

Development and Extension of the Robot Body Schema

Alexander Stoytchev

Mobile Robot Laboratory, Georgia Institute of Technology

Atlanta, Georgia 30332-0280 U.S.A.

e-mail: saho@cc.gatech.edu

The sense of body is probably one of the most important senses and yet it is one of the least well studied. It is a complex sense, which combines information coming from proprioceptive, somatosensory, and visual sensors to build a model of the body called the body schema. It has been shown that the brain keeps and constantly updates such a model in order to register the location of sensations on the body and to control body movements (Iriki et al., 1996, Iriki et al., 2001, Berlucchi and Aglioti, 1997, Graziano et al., 2000, Graziano et al., 2002, Berthoz, 2000).

The notion of *body schema* was first introduced by Head and Holmes (1911). They studied numerous clinical patients who experience disorders in perceiving parts of their bodies often lacking sensations or feeling sensations in the wrong place. They define the *body schema* as a postural model of the body and a model of the surface of the body (Head and Holmes, 1911).

Perhaps the most interesting property of the body schema is that it is not static but can be modified and extended dynamically in very short periods of time. Such extensions can be triggered by the use of noncorporeal objects such as clothes, ornaments, and tools (Tiemersma, 1989, Iriki et al., 1996). Thus, the body schema is not tied to anatomical boundaries. Instead, the actual boundaries depend on the intended use of the body parts and the external objects attached to the body.

It has been suggested that the pliability of the body schema plays a role in the acquisition of tool behaviors (Head and Holmes, 1911, Paillard, 1993). Recent studies have shown that this is indeed the case (Iriki et al., 1996, Berlucchi and Aglioti, 1997, Berti and Frassinetti, 2000). Iriki et al. trained a macaque monkey to retrieve distant objects using a rake and recorded the brain activity of the monkey before, during, and after tool use. They discovered a large number of bimodal neurons, sensitive to visual and tactile stimuli, that appear to code the schema of the hand (Iriki et al., 1996). Before tool use the receptive fields (RF) of these neurons were centered around the hand. During tool use, however, the somatosensory RF stayed the same but the visual RF was altered to include the entire length of the rake or to cover the expanded accessible space.

This modification of the visual receptive field is limited to the time of tool usage and is conditional upon the intention to use the tool. When the monkey stopped using the tool, or even continued to hold the tool without using it, the visual RF contracted back to normal (Iriki et al., 1996). In a follow-up study the monkey was prevented from directly observing its actions and instead was given feedback only through a camera image projected on a video monitor. In this case the visual RF of the bimodal neurons was projected onto the video screen (Iriki et al., 2001).

This study demonstrates preliminary results for a computational model of a robot body schema (RBS) that has extensibility properties similar to its biological analog. The model is based on an existing model first described by Morasso and Sanguineti (1995). This model is modified to include tactile sensors which are used in the extension of the RBS.

In order to describe the RBS model the following notation is introduced. Let $\mu = [\theta_1, \theta_2, \dots, \theta_M]$ represent a joint angle vector and let $\tilde{\mu}_i = [\tilde{\theta}_1^i, \tilde{\theta}_2^i, \dots, \tilde{\theta}_M^i]$ be a specific instance of this vector. Let $L_R = \{L_{r_1}, L_{r_2}, \dots, L_{r_N}\}$ be a set of labels referring to N locations on the body of the robot which can be reliably detected with the robot's sensors. Each body location has an associated touch sensor T_i . Let $\nu = [v_{r_1}, v_{r_2}, \dots, v_{r_N}]$ be a vector which represents the coordinates of locations L_{r_1} through L_{r_N} in sensor space. Also, let $\tilde{\nu}_i = [\tilde{v}_{r_1}^i, \tilde{v}_{r_2}^i, \dots, \tilde{v}_{r_N}^i]$ be a specific instance of this vector.

The body schema model is built around the concept of a *body icon* which is a pair of vectors $(\tilde{\mu}_i, \tilde{\nu}_i)$ representing the motor and sensory components of a specific joint configuration of the robot. A large number of body icons, $[(\tilde{\mu}_i, \tilde{\nu}_i), i = 1, \dots, \mathcal{I}]$, is used to represent the robot body schema. It is believed that the brain uses a similar representation encoded as a cortical map (Morasso and Sanguineti, 1995, Graziano et al., 2002).

The body icons are learned empirically from self-observation data gathered during a motor babbling phase. The learning algorithm described by (Morasso and Sanguineti, 1995) guarantees that each body icon has a neighborhood of similar body icons. This similarity property can be exploited to implement a gradient ascent strategy for moving the robot from one configuration to another.

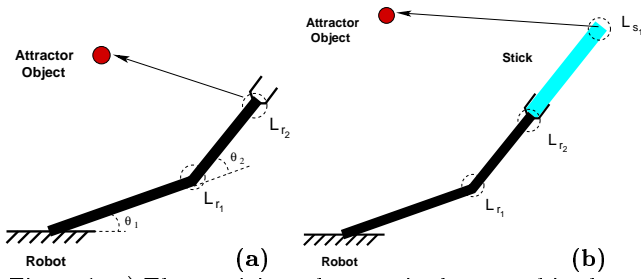


Figure 1: a) The two joint robot manipulator used in the example. b) The same robot holding a stick.

