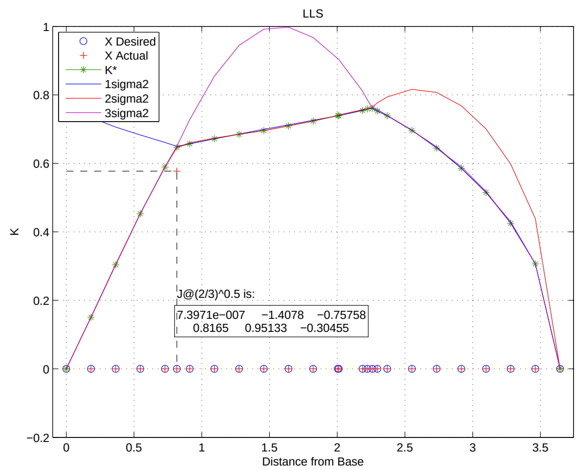

Figure 6. The relationship between $\mathcal{K}$ and the distance from the base for the (L_l, L_l, L_s) robot.

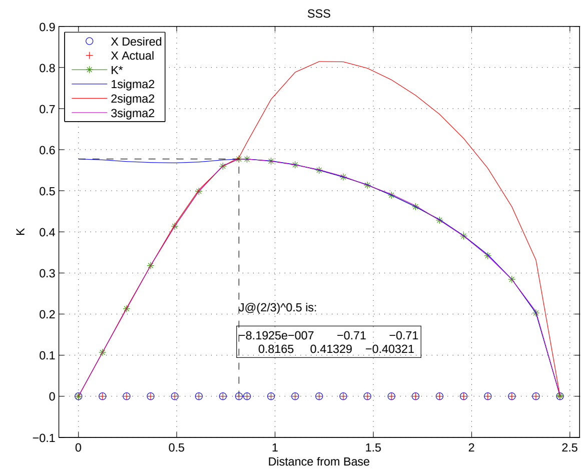

Figure 7. The relationship between $\mathcal{K}$ and the distance from the base for the (L_s, L_s, L_s) robot.

workspaces. Because $\mathcal{K}$ is not a function of θ_1, it is sufficient to compute its maximum value as a function of distance from the base of the manipulator. The maximum value of $\mathcal{K}$ is determined by computing all possible robot configurations for each distance, and calculating $\mathcal{K}$ for the Jacobian at that configuration. The results for each of the four robots is shown in Figures 6 to 9 where all three values of ${}^f\sigma_2$ for the configuration with maximum $\mathcal{K}$ are also plotted.

The first interesting point to note is that the manipulator with link lengths (L_l, L_l, L_s) in Figure 6 actually has a configuration with a larger value of $\mathcal{K}$ at the design point that is a distance of $\sqrt{2/3}$ from the base than that of the optimal value of $\mathcal{K} = \sqrt{1/3}$. This is possible because at this configuration the Jacobian is no longer isotropic, however, its non-isotropy is due to a larger maximum singular value, and so may not be considered undesirable. In addition, the value of $\mathcal{K}$ is significantly higher than the optimal value for a significant portion of this manipulator's workspace, making it particularly well suited for applications that require failure tolerance.

In contrast, consider the manipulator with link lengths (L_s, L_s, L_s) in Figure 7. It has a value of $\mathcal{K} = \sqrt{1/3}$ at the the optimal distance as designed, however, this is its peak value of $\mathcal{K}$, and $\mathcal{K}$ is monotonically decreasing away from this point. Thus, in addition to having the smallest workspace, this manipulator has a significantly smaller tolerance to joint failures throughout its workspace.

The characteristics of the two medium length robots fall somewhat inbetween the two extremes just described. The (L_s, L_l, L_s) robot shown in Figure 8 has a flat region of $\mathcal{K}$ that starts at the optimal point and continues for approximately 1.0 units, i.e., approximately 33% of its total reach. The (L_l, L_s, L_s) robot shown in Figure 9 has comparable magnitudes of $\mathcal{K}$, however, it is unique in that the value of $\mathcal{K}$ has multiple local maxima. In summary, even though all four robots are derived from the same optimally fault-tolerant Jacobian, their global properties are

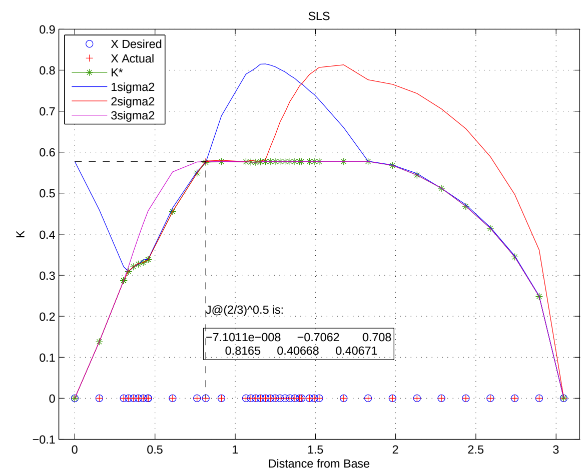

Figure 8. The relationship between $\mathcal{K}$ and the distance from the base for the (L_s, L_l, L_s) robot.

quite different, both prior to a failure and afterward. The (L_l, L_l, L_s) robot is arguably the most preferable due to its larger pre-failure workspace and the large value of fault tolerance over a substantial portion of its workspace.

5. Conclusion and Future Work

This work has presented preliminary results that illustrate how multiple different manipulators can be designed from a Jacobian that has been selected to have desirable failure tolerance properties. It has been shown that even though these manipulators all have the same local properties, their global properties can differ significantly, both in terms of pre-failure kinematics as well as post-failure performance. This can provide robot system designers with a great deal of flexibility when considering the different constraints that arise from different applications.

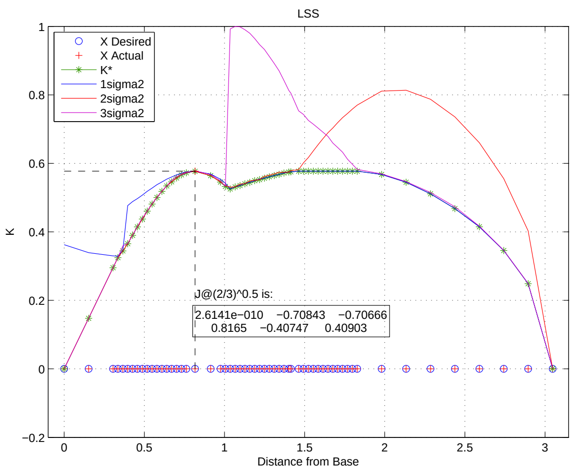

Figure 9. The relationship between $\mathcal{K}$ and the distance from the base for the (L_l, L_s, L_s) robot.

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