Design Space of Multipurpose Daily Worn Snake-Shaped Robotic Appendages

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***Abstract*—Multipurpose Supernumerary Robotic Limbs (SRLs) are an emerging form of wearable robots that can augment our daily physical and digital interactions. Due to their genericity, designing this form of wearables encompass a number of interweaved challenges within multiple research domains. Therefore, my dissertation's main objective is to contribute with a design space that enables designing and evaluating multipurpose SRLs. I carry out a series of case studies to derive needed design dimensions, with emphasis on designing for multipurpose use, social acceptance, and cohesive user experiences. The design space would structure this domain, enabling future researchers to generate and evaluate new case studies, as well as identifying and addressing challenges to advance this emerging research area.**

Keywords—Multipurpose: Wearable, Augmentation

I. MOTIVATION AND RESEARCH QUESTIONS (*HEADING 1*)

The diversity of daily interactions presents numerous interweaved challenges that a single-purpose wearable cannot address. Therefore, a fundamental aspect of the vision of wearable computers is being generic; they can adapt their interaction modalities to conform to the diversity of interaction contexts [1]. A single-purpose wearable could be efficient within a specific domain, but daily worn devices require genericity to be applicable in a variety of contexts.

Wearable robots present numerous interaction potentials. Supernumerary Robotic Limbs (SRLs)]2] are wearable robots that augment humans with additional physical manipulation capabilities. Research in this emerging domain presented SRL prototypes that demonstrate their potential for daily use. However, SRLs face the same challenges that impede the realization of mainstream general-purpose wearables. An SRL worn daily should include multiple interaction capabilities to increase its value for use. Moreover, such wearables should socially be acceptable when worn or used in public.

My dissertation attempts to bridge the gap in this domain by focusing on the design requirements daily usage challenges of multipurpose daily used SRLs, with the overall of constructing a design space for this for form of wearables. To the best of my knowledge, no previous works have attempted to investigate design dimensions for daily worn SRLs. My work focuses on the following research questions:

- What are the user interaction expectations, in terms of tasks and contexts of use, associated with daily worn multipurpose SRLs?
- What are the social challenges for enabling daily use of daily used multipurpose SRLs? And How can we address these challenges?
- How can we design cohesive and cross-contextual user experiences for this form of wearable devices?
- From the perspective of multipurpose use, social acceptance during public use, and cross-contextual user experiences, what are the main dimensions required for designing daily worn multipurpose SRLs?

I base this work on investigating the snake-formfactor for use as a multipurpose SRL, due to its well established versatility across multiple usage contexts.

II. LITERITURE BACKGROUND

Research on SRLs investigated various forms of limbs and associated control and feedback methods in different usage contexts. SRLs were developed for a variety of purposes. Some researchers focused on work-supporting tasks, such as holding components for assembly or drilling holes]2[. Within the context of professional work, a significant portion of related work focuses on supernumerary robotic arms and fingers. A notable work is of Leigh and Maes [3], which introduced a wrist-worn multipurpose SRL.

Existing prototypes have numerous challenges. First, current works focus on industrial or work related activities, therefore making them specialize tools. Such aspects defies interaction genericity, therefore limiting these devices to specific interaction contexts. Social acceptance is also excluded from the design process of such works, as these works focus on functional efficiency within intended contexts rather than public use. Lastly, proposed control methods are optimized for these industrial contexts. Such control methods require the user's constant attention to operate and work with such SRLs, which would be very undesirable for a daily wearable.

III. APPROACH AND METHODOLOGY:

My dissertation is conducted in three main Phases:

- **Phase 1**: Gathering and identifying potential requirements, expectations, challenges regarding daily usage and public wearability of multipurpose SRLs.
- **Phase 2:** Based on analysis results of phase 1, develop and validate case studies that emphasis of daily usability scenarios domains, interaction and control methods and social acceptance challenges.

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- **Phase 3:** Extract design dimensions from existing literatures and developed case studies to construct the design space for daily used multipurpose SRLs.

In the next subsections, I briefly present preliminary and planned work related to phase 1 and phase 2.

A. Orochi: Investigating Challenges and Expectations of Daily Worn Supernumerary Robotic Limbs

In this project, we developed a snake-shaped supernumerary robotic limb that we called Orochi. The robot attempts to fulfil three design considerations (Fig. 1), which are multipurpose use, wearability by context, and unobtrusiveness in public. We used Orochi to address the first and second research questions, by conducting a series of focus groups and a survey to investigate how a multipurpose SRL may be used on daily basis, and how it is perceived when used in public.

