PhD Proposal

Multisensory Integration for Balance Control in Humanoids

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CONTEXT

An essential requirement for many motor actions, in both humans and humanoid robots, is the ability to maintain balance whether in a static posture (*e.g.*, standing upright) or moving (*e.g.*, biped walking). However, there is a major difference between human and robot walking in terms of how balance is maintained. In humanoid robots, the emphasis has been on controlling the centre-of-pressure (COP) based on proprioception and the sense of contact with the support surface, but with little use of vision and vestibular signals (*i.e.*, inertial measurements that combine accelerometers and gyroscopes). However, a flexible sensory integration mechanism is missing in robot control leaving the system vulnerable to instabilities in conditions where humans are able to maintain balance. Moreover, systems having to operate in the real-world must be able to cope with uncertain situations and react quickly to changes in the environment, while moving over various types of terrains.

This research work proposes a paradigm shift through the development of a balance control system based on multiple sources and data fusion algorithms. The primary motivation is to advance our understanding of several key issues in the control of balance by exploiting multisensory integration, including vestibular, proprioceptive and tactile sensing capabilities. Humanoids robotics research is, consensually, considered as a key area for promoting the adoption of biological principles in the design and development phases. The study of these behaviours and their mechanisms in humans and robots may lead to fruitful insights in both directions. In line with this, the human system will serve as a guide for improving robot control, bearing in mind the specific constraints of biological and robotic systems.

The research activities will be conducted in the context of the Humanoid Project at the University of Aveiro. This is a long-term multidisciplinary research activity that aims to combine mechanical, electrical and computer engineering, being the result of the collaboration between the Department of Mechanical Engineering (DEM) and the Department of Electronics, Telecommunications and Informatics (DETI) of the University of Aveiro. The work culminated, in 2009, with the development of a small-sized whole-body humanoid platform based on standard components and open software. This highly integrated robot is oriented for research in biped locomotion, navigation in real-world environments and multi-modal perception for autonomous behaviours.

OBJECTIVES

Although balance control is an integral component of common motor actions in humans, its complex nature make it difficult to replicate in robots. The overall research purpose is to understand the mechanisms underlying multisensory integration that may allow more complex sensorimotor strategies. In this line of thought, the main objectives of this research proposal can be stated as follows:

1. **To study the determinants of functional balance in humans** and the complex array of associated control processes, considering the task characteristics and the environment in which it takes place. It is assumed that the research leading to a robust balance control system requires the continuous study of the human counterpart. The intention is to extract principles to be used in novel engineering implementations leading to more effective machine function, rather than a simple copy of biological models.
2. **To implement a flexible and multimodal sensory system** that combines information from multiple complementary sources, including the vestibular, proprioceptive and tactile systems (otherwise, the role of the visual system will not be taken into account). The signals from the different modalities will be processed at different speeds and they have their own coordinate frame. The vestibular system uses inertial sensors (accelerometers and gyroscopes) for computation of inertial motion and sense of verticality with respect to gravity. The proprioceptive system accounts for joint position/velocity feedback from the motor actuators and a network of inertial sensors. The uniqueness of the proposed development is that a network of these devices is being integrated along the overall robot's structure, not only at the head (or trunk section) as is more common to expect. The tactile system is based on load cells placed on the robot's feet to provide the sense of contact with the support surface, including the estimation of the COP and the distribution of forces.
3. **To address the problem of multisensory integration** through the development and implementation of computational models aiming to create distinct representations of self-motion (*i.e.*, how the system moves relative to the outside world). In line with this, a sensory integration centre is expected to play two crucial roles in balance control: (*i*) to resolve sensory ambiguities inherent in the different sensory systems, and (*ii*) to combine complementary information from multiple sources that individually do not provide an accurate representation of the physical world. An example of sensory ambiguity occurs in the vestibular system when identifying the actual motion associated with linear accelerations: since the accelerometers transduce both inertial and gravitational accelerations, the discrimination between translational motion and head reorientation relative to gravity may be ambiguous. Additionally, multiple sensors and sensor types provide redundant information that gives rise to the sensory weighting problem: how to get the most reliable estimate of a quantity using multiple uncertain and noisy sensory channels? The main goal is to study existing mathematical and computational tools to make decisions under uncertainty. Due to recent increase in the available computational power, statistical methods become feasible in handling uncertainty (*e.g.*, maximum likelihood estimation, Bayesian decision theory) and they promises to reduce the negative consequences of the above mentioned noise and variability.

4. **To develop the global control architecture** that generates adaptive and robust posture and balance control both for standing and walking tasks. Together, the postural and equilibrium components of the balance control should ensure stability of the robot system during widely different activities as a product of the task undertaken and the environmental context. The research efforts will address the concepts of hybrid control aiming to clarify how knowledge-based, predictive and reactive processes can be combined to improve the system's robustness against disturbances, ambiguities and uncertainty. In this study, the idea is to extend the role of prediction to the important perceptual processes by pursuing the following open questions: (*i*) how the prediction of the sensory consequences of actions can be used in motor control and what is the role in the extraction of novelty and awareness, (*ii*) how the information about future can improve the perception of a robot that needs to interact with the environment; (*iii*) how this knowledge can help to determine current and future processing of sensory information.