Graduate School of Creative Science and Engineering
Waseda University

# 博　士　論　文　概　要
# Doctoral Dissertation Synopsis

論　文　題　目
Dissertation Title

Design of Supernumerary Robotic Limb Interface Considering Attention Allocation in Dual-presence Task

Dual-presence Taskにおける注意分配を考慮した拡張肢インタフェースの設計

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This thesis focuses on the question of how to design the interface of Supernumerary Robotic Limbs (SRLs) to perform dual tasks efficiently. In our busy daily lives today, demand of multiple tasks is increasing in order to reduce working time. One solution is to introduce specialized automatic devices for each task (e.g., fully automatic dishwasher, robot vacuum cleaner, etc.). However, in the situation of daily life, the items, the environment, and the human intentions are changed from time to time. In these situations, support method that allows voluntary intervention by humans through some manual operation is required rather than a fully automated response.

Recently, the development of human augmentation technology has contributed to the solution of this problem. In this field, various wearable robotic arm was proposed as the additional arms or legs, allowing one human to perform dual-task. However, while conventional research has given humans the physical means to dual-task, performing dual-tasking efficiently is very difficult for humans from a cognitive perspective. For example, the most flexible method of manipulating an SRL is through a master-slave approach, and some research has attempted to achieve this using the user's foot or head movements as input. However, such a method requires the user to continuously pay a lot of attention to the SRL while manipulating it, which may stop the work done by the natural body arm. On the other hand, some research on the SRL is pursuing an automatic control by measuring human movements and determining assistive actions. This is an approach for humans to pay little attention to the SRL. However, as mentioned above, automatic support by a system is not only unsuitable for the complex environment of daily life, but it also requires the user to pay attention to the robot repeatedly while it is moving automatically, wondering whether it is moving as intended. This can also interrupt the work done by the natural body arm.

Thus, conventional SRL systems do not consider attention problem, making it difficult to achieve high performance in dual-tasks. In this thesis, we discussed the design theory of the SRL from the viewpoint of attention allotment in dual-tasks, and also presented another challenge: to realize dual-tasks at two distant locations (e.g., mixing a pot in the kitchen while opening the front door for a family member who forgot the key). To achieve this, the SRL should not be worn all the time, but detached from the body as needed to create a situation where the user is as if he or she is present at two points simultaneously (dual-presence situation). Previously, the remote tasks are achieved by telepresence technology, but dual-tasks at the remote and current location (dual-presence task) are not achieved. In case of performing dual-presence task by "detachable" body, it is necessary to pay attention to the remote environment at the same time as the local environment. In addition to the problems of high attention to manipulation and distrust during automatic control, this is one of the factors that reduce the performance of dual-tasks.

This research aims to develop a new SRL system, Detachable body, which enables us to perform dual-presence tasks in daily life, and challenges the research question of how to design a system for high performance dual-presence tasks. As an approach to this question, this thesis focused on the

cognitive characteristics of humans during dual-tasks, and raised the following three issues related to attention allocation, and discussed design theory of Detachable body system through each of them.

(1) Voluntary operation demands a large amount of attention.

(2) Anxiety during automatic operation requires frequent attention.

(3) The processing of environmental information at two points requires a large amount of attention.

The thesis is divided into seven chapters.

- In Chapter 1, the effectiveness of human augmentation technology that can perform voluntary physical tasks is discussed from the viewpoint of complexity and fluidity of daily life situations. In addition, the purpose of this thesis is explained by summarizing the difficulty of performing dual-tasks efficiently from the viewpoint of human cognitive characteristics, and presenting three issues in the design theory of conventional human augmentation systems.
- In Chapter 2, the issue (1) is focused and a semi-automatic intermittent instruction system was proposed that points at an object by the direction of the face and performs an action by voice command, as a voluntary manipulation system that can give instructions with a small amount of attention. The system was implemented in an eyeglass-type interface device and enabled pointing with an accuracy of about 1 cm. However, the laser pointer introduced for the purpose of visually indicating the pointing location, improved the accuracy of the instruction but reduced the performance of the task on the natural body. This suggested the design concept that it is better to choose a method that can be manipulated with as small an amount of attention as possible, even if the manipulation involves some error, and that the error can be absorbed by another design element. (e.g., developing an end effector that can robustly grab the instructed object even if the instruction point is slightly off.)
- In Chapter 3, the issue (2) is focused and a feedback (FB) system was proposed that can know the posture information of the Detachable body through somatosensory perception even during automatic operation. The system was implemented in a belt-type device using vibrators, and was able to present the position of end effector with an accuracy of about 10 cm. This system can be used in conjunction with an easy calculation task without degrading the performance of the task. In addition, when it is used in conjunction with another slightly more difficult task of measuring hot water, it tends to improve the performance of the task on the natural body by reducing the number of visual confirmations on the Detachable body. This suggested the design concept that when automatic control is included in the operation of the Detachable body, the state of the robotic arm should be transferred by the somatosensory system in order to reduce the anxiety of the Detachable body during the operation.
- In Chapter 4, the issue (3) is focused and a dual-presence system was proposed that displays two half-transparent images of the environment with binocular disparity as a method to clarify

the task to which the user is mainly paying attention while having access to environmental information at two points. The system was implemented with a head-mounted display and a camera that rotated in sync with the head movement. In the with disparity state, the user was able to immediately distinguish between objects in the current location and objects in the remote location with a correct response rate of about 90%. The system was also evaluated in a dual-presence task in conjunction with the FB system developed in the previous chapter to provide information about the body at the remote location. The results showed that the performance of the natural body task and the subjective evaluation of usability by NASA-TLX were best when there was disparity and FB, when the user was able to focus their attention. This suggested the design concept that it is better to have a clear focus of attention that can be moved and switched freely, rather than a situation where attention is always equally directed to all environments.

- In Chapter 5, issues mentioned in Chapters 2 to 4 were discussed again and the contributions and limitations of this thesis were described. As embodied in the three design concepts suggested in the chapters, the design theory of SRLs for working in dual-presence tasks to consider the amount of which it deprives people of attention and the amount of which it inhibits or facilitates the switching and distribution of attention when selecting design elements that satisfy the required working functions. The limitation of this thesis is that it fails to consider the nature of tasks performed with natural bodies and the temporal changes in attention paid to them when examining dual tasks. As another limitation, the extension from dual-presence tasks to multi-presence tasks, and the scientific implications of using a robotic arm that the user perceives as a body rather than a simple robotic arm for these tasks are expected future research developments.
- In Chapter 6, current work progress on the application to the multi-presence task which mentioned as a future study was introduced. The effect of increasing the number of tasks on attention allocation through user testing of the multi-presence task was discussed, in which the user performs tasks in six locations simultaneously. Finally, Chapter 7 concludes and summarizes this thesis.

# List of research achievements for application of Doctor of Engineering, Waseda University

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| 種類別 (By Type) | 題名、 発表・発行掲載誌名、 発表・発行年月、 連名者（申請者含む） (theme, journal name, date & year of publication, name of authors inc. yourself) |
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