Is the movement of the human arm controlled by means of cost functions?

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The aim of the investigation is to understand the mechanisms which control the movement of the human arm. The arm is here considered as a redundant system: the shoulder, elbow and wrist joints, which provide three degrees of freedom, combine to move the hand in a horizontal plane, i.e. a two dimensional space. Thus the system has one extra degree of freedom.

Earlier investigations of the static situation led to the hypothesis that independent cost functions were attached to each of the three joints and that the joint configuration chosen for a given hand position is that which provides the minimum total cost (Cruse, Biol. Cybern. 54, 125-132, 1986). For further investigation of this system we developed a new method. The arm was fixed to a manipulandum by means of which the values of the joint angles could be read on-line into a microcomputer (Apple II). The hypothetical cost functions, defined as those providing the best fit to the data according to the criterion of smallest mean square deviation, were calculated by means of an automatic method (using simulated annealing).

With these methods the earlier experiments were repeated using more target points and the hypothesis was confirmed. The cost function can be interpreted as a measure of comfort for a given joint position. Psychophysic measurements showed that in contrast to the first assumption a small but significant correlation between the most comfortable position of the wrist joint and the elbow angle could be found. No such dependence was found for other pairs of angles. A kind of hysteresis was found in the sense that for a given end point the joint angle values depended on the direction from which the hand approached the endpoint.

The investigation of the kinematics showed that the movement of the arm could not be described when only the cost functions were used as a basis of the control system. Neither did the application of the pseudoinverse control - often used in the control of robot manipulators - fit the experimental results. A combination of both was able to simulate those movements quite well in which the hand followed a straight path in the workspace (see similar proposals for robot control by Yoshikawa, Robotic Research: M. Brady, R. Paul (eds.), 735-747, 1986). In contrast to reports in the literature, curved paths were also observed in our experiments. A model augmented according to the basic ideas of the mass-spring control (Fel'dman, Biophysics 19, 544-548, 1974) was able to describe both experimental results, those with straight and those with curved paths.