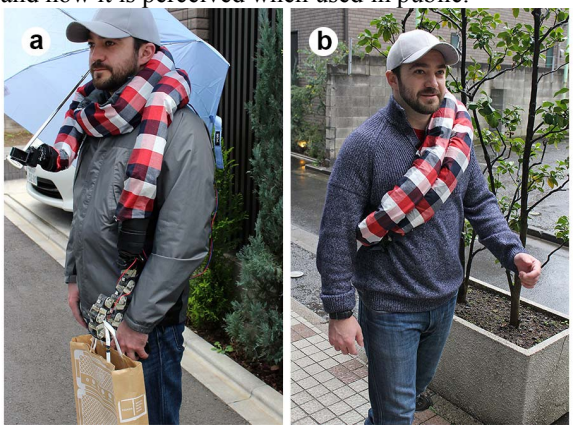

Fig. 1. (a) Orochi is a multipurpose daily worn robot that can be used across a wide variety of daily contexts, (b) its flexible design allows it to be worn in multiple ways whilst being unobtrusive.

B. HapticSnakes: Multi-Feedback Wearable Robot for VR

HapticSnake was developed to address the third research question, where wearable serpentine robots can be used to deliver a variety of feedback to correspond to services. Therefore, our main aim of this case study is to explore novel feedback opportunities enabled by the wearable serpentine formfactor. We focus our work on casual virtual reality experiences as an application domain of feedback potentials. HapticSnakes consists of a snake-shaped robot, waist-worn on a fixed base, that can deliver a variety of novel feedback that have not been explored previously, like gestures, shear forces, as well as gripper-based experiences (e.g. tugging or feeding users). HapticSnakes can deliver mentioned feedback on different body locations, such as front or back torso, neck as well as hands (Fig. 2).

C. weARable: Exploring Augmented Reality Interaction for Everyday Multipurpose Wearable Robots

In this case study, we address the third research question by investigating the use of augmented reality (AR) for use as a generic interaction medium for cross-contextual control of daily worn SRLs. Our work focuses on proposing an interoperability framework for integrating AR. To test our framework, we developed a wrist worn SRL (Fig. 3) and utilize an AR head mounted display to investigate a variety of experiences, such as to display internal robot status (e.g. servo angles or temperatures), haptic and shape-changing experiences, and to control the robot's pose.

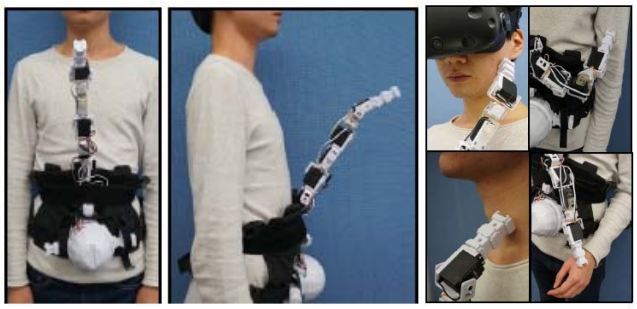

Fig. 2. HapticSnake robots can deliver a variety of haptic feedbacks to different locations around the body.

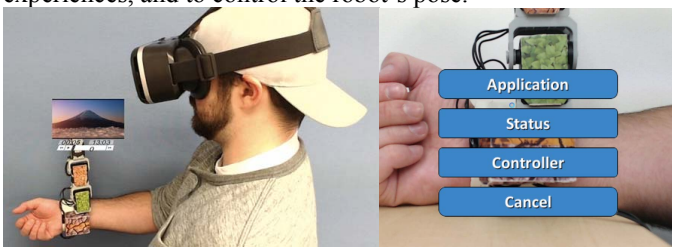

Fig. 3. weARable investigates the use of AR for controlling multipurpose SRLs. AR is a rich medium to visualize information and control these wearables.

IV. CONTRIBUTION

The main contribution of my dissertation is to advance knowledge about multipurpose daily worn SRLs. Despite the various potential benefits and potential usage domains for daily use, the scarcity of works in this domain makes reaping these benefits difficult to accomplish. Therefore, my work attempts to bridge this gap by identifying essential design dimensions and structuring them within one cohesive framework. Such framework can be utilized for generating new case studies, based on grounded knowledge, that tackle essential research challenges across multiple domains.

V. ACKNOLEDGEMENT

This doctoral thesis is supervised by Professor Tatsuo Nakajima, Department of Computer Science and Engineering, Waseda University, Tokyo, Japan. Tatsuo@dcl.cs.waseda.ac.jp

VI. REFERENCES

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