Modeling planning and reaching

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Abstract

Recently developed models of reaching have been based on the general principle that an actor first specifies a task goal, then plans a goal posture that can achieve the task, and then specifies a movement to that goal posture. Selection of a particular goal posture is based on the degree to which movement from the starting posture to possible candidate goal postures best satisfies a number of constraints, including biomechanical efficiency and the avoidance of obstacles. We describe methods used to simulate and test this model.

Modeling Planning and Reaching

Most tasks can be accomplished by a potentially infinite number of distinguishable alternative actions. This is particularly true of movements such as reaching for and grasping objects, because, as Bernstein (1967) pointed out, the musculo-skeletal system provides a larger number of degrees of freedom than are typically constrained by the ostensive description of a physical task.

We have developed and tested a series of increasingly powerful computational models that simulate reaching to target locations. These models (Rosenbaum, Engelbrecht, Bushe, & Loukopoulos, 1993; Rosenbaum, Loukopoulos, Meulenbroek, Vaughan, & Engelbrecht, 1995; Rosenbaum, Meulenbroek, Jansen, Vaughan, & Lelivelt, 1997) have been applied to the selection of postures in reaching for static targets (Vaughan, Rosenbaum, Harp, Loukopoulos, & Engelbrecht, 1997), generation of repetitive movement patterns (Fischer, Rosenbaum, & Vaughan, 1997), and generation of the pentip trajectory in handwriting (Meulenbroek, Rosenbaum, Thomassen, Loukopoulos, & Vaughan, 1996). While the details of the models have changed, the main ideas running through them have been preserved. The description below applies to the most recently developed version of the model (Rosenbaum et al., 1997).

Characteristics of the Model

According to the model, planning is based on a constraint hierarchy — a prioritized list of desiderata including such features as spatial accuracy, efficiency, speed, and the avoidance of collision with obstacles. The constraint hierarchy, which is established by the actor in interaction with the environment, defines the task to be performed. Once the constraint hierarchy is established, a target position of the body (a goal posture) is chosen based on a two-stage process of identifying the most promising stored posture for the task and then by generating postures similar to the most promising stored posture until a dynamically set deadline is reached. The very best posture identified at the time of the deadline defines the goal posture. The deadline is shortened for the next trial if the ultimately chosen posture was found before the deadline was reached, or the deadline is lengthened for the next trial if the ultimately chosen posture was found at the time the deadline was reached. Postures are defined as vectors of joint angles assumed by such joints as the hip, shoulder, elbow, and wrist. Once the goal posture is found, a movement to the goal posture is internally generated and internally modified if an obstacle is in the way. Finally, a movement is performed overtly.

This model allows for reaching to and touching a target with any end-effector (e.g., the hand, the elbow, or the tip of a tool). It also allows for reaching automatically following decrements in mobility of any joint due to encumbrance, disease, or injury, as well as accommodating an increment in range by the use of a tool to extend the limit of the hand. Finally, reaching is generalized to the grasping of objects with the opposed thumb and fingers, by considering grasping as a special case of reaching in the presence of obstacles.

The model's free parameters are an expense factor for each joint, characterizing the mobility of that joint as affected by stiffness, the energy cost of movement, or injury. Currently, because the scope of the model is limited to kinematics, none of the joint's expense factors takes into account the cost of moving a given joint while another joint is in motion. In other words, the models currently treats the joints as independent.

Simulations

Simulations of the model, instantiated as a stick-figure, have been used to describe the performance of subjects reaching to a variety of locations in a parasagittal plane, using rotations of the hip, shoulder, elbow, and wrist. Individual movements are simulated by specifying a starting posture, the locations of targets, and the locations and shapes of obstacles that must be avoided in moving from starting postures to target postures. To determine the relative cost of moving to different candidate postures, movement costs are calculated based on the degree to which each joint must be rotated to achieve the target posture, weighted by the expense factor of each joint.

