Developing a sense of bodily self

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Abstract

The development and expression of higher cognitive functions, such as imitation, spatial perception, and tool-use rely on a body schema. Up to date, no general methodology exists about how a robot could learn its body representation. We propose a developmental approach to build the bodily self from the robot own multimodal sensorimotor experiences of self-observation and active interaction with the environment.

1. Background

Without any internal representation of the body, we would be unable to perform the most basic actions, such as reaching for a pen or holding a book. Humans and animals are able to acquire their body representation in their development (Rochat, 2003), but for robots this is a very hard task (Natale et al., 2005). The bodily sense of self can be defined as a sense of own body as a differentiated agent situated in the environment. Recent empirical findings suggest that infants are capable of demonstrating a sense of their own body as a differentiated entity; they distinguish between self- vs. non-self touch, between stimulation originating from either their own body or an external source (Rochat, 2003). Neonates perceive a unique sensation from their experience while crying (produced and heard sounds at the same time), or touching themselves ("double touch"), or feeling the perfect contingency of visual-proprioceptive experience accompanying self-produced movements. The neonates' motor repertoire consists mainly of reflexes that create a base for future motor development (Slater and Lewis, 2002).

The problem of embodiment and body ownership is related to the encoding of spatial information by humans. Bodily signals that are relevant for self-location and ownership are encoded with respect to body-centered and gravity-centered reference frames. The deficient multisensory integration with respect to these reference frames was found in patients with out-of-body experiences and heautoscopy (Lopez et al., 2008).

2. Model Overview

The model of bodily self development for a robot is based on neurophysiological and psychological studies in humans. Robotic implementation of a model of vision-based grasping strongly based on neuroscience data, that has been developed in our laboratory, has proven to be very promising (Chinellato et al., 2008), and apart from fulfilling the exemplary role, it can be later integrated with the proposed model.

The focus of the presented model lies on self-development, which implies the existence of some initial phylogenetic configuration as a basis for the development. Within this framework the basic phylogenetic skills include: grasping reflex, equilibrium reactions, righting reactions, distinction between self- and non-self touch, and distinction between stimulation originating from either their own body or an external source. A general framework is presented in Fig. 1.

In our model, to build a basic body schema we make use of Piaget's primary circular reactions, which are simple, repetitive acts, that involve the infant's own body. While engaging in the acts, the neonates experience pleasure, which pushes them to reproduce these acts. To produce the same effect with the robot, we introduce in the model the pleasure as a variable that substantially increases when a certain tension rapidly discharge. Our architecture employs two types of devices: tension accumulators and tension dischargers. A tension accumulator exibits the current tension level, whereas the tension discharger causes such motions of the robot that it can get sensory patterns causing possibly rapid discharge of a tension accumulated at a given acumulator (Matosiuk and Grzyb, 2006). The dynamic patterns of movements and resulting end-states are being monitored proprioceptively and vestibulary, and thus a basic body schema that includes kinematics (length of body segments and their relative position) and dynamics (moments of inertia, weight) is constructed.

Having acquired some basic movements, the interplay between motor system and sensory systems may be triggered and different kinds of bodily senses, such as visual, tactile, and proprioceptive origi-

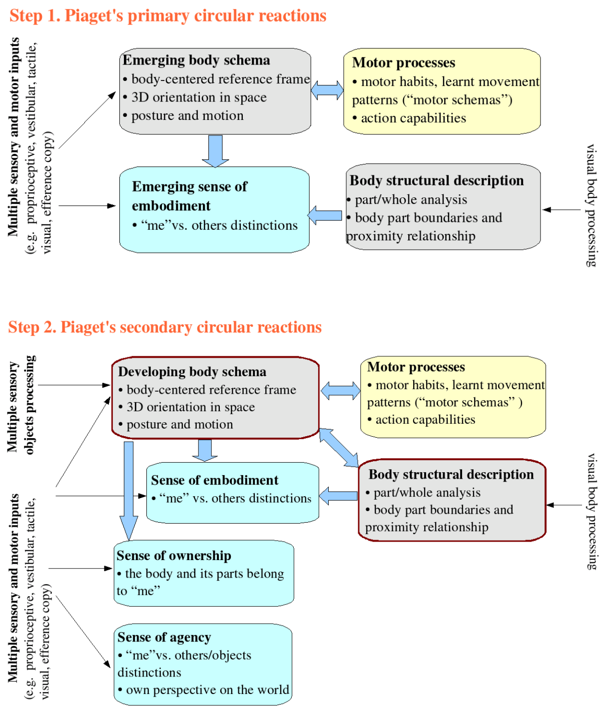

Figure 1: Schematic diagram of postulated development of bodily self for robots. The diagram is an adaptation and extension of the diagram of the body knowledge representation that can be found in (Sirigu et al., 1991).

nating from self-observation experiences are combined and cross-referenced. The approach followed here is related to the previous work on employing self-generated motion to segment the robot body from the background (Metta and Fitzpatrick, 2003, Natale et al., 2005). During self-produced movements the correlation between motor commands and motion in the visual field is used to outline the body silhouette. Once the boundary of the body is marked, the robot begins to investigate its body with tactile sensors. Combined "double touch" and multimodal correlation allow the robot to learn that its body is a distinct entity in the enviroment. Particulary important is multisensory information that is processed within body-centered and gravity-centered reference frames.

The next step of developing a body schema, after self-observation, is interaction with the environment. The sensory-motor actions, such as looking at the object, pointing, touching, moving the fingers over a surface or along an edge, manipulation etc., provide a lot of experience for further development of the body representation and perception. The ability of manipulation enables the robot to engage in the so called Piaget's secondary circular reactions, which are simple repetitive actions performed with objects (Slater and Lewis, 2002). We mainly focus on manipulation, because it offers the possibility to investigate active learning, and allows the robot to collect information about objects and its body by performing specific exploratory actions on them. For example, when a robot grasps and lifts an object, the simultaneous activation of the tactile sensors in its hand and the visual signal from the camera, together with proprioceptive sensors such as the force sensors on the actuators, gives information not just about the object but also about how its hand and arm work. The maturation of the system gradually allows for reflexive behaviors to be inhibited.

In conclusion, the model we presented leads not only to building a body schema, but also to developing sensations, such as embodiment, ownership or agency. This is a novel approach to create a more comprehensive robot's body representation and perception. The model can be used also to validate theories of human body representation and to investigate disorders of body representation, such as phantom limbs.

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