# Human Movement Execution Control Combined with Posture Control—A Neurorobotics Approach

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**Abstract** The human-derived sensorimotor control concept DEC (for Disturbance Estimation and Compensation) is here considered with three issues: (1) DEC can be used in a modular control architecture for multi-DoF applications. (2) DEC can easily be implemented on humanoid robotics platforms that have human-inspired sensors and force-controlled actuations. (3) Comparing different bio-inspired control concepts with each other on the same robot helps to define criteria for human-likeness of control algorithms—with potential benefits for user acceptance in assistive robotics.

## 1 Introduction

Human control of skeletal movement execution involves managing of several posture control tasks such as buttressing, balancing, inter-segmental coordination, and coping with coupling forces. An early neurological concept of sensorimotor control combined posture (pose) and movement in one neural mechanism, consisting of a servo with muscle spindle feedback [1]. Later work rejected this control concept, because of insufficient compensation of external disturbances such as gravity [2]—a problem that is enhanced by the neural time delays in the sensory feedback. Recently, however, the DEC concept [3] revived the servo concept in modified form, combining it with disturbance compensation loops (Fig. 1). In this form, the servo includes in its output, i.e. in the force production for actuation, the compensation of unforeseen and predicted disturbances. Model simulations and robot experiments so far compared favorably to corresponding human experimental data [4, 5].

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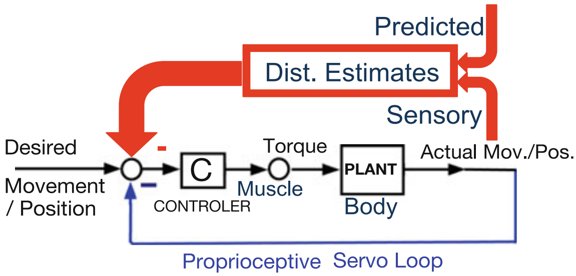


**Fig. 1** Simplified scheme of the DEC concept

This contribution reports research on: (1) How can DEC be used with multi-DoF systems? (2) What are the premises for implementing DEC on robotics or assistive platforms? (3) How can robot experiments help to decide between competing bio-inspired control concepts?

## 2 Results

### *2.1 DEC for Multi-DoF Systems*

System identification of human control of biped balancing provided insights into basics of human sensorimotor control, when using for modeling and corresponding neurorobotics experiments the single inverted pendulum biomechanics (SIP) scenarios with one DEC control module [4, 6] and superposition of two modules for the double inverted pendulum (DIP) scenario [5]. The robot experiments were performed in corresponding SIP and DIP robots (Posturob I and II).

A generalization of the DEC control principles for use in a multi-link system was proposed [7], where each joint (DoF) is controlled by one DEC module, sensory information is exchanged between neighboring modules, and for posture control all links supported by a joint are treated as if they were one SIP. Here, performance of the extended DEC control concept in a 14 DoF robot is shown: Posturob III (called Lucy) performs voluntary knee squatting with superimposed lateral body movements and external disturbances: https://www.uniklinik-freiburg.de/neurologie/forschung/neurologische-arbeitsgruppen/postural-control/video.html.

### *2.2 Premises for Using DEC in Robotic or Assistive Devices*

The backbone of DEC is the human-inspired sensory reconstruction of the four external disturbances: Support surface rotation and translational acceleration and contact and field forces. The reconstructions are based on fusions of vestibular, joint torque, joint angle and angular velocity, and plantar normal force signals (these sensor signals in humans are thought to be derived in turn from fusion of various sensory receptor signals). Vision improves the estimates, but is not considered instrumental.

Another prerequisite for the use of the DEC control in robotic devices is the force or impedance controlled actuation. In Posturob I and II, the actuation is realized in the form of pneumatic muscles and in Lucy Posturob by electro-motors. Human-like mechanical compliance of joints results from low loop gain, maintained at a level to just resist gravity. The compliance is advantageous for human-robot interaction, collisions, and energy consumption.

Current versions of DEC are implemented in Simulink/Matlab. This eases migration across PCs and robotic platforms, as it was performed on the Toro robot from DLR: https://www.uniklinik-freiburg.de/neurologie/video.html.

## *2.3 Comparison of DEC with Other Solutions*

For a given sensorimotor control function, often more than one solution is suggested in literature, and robotics research may offer further alternatives. It therefore appears desirable to establish a framework for comparison across solutions and, given that 'human-like' is an aim, to seek for selection criteria such as control stability, fail-safe robustness, versatility, and conflict-free superposition of sensorimotor functions. An example for the simultaneous control of balance in the frontal and sagittal plane is shown in Fig. 2 [8].

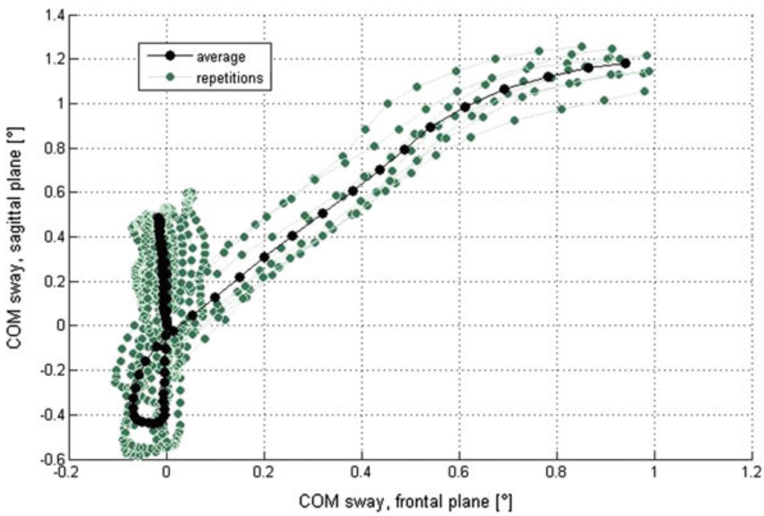


**Fig. 2** Transient responses to angular displacement of the COM back towards the vertical position (0°, 0°) in both planes. In *green* the trajectories produced during several trials, in *black* the average trajectory (time: 50 ms between *dots*). The control system used is described in [8]

This idea lead us to use Posturob II for proof-of-principle tests of a human-inspired control of inter-segmental coupling forces, called the Eigen-movement control, from another group [9]. The experiments yielded efficient performance: https://www.uniklinik-freiburg.de/neurologie/forschung/neurologische-arbeitsgruppen/postural-control/video2.html, albeit with a narrow range of control stability [10]. Current work compares these findings with a solution for the coupling forces provided by the DEC concept (in terms of disturbance compensation by feedback and passive stiffness modulation, and by using jerk-optimal movement trajectories).

The idea led us furthermore to compare in the Toro robot the control stability of DEC with a model based robotics concept of body balancing during external disturbances [11]. A conclusion was that each of the two concepts has the potential to inspire improvements of the other concept [12].

## 3 Conclusions

The DEC concept allows implementing in robots and assistive devices a human-inspired method that combines movement execution and posture control. The method is suited for multi-DoF devices, given a basic set of sensory inputs and force-controlled actuations are provided. In turn, robots may be used for neuroscientific purposes, e.g. when it comes to decide for one or the other bio-inspired or robot-inspired solution, applying criteria such as fail-safe robustness, versatility, or conflict-free interactions between functions.

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