博士(人間情報学)論文概要

A Study on Upper-body based Shared Navigation Control for Assistive Mobility Devices
(支援モビリティのための上体によるナビゲーション共有制御に関する研究)

グローバル教育院　エンパワーメント情報学プログラム

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Proposed Contents

Introduction

Nowadays, there are a lot of spinal cord injury (SCI) patients around the world, usually they use assistive device as a support for improving their quality of locomotion life (QOLO), such as exoskeleton, smart walkers, etc. Among all the choices, electric powered wheelchair has been the most common mobility aid due to the feature of easy-to-use, robust control and acceptable cost. However, there are two main aspects which significantly limit powered wheelchair users' freedom and increase the load during navigation, one is that hands control limits users' hand freedom, another one is that refined backward navigation is complicated, and causes high cognitive and physical load. Hands control is necessary for the joystick interface which is the current standard solution, however, it constraints at least one of user's hand on the interface, limiting user's freedom of conducting other activities. The refined backward navigation is usually difficult for the user since people are naturally used to looking forward.

The purpose of this research is to develop and evaluate an upper body-based shared navigation control system for assistive mobility devices.

The goal of this study was addressed by exploring three main research questions (RQ) as follows:

RQ 1. How to enhance users' freedom and reduce the load during navigation control of assistive mobility device?

RQ 2. What hands-free solution is effective for assistive mobility devices?

RQ 3. How can the user achieve a refined backward navigation by using autonomous docking technology?

The dissertation includes six chapters. Chapter 1 addresses the outline of this research. Chapter 2 introduces the literature review. Chapter 3, 4 are related to exploring RQ 2. Chapter 5 investigates RQ 3. The research questions were explored quantitatively and qualitatively by developing and evaluating new control system. Finally, the conclusion of this research and future directions are addressed in Chapter 6.

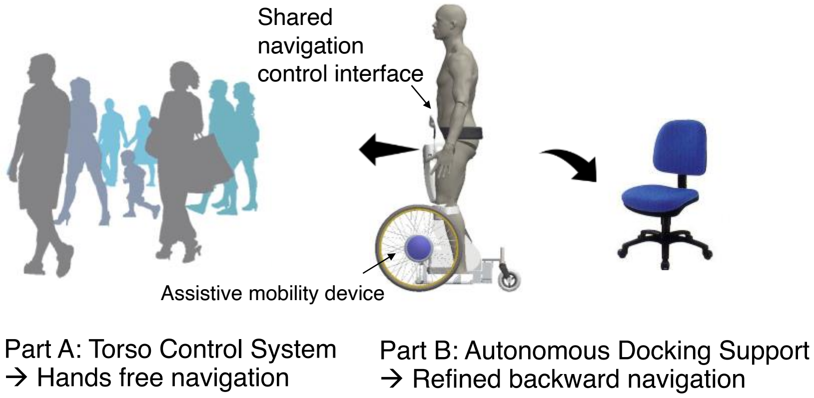

Fig. 1 The concept of upper-body based shared navigation control

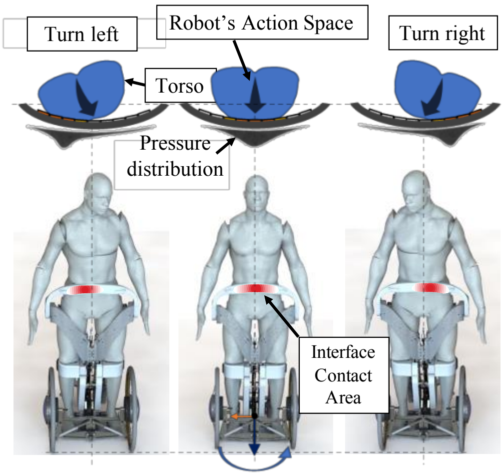

Fig. 2 The concept of torso control interface

Methodology

I propose an upper-body based shared navigation control method for assistive mobility devices to enhance human's freedom and reduce load, which contains a torso control system for free forward navigation and an autonomous docking support system for refined backward navigation, both share the navigation tasks required by the user (Fig. 1).

