ARTICLE IN PRESS

Mechanical Systems and Signal Processing xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Fault classification with discriminant analysis during sit-to-stand movement assisted by a nursing care robot

Tianyi Wang [a,*], Hieyong Jeong [b,*], Mikio Watanabe [c], Yoshinori Iwatani [c], Yuko Ohno [a]

[a] Department of Mathematical Health Science, Graduate School of Medicine, Osaka University, 1-7 Yamada-oka, Suita, Osaka 565-0871, Japan
[b] Department of R&D for Innovative Healthcare, Graduate School of Medicine, Osaka University, 1-7 Yamada-oka, Suita, Osaka 565-0871, Japan
[c] Department of Biomedical Informatics, Graduate School of Medicine, Osaka University, 1-7 Yamada-oka, Suita, Osaka 565-0871, Japan

ARTICLE INFO

Article history:
Received 30 June 2016
Received in revised form 15 December 2016
Accepted 30 January 2017
Available online xxxx

Keywords:
Center of mass
Fault detection
Nursing care robot
Sit-to-stand movement
Vertical ground reaction force

ABSTRACT

Many nursing care robots have been developed to assist patients with sit-to-stand (STS) movement. However, little research has focused on user's negative psychological changes during STS movement when assisted by a robot. STS movement accompanied with a negative psychological change is defined as a fault. The main purpose of this study was to propose a method of conveying faults to a nursing care robot through the vertical ground reaction force (vGRF). Experiments on STS movement were executed five times with ten healthy subjects under four conditions: two self-performed STSs with seat heights of 43 and 62 cm, and two robot-assisted STSs with a seat height of 43 cm and end-effector speeds of 2 and 5 s. Subjects answered a questionnaire on how they felt under the four experimental conditions. Time series data on the vGRF were measured with a Wii Balance Board (WBB). A classifier was designed according to the data on the STS smoothness in the frequency domain. The results showed that the proposed classifier had a high probability of discriminating fault classes from others. Furthermore, faults were found to result in larger standard deviations of the peak values of smoothness. The center of mass trajectories of the human body under the same experimental conditions were used to crosscheck the experimental results. Then, the angles and angular velocities of the trunk and ankle were utilized to discuss the synchrony of the body segments. Other works on more advanced signal analysis and superior fault classification approaches were also discussed. It was concluded that faults in the assistance of nursing care robots can be detected from the STS smoothness by measuring the vGRF.

1. Introduction

The sit-to-stand (STS) movement is essential to daily life and is used to change from a sitting position to a standing position. Dall and Kerr [1] pointed out that healthy adults performed 60 ± 22 STS movements every day on average. Grant et al. [2] reported that healthy older adults living in the community performed significantly more STS movements per day (71 ± 25) than older adults attending a day hospital (57 ± 23) or frail older patients in a rehabilitation ward (36 ± 16). For the elderly, their ability to perform this basic task weakens from the deterioration of muscle strength, joint range of motion, and balance. This can increase the risk of institutionalization, impaired functioning and mobility for activities of

* Corresponding authors.
E-mail addresses: wangtianyi@sahs.med.osaka-u.ac.jp (T. Wang), h.jeong@sahs.med.osaka-u.ac.jp (H. Jeong).

http://dx.doi.org/10.1016/j.ymssp.2017.01.051
0888-3270/

Please cite this article in press as: T. Wang et al., Fault classification with discriminant analysis during sit-to-stand movement assisted by a nursing care robot, Mech. Syst. Signal Process. (2017), http://dx.doi.org/10.1016/j.ymssp.2017.01.051

daily living (ADL), or even death [3–5]. With the continuous decrease in the number of nursing care specialists, there is an urgent need for the development of STS-assisting robots.

