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NEUROROBOTICS: A REVIEW FROM VISION TO ACTION

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ABSTRACT

Humanoid robotics finds its natural inspiration in the study of humans themselves and its objectives in developing robots with human-like skills. Neurorobotics in particular exploits findings of neuroscience with the aim to implement bioinspired sensory input processing, movement control, decision making, and more. Moreover neurorobotics provides a way to test theories of human sensorimotor control and its dysfunctions in patients by embodying them in real world devices. The two aspects of designing robot control systems and understanding the control of humans integrate and improve each other. This will be shown here in the context of posture control by presenting the human inspired Disturbance Estimation and Compensation (DEC) concept in humanoids.

INTRODUCTION

Overview

posture control is a fundamental task of humanoid robots, since it is a prerequisite for other tasks such standing, walking or performing a manipulation. This owes to the intrinsically unstable nature of humanoid body stance. In fact, posture control is an issue also for humans, where postural adjustments provide the movement buttress that the action-reaction law of physics prescribes and maintain body equilibrium by balancing the body's center of mass (body COM) over the base of support. Impairment of posture control in humans causes severely disabling syndromes such as ataxia, with jerky and dysmetric movements and postural instability [1]. In controlling bipedal balance, humans are still better than humanoids with respect to robustness and versatility [2]. Human-likeness of bipedal control both in walking and balancing is an open research topic in humanoid robotics [3].

The embodiment of human-inspired neural control in robots can be performed at several levels of abstractions: From the reproduction of low level mechanisms such as simulated spiking neural networks for the control of voluntary movements [4] or central pattern generators for gait [5] to the reconstruction of higher level phenomena such as movement synergies [6]. The DEC concept [7] provides an intermediate to high-level description of sensor fusion and posture control. High-level signals are internally used in the control loop. However, the concept leaves open where in the brain or in the spinal cord the processing occurs. Also, the concept takes in account low-level features such as neural time delays, but does not specify behaviors (like synergies), which in the DEC are emerging from interactions between control elements and body biomechanics. The DEC concept has been embodied into humanoid robots in order to test posture control in the same experimental context as tested in humans (i.e. tracking body position while standing on a moving platform or being pulled by an external force acting on the body). Furthermore the concept has been generalized to full body control of several humanoids [8,9,10,11].

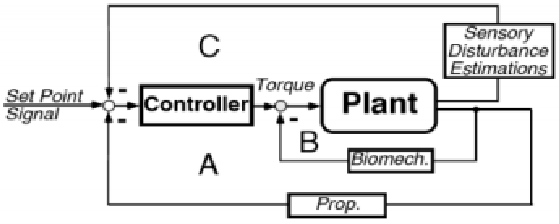

Fig. 1. Simplified scheme of DEC model.

DEC CONCEPT

In the DEC concept, human posture control builds upon a proprioceptive servo feedback loop that controls voluntary movements (A in Fig. 1). The control also comprises an intrinsic musculoskeletal stiffness and damping loop (B) and DEC loops (C, four in a complete scheme). Estimates of the external disturbances, achieved through sensor fusions, command via negative feedback the servo to produce the extra joint torque that is needed to compensate for the disturbances.

Assuming ideal compensation, the movement control can function as if there were no disturbances. This concept can be extended to multi-DOF, as shown in [9] for two degrees of freedom and in [10] for the general case. The effects of the external world on the body are described in DEC by four external disturbances [7]: support surface rotation ('platform tilt') and translation ('platform acceleration') and field forces (such as gravity) and contact forces ('external torque'). For the estimates of the disturbances, humans fuse signals of physical variables, which they derive in turn from multisensory integration of vestibular signals, vision, touch, force, and joint proprioception [12]. Inspiration for this form of multisensory integration was derived from studies on human self-motion perception [13].

II. HUMANOID ROBOT CONTROL

Robots and tasks

The three humanoids developed at the University Clinics of Freiburg are shown in Fig. 2. The first humanoid Posturob I has been used to reproduce human upright stance in the presence of moderate perturbations, i.e. balancing using the ankle joints (single inverted pendulum, SIP, scenario). It is able to compensate the four external disturbances while performing voluntary movements, and it is able to control balance on compliant support surfaces (or on a surface rotating together with the body). Posturob II extends the capabilities of Posturob I, adding the control of the hip joint. This allowed the DEC control to reproduce human behavior in terms of leg and trunk sway in the presence of support surface tilt, to control the robot during superposition of disturbances and voluntary movements, and to show the emergence of inter-link coordination [9, 14]. This robot can also be used to test body coordination patterns during leg swing Both Posturob I and II are actuated with pneumatic muscles, optionally with springs in series (that can also be changed or removed), demonstrating that the DEC system provides a robust control in the presence of series elastic stiffness. The Lucy robot (Posturob III, 14 DOF) was used to show how the DEC can be applied to both frontal and sagittal planes when maintaining balance in the three-dimensional space, while perform voluntary

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movements in both the planes [11]. The DEC concept has been applied also to the TORO robot platform from DLR.

This robot has a very fast joint torque control system that allowed simulating a parallel passive stiffness, demonstrating that the DEC can integrate and exploit it in the presence of time delays [8]. The DEC concept is expected to be robust to time delays because they are present in humans. On the other hand, tolerance to delays may lower the performance requirements of the control hardware.

Open issues and future work

The ongoing research is focused on the exploitation and modulation of passive stiffness, the compensation of coupling forces, prediction of self-produced disturbances [15], the integration of learning processes, and the creation of a model for human transient response to external stimuli [16]. Posture control is expected by us to be a key for human inspired algorithms for the control of humanoid gait. Neurorobotics findings on posture control will find an application in assistive devices for patient rehabilitation and support.

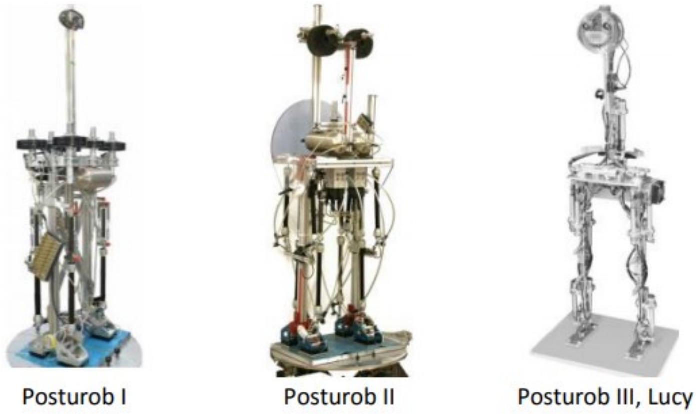

Fig. 2. Humanoid robots used for neurorobotics experiments.

CONCLUSION

Human-inspired sensorimotor control provides a robust solution for humanoid posture control. This will help to improve the versatility of humanoid robots and, because these robots may serve as blueprints for exoskeletons, may enhance acceptance of assistive devices.

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