A representative simulation is shown in Figure 1. This figure shows a single movement of a seated cartoon figure, from a starting location (S) to a target (T), in the absence or in the presence of an obstacle (O). The stick figure was provided with a short tool, so movement of the end effector was achieved through combined rotations about the shoulder, elbow, and wrist.

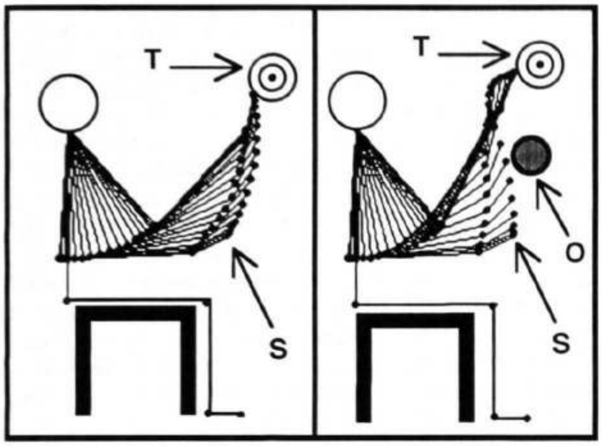

Figure 1: Simulation of movement from a starting posture (indicated by **S**) to touch a target (**T**). Left Panel: No obstacle present. Right Panel: Single obstacle (**O**) present.

Evaluation of the Simulations

The simulated movements have been compared with movements made by human volunteers who likewise made movements in the parasagittal plane to touch targets (either real or presented through a virtual-reality arrangement), in several different experiments, while their movements were recorded on videotape or by an OPTOTRAK motion recording system. In one of these experiments (Vaughan et al., 1997), subjects reached to each of 12 targets in the parasagittal plane, bending at the hip, shoulder, and elbow. The downhill simplex method (Press, Flannery, Teukolsky, & Vetterling, 1989) was used to estimate the expense factors for the three joints. Figure 2 shows a representative fit of the model to the goal postures for reaches to four different targets. In this case, the model accounted for at least 95% of the variance across 4 subjects and 12 positions adopted at the target locations.

In another experiment, subjects were instructed to make a series of movements (Fischer et al., 1997) through an intermediate target location on the way to each of a number of target locations. In this case, the model accounted for 88% of the variance in joint angles adopted at the target locations. In both the Fischer et al. and Vaughan et al. studies, alternative models, designed to evaluate the necessity of the assumptions of the model, did significantly less well than the model itself.

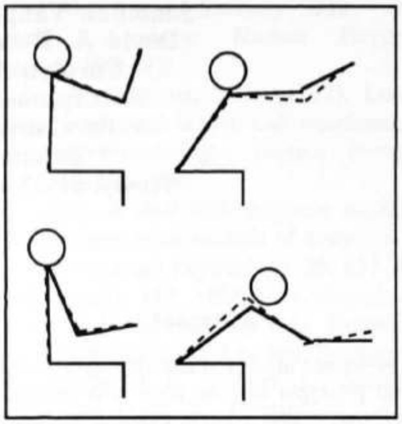

Figure 2: Observed (solid lines) and simulated (dashed lines) postures for one subject, reaching to four different target locations.

Summary and Conclusions

The model described here predicts the main features of freely selected postures adopted at target locations in a wide range of tasks. Although space limitations in this brief report prevent us from describing the model in full, and so explaining how it manages to predict performance in tasks as disparate as obstacle avoidance, writing, and prehension, the fact that it applies to such a wide range of tasks is encouraging. What distinguishes the model from others is reliance on the constraint hierarchy, reliance on goal-posture specification prior to movement specification, and something not reviewed above -- the superposition of movements to and from subgoal postures during movements to goal postures, especially during obstacle avoidance. Although the model still requires more complete behavioral testing, its generalizability suggests that its core principles are on the right track.

Acknowledgements

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