Integrating Posture Control in Assistive Robotic Devices to Support Standing Balance

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Abstract—**To date, exoskeletons typically only allow paraplegic users to stand or walk quadruped-like with crutches to maintain balance. The problem with today's robotic assistive devices that are supporting or restituting stance and walking in paraplegic users is inadequate posture control, which endangers balance and increases the likelihood of a fall occurring. We address this issue in this Methods article by describing the posture-movement interrelations in humans, suggesting the inclusion of posture control in assistive robotic devices, and recommending their experimental testing prior to application for biped use.**

I. Introduction

When humans perform voluntary movements such as reaching for an object, they consciously control hand, arm and body movements while subconsciously performing postural compensations. The postural compensations in this example are primarily the gravitational torques arising in the ankle, hip, and shoulder joints. The reaching motion is under conscious control of cortical brain centers, whereas the compensation of the self-produced disturbances tends to be performed subconsciously by posture control centers in the *e*xtra*p*yramidal *s*ystem (EPS), which is located mainly in the brainstem, basal ganglia and cerebellum. When a physically handicapped patient uses a robotic device to augment or perform body movements, the device should provide its own postural adjustments. In the case where the patient's deficits include very severe sensory and/or motor defects (e.g., missing sensory information from the feet), the device might even provide the balancing of both the exoskeleton and patient. Danger of falling may arise if the patient erroneously interprets the robot's postural actions as *external* disturbances (having an impact on both body and device) and thereby, tries to enforce a compensation that is inadequate (a 'user-device conflict', possibly with disastrous positive feedback). These considerations apply to patients who use an exoskeleton for *biped* balancing, which we consider a desired goal for the future.

Understanding posture control mechanisms in humans and the humanoid robot is a prerequisite for research of this topic. In retrospect, many falls in DARPA challenges may be due to insufficient or inappropriate consideration of posture control in biped stance or walking [1]. Therefore, posture control has been included in recent proposals for robot benchmarking, which suggested using human balancing as a gold standard for humanoids [2]. A recent article from our laboratory [3] targeted the issue of balancing stance. Therein, we noted that the large diversity of software and hardware solutions in robots may be successfully handled given that the applied balancing tests address (a) the four basic, physical disturbances (*support surface rotation* and *translation*, *contact* and *field forces*) and their compensation, and (b) the most critical joints used for standing balance (ankle and hip joints in the body's sagittal plane; see [3] [4]). We conceive that implementation of robotic assistance for *biped* stance and walking will become possible in the future. However, we maintain that this still requires considerable research on how to provide postural stability in the human-robot interaction and cooperation.

In the following article, we outline the postural control tests that address the four basic external or self-produced posture disturbances common in both humans and humanoid robots. We posit that these tests can be similarly applied to humans using robotic devices for biped stance and walking. Balancing of biped walking and the disturbance compensation in ankle and hip joints, such as balancing stance by making steps or holding with the arms, or by adjusting foot placements during walking, are not discussed in this article.

II. Results

A. Tests of the four basic *physical disturbances*

The four basic physical disturbances affecting standing balance which are well captured by established balancing tests often used for the evaluation of human balance control include: *Support surface rotation* (1) and *translation* (2), as well as *contact forces* applied as a pull or push perturbation (3) and *field force*s, such as gravity (4). The stimuli tend to evoke body lean in space and thereby produce or enhance gravitational torque in the ankle joints. While the experimental implementation of 1-3 is intuitive (Fig. 1A-C), testing of 4 is often realized as a selective testing of the vestibular sensor using the 'body-sway referenced platform' (BSRP) paradigm. In this test (Fig. 1D), support surface motion is locked to body sway that arises internally (e.g., by internal noise). In the absence of visual orientation cues, this selectively evokes the vestibular signal of body-in-space sway, which then dominates the balancing. The sensory disturbance estimation and compensation of the four basic physical disturbances represents the core principle of the DEC model of human postural control [4], which has been

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implemented as modular control architecture and successfully tested in humanoid robots (see [3], [5] - [7]). In the human solution, the control of voluntary movements and the disturbance compensation are combined in a conflict-free way for each degree of freedom (DoF) of the musculoskeletal system.

In upright stance, the human balancing control is mainly concerned with sway in the body's sagittal plane around the ankle joints and with trunk sway around the hip joints, as well as the hip-ankle coordination. Plantar force cues play no major role for the balancing. Rather, the balancing draws mainly on joint proprioceptive, vestibular and visual cues, which allow humans to balance even on rough terrains where plantar force distribution may be irregular (cf. [8]).

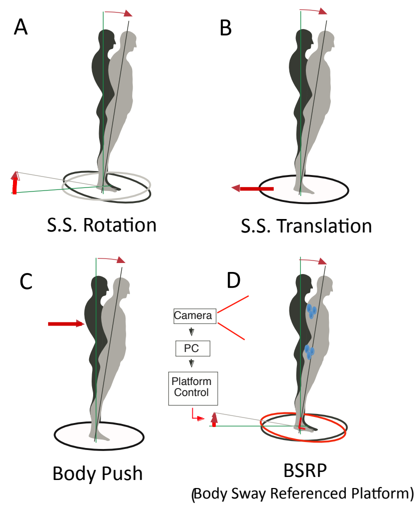

Fig. 1. The four basic tests of biped postural control (SS, support surface)

B. Achieving conflict-free interaction and co-operation between robotic and human postural controls

The above described DEC principles identified in human control, as well as their successful implementation in humanoid robots, suggest that these principles can also be used in a robotic assistive device for maintaining standing balance by paraplegic and paraparetic patients. Among patients, one faces a variety of sensorimotor deficits, where pyramidal and extrapyramidal systems may be impaired to various degrees (while reduced muscle force alone is an exception). Referencing human similarity may help to model the sensorimotor conditions specific for a patient and to take these into account when designing or adjusting the control of the assistive system. The DEC concept allows for the modelling of specific conditions in terms of sensory inputs and control strategies, and sensory availability. However, DEC control in robotic devices requires the use of impedance-controlled actuation. Using human-like low loop gain, maintained at a level sufficient to resist gravity, provides human-like compliance, which is advantageous for human-robot interaction, collision, and energy consumption. Current versions of DEC are implemented in Simulink/Matlab, which eases the migration across PCs for simulations and for controlling robotic platforms in 'real world' tests.

It remains to be shown experimentally to what extent the matching of control concepts in the patient and the assistive device helps to avoid user-device conflicts such as the one mentioned above (where the patient experiences postural adjustments of the assistive device as external disturbances). We conceive that patients may learn to deal with such conflicts. The learning likely requires several evaluation and training sessions, in which the balancing tests are repeatedly performed and appropriate skills are developed with the help of cognition and vision.

III. Conclusions

A paraplegic or paraparetic patient controlling balance in biped stance using an assistive device may face user-device conflicts in posture control, which requires testing for each individual case and eventually training the patient to cope with the conflict. This issue requires further research into such user-device interactions and training for co-operation. To this end, we suggest applying specific tests, which are already in use in postural control research of both human and humanoid robots. We maintain that designing the control of the assistive device should not only take into account actuation and biomechanics abilities of the user, but also the user's notion to use sensory-based compensation of external disturbances. Neurorobotics can provide models (see [6] and [9]) that can be used to integrate the corresponding sensory-based mechanisms into the device.

IV. References

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