1. Upper body-based control interface

Basic interface and algorithm design

Most standing mobility devices rely on hand operation for controlling the devices, however, with one hand limited for controlling the device, it is inconvenient when the users need to carry something in hand or shaking hands with other people. Therefore, hands-free control is required in daily life for those standing mobility devices. Some hands-free solutions for personal mobility devices have been proposed, such as EOG, shoulder motion, but they are not yet to replace joystick due to different drawbacks.

I proposed a torso control interface as shown in Fig. 2, a support bar with a pressure sensor array attached (Fig. 3) is used to detect human's postures, through which the user could control the locomotion by natural upper-body movement. The raw data we obtained are readings from force sensitive resistors (FSR), we calculate the center of pressure (COP) to continuously represent the posture of the user, we normalize the COP to a range of -1 to 1, depends on the location of the COP, we use 4 points to distinguish five basic postures as shown in Fig. 3. COP is mapped to the relative ratio of linear velocity and angular velocity; the magnitude of the velocity is proportional to the maximum reading of FSR. As people come in different shapes and sizes, moreover, people have different proprioceptive control of their bodies, The classification points β_1, β_2, β_3, β_4 in Fig. 3 can be calibrated to adapt to different users, thus, allowing body-specific control. The algorithm could be called by the user through an independent trigger

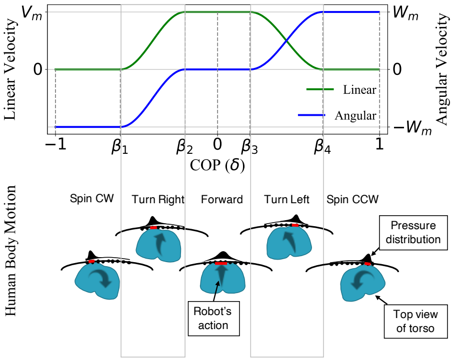

Fig. 3 Expected posture-action

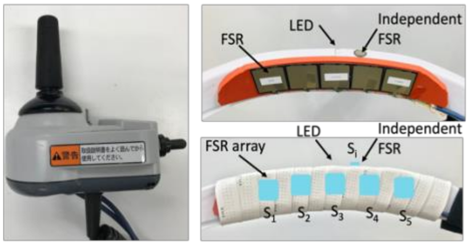

Fig. 4 Commercial joystick and proposed control interface

(an onboard sensor attached on the exterior side of torso bar).

Trunk muscles usage during driving control of the standing mobility vehicle through the proposed torso interface was analyzed with 6 healthy participants. These results, consistent among all subjects suggest that lumbar level erector spinae (ES) and rectus abdominis (RA) (high level) are the most relevant muscle groups involved in controlling the robot with the proposed torso control interface.

The proposed interface was compared with the standard commercial joystick interface in Fig. 4 as a baseline measurement. The experiment consists of controlling the device to move in a circuit routine around two markers in an 8-like shape and then back to the start point. The torso interface takes a longer time than the joystick for completing the task. However, an improvement in the consumed time observed for most participants suggests to us that there is a learning effect in the torso control. From the feedback of the users, there was a significant difference in the users' perception with a higher score in terms of System Usability Score (SUS), however, participants also showed high acceptance in terms of how anthropomorphic the interface could be, as well as animated and even safe for standing locomotion.

Fig. 5 Motion sequence of a participant driving the device

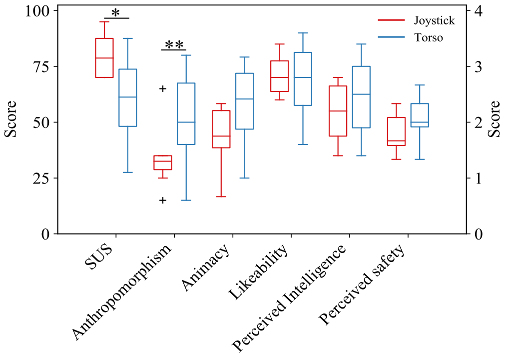

Fig. 6 Participants' perception scores of torso/joystick control

Improved coupling between torso and interface

"It will be published within three years."