The gradient ascent is carried out in a potential field in which the location of the target has a maximum value and all other points are assigned values in proportion to their distance from the target. The potential field is imposed on the $\tilde{\mu}_i$ components of the body icons but is computed based on the \tilde{v}_i components and their distance to the goal in visual space.

The representation of the RBS in terms of body icons allows extensions of the RBS similar to its biological analog. This is achieved by adding offset vectors to the sensory components of the body icons whose touch sensors are activated by an attached object. In other words, if touch sensor T_i is triggered then $\tilde{v}_{r_j}^i = \tilde{v}_{r_j}^i + \text{offset}_{r_j}^i$. The offset vectors shift the centers of the visual receptive fields of the body icons. These vectors can be computed as a function of the existing body icons and the sensory features of the attached object.

To illustrate these ideas consider the example shown in Figure 1. The robot is a two-dimensional manipulator arm with two rigid limbs and a gripper. Both joints can rotate 180 degrees ($0 \leq \theta_1, \theta_2 \leq \pi$). The robot has two body locations, L_{r_1} and L_{r_2} , associated with its “elbow” and “wrist”. The sensory vector $\nu = \{v_{r_1}, v_{r_2}\}$ is computed from a camera image. The joint angle vector is given by $\mu = \{\theta_1, \theta_2\}$.

The RBS model described above was tested in simulation by placing an attractor object at different places in the robot’s environment. Reaching behaviors toward the attractor were executed using the potential field method. The same experiments were repeated with the robot holding a stick. In the lat-

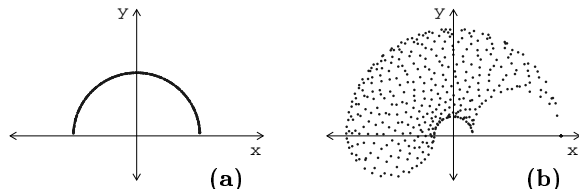


Figure 2: The sensory components of the body icons of the two joint manipulator: a) elbow; b) wrist.

ter case the potential field was calculated using the extended body icons of the wrist (Figure 3). These are computed as $\tilde{v}_{r_2}^i = \tilde{v}_{r_2}^i + \tilde{e}_i \|v_{s_1} - v_{r_2}\|$ where $\tilde{e}_i = (\tilde{v}_{r_2}^i - \tilde{v}_{r_1}^i) / \|\tilde{v}_{r_2}^i - \tilde{v}_{r_1}^i\|$ are unit vectors computed using the positions of the two robot body locations stored in all body icons.

In conclusion, there are several reasons why a robot should have a *robot body schema*: 1) it provides the robot with a sensory-motor model of its body that can be used for control of robot movements; 2) it makes explicit the distinction between sensory stimuli coming from the environment and sensory stimuli coming from the robot which can potentially simplify the process of behavioral specification; 3) it can be learned automatically from self-observation; 4) it can accommodate changes in the configuration of the robot.

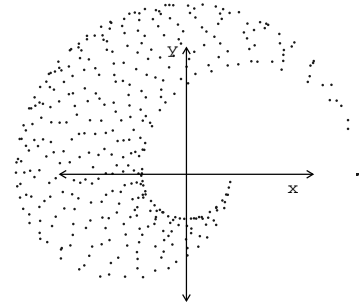


Figure 3: The sensory components of the extended body icons. In this example only the wrist components are extended by the stick.

References

- Berlucchi, G. and Aglioti, S. (1997). The body in the brain: neural bases of corporeal awareness. *Trends in Neuroscience*, 20(12):560–564.
- Berthoz, A. (2000). *The brain’s sense of movement*. Harvard University Press.
- Berti, A. and Frassinetti, F. (2000). When far becomes near remapping of space by tool use. *Journal of Cognitive Neuroscience*, 12(3):415–420.
- Graziano, M., Cooke, D., and Taylor, C. (2000). Coding the location of the arm by sight. *Science*, 290:1782–1786.
- Graziano, M., Taylor, C., and Moore, T. (2002). Complex movements evoked by microstimulation of precentral cortex. *Neuron*, 34:841–851.
- Head, H. and Holmes, G. (1911). Sensory disturbance from cerebral lesions. *Brain*, 34:102–254.
- Iriki, A. et al. (1996). Coding of modified body schema during tool use by macaque postcentral neurons. *Neuroreport*, 7:2325–2330.
- Iriki, A. et al. (2001). Self-images in the video monitor coded by monkey intraparietal neurons. *Neuroscience Research*, 40:163–173.
- Morasso, P. and Sanguineti, V. (1995). Self-organizing body-schema for motor planning. *Journal of Motor Behavior*, 27(1):52–66.
- Paillard, J. (1993). The hand and the tool: The functional architecture of human technical skills. In *The Use of Tools by Human and Non-human Primates*, pages 36–46. Oxford University Press.
- Tiemersma, D. (1989). *Body Schema and Body Image: An Interdisciplinary and Philosophical Study*. Swets and Zeitlinger B. V., Amsterdam.