Only a few studies have focused on STS-assisting robots. Chuy et al. [6] presented two approaches to assisting with STS movement by using a robotic walking support system and showed that this system can track the desired support force. Rather than using kinematic data, Burnfield et al. [7] compared muscle demands through electromyography during self-performed and device-assisted STS transfers. Geravand et al. [8] formulated unassisted and assisted STS transfers as a control problem and found a balance among the end-point accuracy, human balance, energy consumption, and smoothness of motion.

However, studies on assisting robots have neglected the psychological impact on subjects so far. Good understanding of psychological issues may help facilitate better integration of medical devices with users. Thomson et al. [9] emphasized that medical devices have both positive and negative psychological impacts on users and that simply addressing safety requirements does not guarantee user satisfaction. Because the duty of an assisting robot is to provide satisfaction with its assistance, cases where robot assistance fails to meet this need can reasonably be defined as a fault.

A robot does not have the ability to tell whether or not its service satisfies its user. In other words, the robot is not aware of its fault. Inferring human psychology is an essential step towards understanding human actions and hence is critical for realizing human–robot interaction. Recent advances in sensors and algorithms have allowed researchers to improve the perception ability of robots. However, only perception may not be sufficient for efficient interaction between a human and robot because the robot's reaction should depend on its understanding of human actions. This observation raises the question of how to correlate human psychological changes to legible data. Answering this question can provide methods for giving feedback to a nursing care robot so that it can offer better healthcare service and assistance.

In contrast to a laboratory environment, the situations in hospitals, rehabilitation centers, and nursing homes always have conditions that do not allow the use of large-size experimental equipment, such as a motion capture system or traditional force plate board. Thus, our aim in this study was to convey a fault to a robot though a practical, economical, and reliable method of providing rapid feedback. Psychological results were collected by asking subjects to answer a questionnaire. The results showed that the proposed method discriminates faults with a high probability and is suitable for clinical research.

The paper is organized into five sections. Section 2 explains the subjects, experimental system, and proposed method for analyzing the STS performance under different experimental conditions. Section 3 describes the experimental results. Section 4 crosschecks the experimental results with kinematic analysis data from a high-speed camera system and introduces other advanced signal analysis and classification approaches. Finally, Section 5 concludes the paper.

2. Subjects and methods

2.1. Subjects

Most nursing care robots were originally designed for the elderly or patients with particular diseases. The elderly and patients were allowed to freely participate in our experiment because no clinical evidence had demonstrated the effectiveness and availability of nursing care robots.

Ten human subjects (age: 38.6 ± 12.2 years old, height: 1.72 ± 0.06 m, body mass index: 22.37 ± 2.60 kg/m^2) volunteered for the experiment. No subject reported a major back pain or lower limb pathology, use of medication, or history of neurological disease that may influence the standing balance. There was no large difference in BMI for all subjects ($P > 0.05$).

The experimental procedures of the present study were in accordance with the Declaration of Helsinki and approved by the Ethics Committee on the Division of Health Sciences, Graduate School of Medicine, Osaka University (No. 305, August 21, 2014). Informed consent was obtained from all subjects.

2.2. STS assistance system

The STS assistance system consisted of three pieces of equipment: a height-adjustable chair for initializing STS movement, a nursing care robot for assisting with STS movement, and a Wii Balance Board (WBB) for measuring STS movement.

A chair (CS-320A) was used to adjust the seat height during STS movement. The model could adjust the height to six levels (32–62 cm). The chair had the dimensions of a 35 cm width, 48 cm depth, and 78 cm height.

Fig. 1(a) shows an overview of the nursing care robot developed to assist with STS movement. The prototype of the self-reliance support robot could help users stand up, walk, and sit down. The speed of the end-effector was regulated from 1.5 s to 5.0 s. Fig. 1(b) showed each step of the STS movement with assistance from the nursing care robot. The steps followed the definitions provided by Schenkman et al. [10] and are marked by four events. The path of the end-effector could be controlled so that the robot could match the user's trunk movement with self-performed STS. The individual differences in body height could be also accounted for through the control of the robot.