2. Autonomous docking support

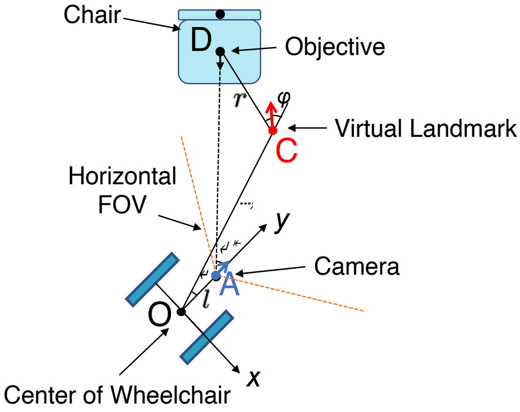

Fig. 7 Strategy of autonomous docking system

With the torso control system, the user is able to navigate around intuitively, which greatly enhances the freedom of the user. However, powered wheelchairs operation also requires docking as one of the daily activities, for example, driving back to face a chair or laterally to a bed so that, the user can transfer between the wheelchair and other surfaces. However, this operation is usually difficult for individuals with lower-limb disabilities because twisting their upper body to look backward while in the device is rather limited or some users might have limited muscle control. Thus, we think automating this process to assist end-users who may struggle with this task would be feasible.

In this part of work, I aim to develop an autonomous docking support system for assistive mobility devices.

Problem Definition: For wheelchair docking control, a camera rigidly fixed on the wheelchair body is the most common and viable choice as source of visual feedback for generating the target pose. The problem of maintaining an actual object within the horizontal field of view (HFOV) of a camera and navigate to a virtual landmark inferred from the same object, as depicted in Fig. 7, is proposed here as a novel description.

Virtual Landmark Estimation: My method doesn't rely on any pre-installed landmark on the chair. First, we used an RGB-D camera to recognize the chair through point cloud processing. Then we obtain the pose of the chair depends on

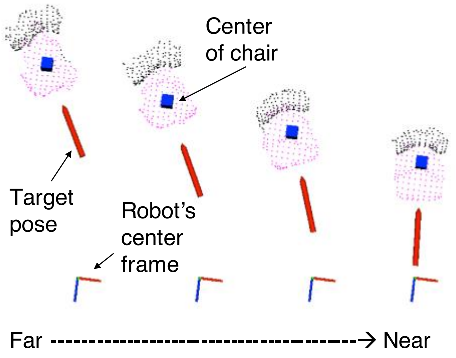

Fig. 8 The estimation of target pose by camera from different locations

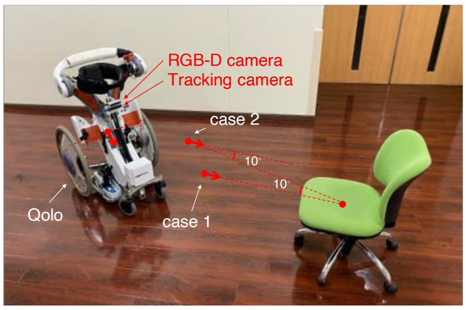

Fig. 9 Snapshot of preliminary autonomous docking experiment

the prior geometry knowledge of the chair. Finally, the virtual landmark is generated as a relative pose to the pose of the chair.

Nonlinear Feedback Controller: I designed a nonlinear feedback controller which takes the constraint of the depth camera's FOV and the non-holonomic property of the robot into consideration. I use Lyapunov indirect method to optimize the gains of the controller. Then a numerical method is proposed to find the feasible space of initial states where convergence could be guaranteed as shown in Fig. 10.

The virtual landmark estimation algorithm was validated by locating the robot at different relative poses to the chair (snapshots are shown in Fig. 10, 11). Qualitatively, the chair is clearly recognized from the environment, bottom and back are separated well. The convergence of robot states (ρ, α, φ) were validated through the trajectories of the robot (Fig. 11) and final states of the robot (Fig. 12). The robot could converge to the virtual landmark while respecting the FOV constraints.

