Benchmarking human-likeness of robot postural control – Suggestions from human experiments

Vittorio Lippi, Diego Torricelli, Georg Hettich, and Thomas Mergner

Human-likeness of sensorimotor control in humanoid artifacts interests both roboticists and neurologists. Roboticists may want to improve human-robot interactions or exploit biological solutions for unsolved problems such as robot mechanical compliance and energy consumption. Neurologists hope for more human-likeness of medical assistive devices such as neural prostheses and exoskeletons to improve acceptance by the patients. Before considering how much human-likeness may finally be needed for a given aim, however, one has to clarify which sensorimotor *function* is considered, and which of its *features* are so typical that they can be used as criterion for human-likeness.

Human motor behavior such as standing, walking or reaching comprises two basic interrelated sensorimotor functions. One function deals with movement planning and execution, the other with postural adjustments (PAs). PAs cope with consequences of the action-reaction law of physics (buttressing of movements such the push off for a sprint start, coupling torques) and with self-produced and external disturbances having impact on the body and its equilibrium. The importance of PAs is evident in neurological patients, where PAs may *selectively* be impaired by damage of sensory systems or the cerebellum. The impairment often results in a disabling syndrome called ataxia with jerky and dysmetric movements and postural instability. Recent research of human PAs often focused on biped balancing of external disturbances, applying engineering model-based approaches.

One of these approaches [1] developed elaborate methods for characterizing the balancing responses and demonstrated that it is possible to describe basic control principles by a simple model with proprioceptive and vestibular feedback. From this work one can deduce some *basic features* that highlight paradigmatic differences between the human control and classical engineering approaches. A basic difference is that the human control contains long neural time delays that potentially endanger control stability. This entails a chain of further basic features. One is a low loop gain of the control, which helps humans to prevent resonance behavior. The gain is kept only slightly above the minimal value that is required for balancing. The low gain, in turn, entails a low mechanical resistance to external perturbation and low energy consumption.

The simple model does not cover, however, other important features of the human balancing behavior such as automatic adjustments of the control to changes in the balancing scenario. More complex models, on the other hand, are more difficult to identify, because the number of possible solutions tends to increases with complexity. The approach from our laboratory [2-5] extended the simple model by implementing human sensor fusion mechanisms that were derived from models of human self-motion perception and can be thought to work also in balancing control.

The extended posture control model *automatically* adjusts the response behavior to changing scenarios. This applies even if the change is unforeseen and the response therefore sensory driven. Underlying is a 'multisensory integration' of joint proprioceptive, force/torque, vestibular, and visual sensor inputs in the central nervous system. One of the *behavioral features* is the *disturbance specificity* of the balancing responses. Specificity here means that the contributions from the sensors demonstrably differ depending on whether the disturbance stems from a support surface rotation or translation, a contact force or a field force such as gravity. In the extended model, sensor fusion mechanisms reconstruct and estimate each of the four disturbance types. The estimate then commands the controller to produce compensatory joint torque- this only when, and to the extent that the identified disturbance has impact. These adjustments to disturbance type help to keep the loop gain at a low level. A related feature is the adjustment to disturbance magnitude. It stems from a non-linearity in the estimation, by which decreasing disturbance magnitude leads to disproportionate reduction of the response. Furthermore, there exist adjustments to sensor availability, which allows humans for example to close or open their eyes during balancing. This feature

Vittorio Lippi, Georg Hettich, and Thomas Mergner are with the Neurological University Clinic, Freiburg, Germany.

Diego Torricelli is with the Spanish National Research Council, Madrid, Spain.

contributes to the human fail-safe robustness that owes to the multisensory nature of the control.

The extended model was recently found to lend itself to a modular control architecture in a 2-DOF or multi-DOF system [6]. This work alerted us to further human-like behavioral features. One is a robustness of control stability with changes in the number of DOF. This can be seen in humans when, for example, an ankle joint is immobilized by a plaster after an accident, or when it is later reactivated. The other feature is the occurrence of automatic inter-segmental movement coordination. For example, a reactive or voluntary trunk lean is by default automatically associated with a counter-lean of the leg segments, which keeps the whole-body center of mass (body COM) above the base of support, the feet. Model re-embodiment into humanoid robots, which allowed us a *direct comparisons* of these features between robots and in the human posture control laboratory [5,6], alerted us to further features that may potentially be used for the benchmarking, but still require more human research: (a) the volitional control over PAs, (b) differences between the PAs that arise with voluntary movements and those evoked by external disturbances, and (c) the effects that sensory noise has on the human control.

For a quantitative benchmarking of the basic and behavioral features in robots, the human experimental data presented in [1-6] may serve as reference. The basic features can be directly quantified in robots if one has access to their physical parameters and their control system. Both, the basic and behavioral features can be quantified on the basis of balancing responses using methods as described in [1-6]. Also qualitative benchmarking with the above described features as knockout criteria can be performed in direct robot-human or robot-robot comparisons or competitions.

Finally, we additionally suggest a psychological approach that does not use the features as criterion, but may help to use time series of kinematic variables or even video clips for the benchmarking. It proceeds from the impressive human ability to distinguish in dot motion displays 'biological motion' from 'machine motion'. Human subjects are presented with dot motion displays derived from postural responses of humans, robots, and model simulations. The subjects judge whether the observed movements stem from a human or not as a basis for statistical analyses. The approach requires that the time series or video data be transformed into dot motion displays. The transformation may include hypothesis-driven modifications of local and global dot motion variables, noise, and more. Using a human brain function as a "bio-analyzer" and defining the question of what is human-like operationally makes this approach somewhat reminiscent of the "Turing test".

REFERENCES

[1] R.J. Peterka, *J Neurophysiol*, 88: 1097-1118, 2002.

[2] T. Mergner, C. Maurer, & R. J. Peterka, *Progr Brain Res*, 142: 189-201, 2003.

[3] C. Maurer, T. Mergner, & R. J. Peterka, *Exp Brain Res*, 171: 231–250, 2006.

[4] T. Mergner, *Annu Rev Control*, 34: 177-198, 2010.

[5] T. Mergner, G. Schweigart, L. Fennell, *J Physiol Paris*, 103: 178–194, 2009. [6] G. Hettich, L. Assländer, A. Gollhofer, & T. Mergner, *Submitted*.