretical research in advancing practical applications. Additionally, it outlines future agendas to guide researchers and designers in the HCI community and concludes with reflections on the entire doctoral dissertation. Overall, the chapter offers readers a deeper understanding and outlook while providing valuable insights and directions for the future development of synergized interactions.

5. Future Agendas

Above all, we advocate that future research of synergized interaction should consider

further exploration on the following agendas.

- First, a more systematic and refined theoretical framework is needed to deepen our understanding of the multidimensional characteristics and underlying mechanisms of synergized interactions.
- Second, more empirical research should be conducted to validate and extend existing theoretical models and to explore the effects and factors influencing synergized interactions in different contexts.
- Third, synergized interaction technologies should not only consider the technical implementation of HCI, but also focus on user experience and social impact, in order to achieve harmonious development between technology and society.
- Finally, it is recommended to conduct long-term longitudinal studies to observe and analyze the long-term effects and potential issues of synergized interaction technologies in practical applications.

6. Contents of the Dissertation