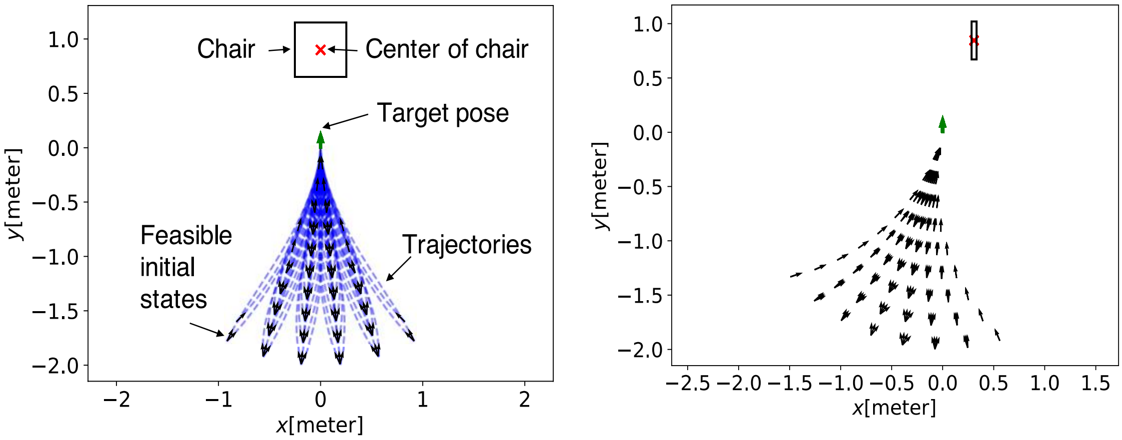

Fig. 10 Simulated autonomous docking from different initial states

Sharing control strategy: In order to provide a bridge between human control and autonomous control, I integrated a switching strategy into the embodied interface (depicted in Fig. 4). With an array of 5 FSR as example, to avoid the conflict with torso control command, I command FSR S2 and S4 pressed together as autonomous docking actuation, whenever S2 and S4 are pressed together, the autonomous docking will be actuated, otherwise, the autonomous docking will be shut down and the user could switch to hands-free control.

3. Conclusion and future directions

This study introduces an upper-body based shared navigation control methodology for enhancing users’ freedom and reducing the load. It mainly consists of two parts, sharing the navigation task required by the user. The first part is a torso control interface, through which the user is able to control the locomotion of the device intuitively with hands-free. The second part is an

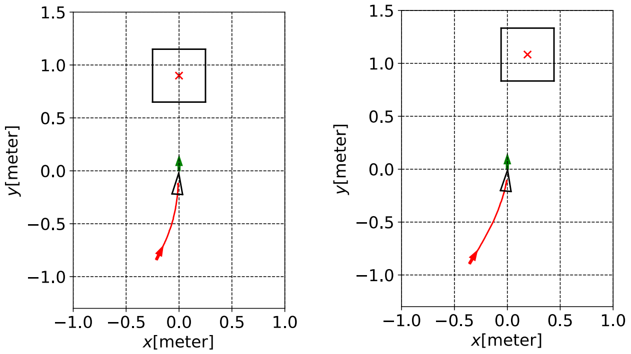

Fig. 11 Robot's example trajectories in the experiment

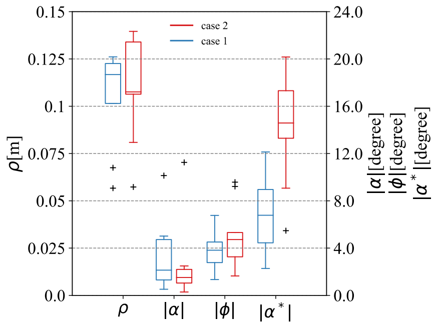

Fig. 12 The final states of the robot

autonomous docking support which helps the user achieve a refined backward navigation. Experiments have been conducted for both systems, which showed promising results. In the future, the obstacle avoidance and autonomous navigation technology can be combined with the proposed technology, then the upper-body based shared navigation control could enable assistive mobility devices users free access anywhere easily. As a result, the assistive mobility devices users would have the same freedom as healthy people.

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