For any given $a$ and $b$ such that $a \leq b$, the primary workspace is largest when $h = b$.

Conclusions

We have shown that it is possible to analyze the shape of workspaces and determine the influence of hand size on the ratio of primary to total workspace. We have treated the cases of three mutually orthogonal intersecting axes in detail and provided a basis for designers to rationally determine the dimensions of 6-degree-of-freedom manipulators. These results can be applied to designing for a total workspace or for a certain primary workspace; most important, they deal with the much neglected question of hand size.

Acknowledgments

The financial support of the National Science Foundation under grant ENG 79-23193 to the University of Illinois at Chicago Circle and grant ENG 79-10313 to Stanford University is acknowledged.

References


Discussion

D. Yang. This is a well-written and thought-provoking paper. It represents an original contribution.

An important concept given in the paper involves the replacement of "three orthogonally intersecting revolute joints" by a spherical joint. The wording "intersect orthogonally" or its equivalent has appeared several places in the paper. It seems to this writer that some explanation may be warranted with reference to the condition of the intersection. Perhaps it could be stated more rigorously as "three consecutive intersecting revolute joints with two pairs of orthogonal axes." It is worth noting that it would not be possible to have three consecutive (or mutually) orthogonally intersecting revolute joints. One of the twist angles between two of the axes cannot be fixed to any angle. It should be left as a variable which would allow the turning of its corresponding joint.

The authors deserve compliments for having made a valuable contribution to the basic concepts regarding manipulator workspaces.

Authors’ Closure

We thank Mr. D. Yang for his thoughtful reading of our paper. We agree with him that a more precise phrase could have been devised for describing the special configurations shown in Figs. 7, 14, and 18. In each of these cases three revolute axes, associated with two adjacent links, are concurrent. This concurrence condition is sufficient to make the three revolute joints kinematically equivalent to a single spherical joint. However, this will not yield a full range of rotation, i.e., the equivalency will be to a spherical joint with mechanical interference.

If we are interested in an idealized spherical joint, with a full range of rotation and without any mechanical interference, it is necessary that, in addition to the concurrency condition, the twist angle in each of the two links be 90 deg. Hence, the concurrency of the three adjacent axes and the orthogonality of both of the two adjacent pairs are the necessary and sufficient conditions for three revolute joints (with full 360 deg rotation range in each) to be kinematically equivalent to an idealized spherical joint.