

# Online Adaptation of a Robot Body Schema Based on Internal Simulation and Multisensory Feedback

Pedro Vicente, Lorenzo Jamone, Alexandre Bernardino  
Institute for Systems and Robotics,  
Instituto Superior Técnico – Universidade de Lisboa,  
Lisboa, Portugal  
Email: {pvicente, ljamone, alex}@isr.tecnico.ulisboa.pt

Humans develop body awareness through an incremental learning process that starts in early infancy [1], and probably even prenatally [2]. Such awareness is supported by a neural representation of the body that is constantly updated with multimodal sensorimotor information acquired during motor experience and that can be used to infer the limbs' position in space and guide motor behaviors: a body schema [3]. Although it is yet not clear how much of this knowledge is "innate" and how much is ecologically learned, and what are the underlying representational structures, it is evident that a continuous adaptation is performed, both at a kinematic and at a dynamic level, to cope with a number of gradual (e.g. body growth, modification in the muscular structure) and abrupt (e.g. inclusion of tools) modifications that the human body faces over time. Endowing humanoid robots with similar adaptation capabilities is a major challenge for cognitive developmental roboticists.

In this work, we propose a novel approach to obtain automatic adaptation of the robot body schema and to improve the robot perceptual and motor skills based on this body knowledge. Predictions obtained through a mental simulation of the body are combined with the real sensory feedback to achieve two objectives simultaneously: body schema adaptation and markerless 6D hand pose estimation. The body schema consists of a computer graphics simulation of the robot, which includes the arm and head kinematics [4] (adapted online during the movements) and an appearance model of the hand shape and texture. The mental simulation process generates predictions on how the hand will appear in the robot camera images, based on the body schema and the proprioceptive information (i.e. motor encoders). These predictions are compared to the actual images using Sequential Monte Carlo techniques to feed a particle-based Bayesian estimation method to estimate the parameters of the body schema. During the last two years, we performed extensive experiments with the iCub humanoid robot to support the validity of our approach [5, 6, 7, 8].

Currently, we are investigating how to incorporate the information from visual perception into the body schema adaptation. The goal is to adapt not only the kinematic parameters but also the appearance model in order to enable the agent to adapt to visual changes in its appearance (e.g. wearing a glove).

*Keywords: humanoid robot; internal learning model; simulation; body schema*

## **References:**

- [1] von Hofsten, C. (2004). "An action perspective on motor development". *Trends in Cognitive Sciences*. 8, 266–272. DOI:10.1016/j.tics.2004.04.002
- [2] Joseph, R. (2000). "Fetal brain behavior and cognitive development. *Developmental Review*". 20, 81–98. DOI:10.1006/drev.1999.0486
- [3] Berlucchi, G., and Aglioti, S. (1997). "The body in the brain: neural bases of corporeal awareness". *Trends Neurosciences*. 20, 560–564. DOI:10.1007/s00221-009-1970-7
- [4] Pattacini, U. (2011). "Modular Cartesian Controllers for Humanoid Robots: Design and Implementation on the iCub". Ph.D. thesis, Italian Institute of Technology, Genoa.
- [5] Vicente, P., Ferreira, R., Jamone, L., and Bernardino, A. (2014). "Eye-hand online adaptation during reaching tasks in a humanoid robot". in *IEEE International Conferences on Development and Learning and Epigenetic Robotics (ICDL- Epirob)* (Genoa), 175–180. DOI:10.1109/DEVLRN.2014.6982978
- [6] Vicente, P., Ferreira, R., Jamone, L., and Bernardino, A. (2015). "GPU-enabled particle based optimization for robotic hand pose estimation and self-calibration". in *IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC)* (Vila Real), 3–8. DOI:10.1109/ICARSC.2015.25
- [7] P. Vicente, L. Jamone, and A. Bernardino. (2016). "Robotic Hand Pose Estimation Based on Stereo Vision and GPU-enabled Internal Graphical Simulation". *Journal of Intelligent & Robotic Systems*, pp. 1-20. DOI:10.1007/s10846-016-0376-6
- [8] P. Vicente, L. Jamone, and A. Bernardino. (2016). Online body schema adaptation based on internal mental simulation and multisensory feedback. *Frontiers in Robotics and AI*, vol. 3, no. 7, 2016. DOI:10.3389/frobt.2016.00007