Conclusion

The primary goal of this research effort was to demonstrate that a relatively complex EVA task could be simulated using computational multibody dynamics. The objective was not to showcase the full range of capabilities of computational simulation but rather to establish a testbed that could be used for further exploration of simulation techniques. Although the dynamic system itself is of a relatively high fidelity, some limitations remain. Most notable among these is the use of simple control laws to model astronaut hand forces and body torques. There exists an opportunity for additional work on simulations that employ more advanced control, including theory to account for the intelligence of the astronaut. Other limitations that should be addressed in future studies include a more scientific approach to the selection of control parameters and other constants, the influence of the EVA spacesuit on joint mobility, and compliance in the anchoring of the astronaut's feet (such as that expected from a portable foot restraint attached to the Orbiter's Remote Manipulator System).

In spite of these limitations, some important conclusions can be derived from this work. Figure 2 shows that the asymmetrical location of the capture bar's center of mass causes an initial yaw motion that brings the left-hand side of the capture bar into contact with the satellite before the right-hand side. As a result, roll and pitch disturbances are introduced that, together with the rebounds caused by the relatively noncompliant interface between the v-guides and the satellite interface ring, make it difficult for the astronaut to maintain the proper alignment between the capture bar and the satellite. In addition, the contact duration of 5–6 s was not sufficient to allow the satellite to rotate to the position where the capture bar latches would be triggered by structural elements on the satellite, an observation confirmed by video footage of STS-49. Furthermore, the slowing of the satellite's spin due to friction with the capture bar and the yaw and pitch rates caused by the unequal forces at the left and right contact points (also a consequence of the capture bar's center-of-mass asymmetry) could complicate further EVA capture attempts.

The fact that the satellite quickly translates out of reach when force is applied, combined with the observation of low torque values on body joints, indicates that a very light touch is required for this type of EVA task. Such a light touch may be difficult to apply because, according to EVA crewmembers, the spacesuit restricts tactility and proprioception, making it difficult to exert precision forces below a certain threshold (estimated to be as much as 40 N in the spacesuit).

A number of recommendations are suggested by the results of this simulation. For this type of task, astronauts should use very small, precise forces, even when dealing with objects of large mass. To compensate for the limited tactility allowed by a spacesuit, a mechanism such as the capture bar should be designed with additional compliance and minimal friction at the contact interface. Wherever possible, the center of mass of the manipulated object should be aligned with the center of the astronaut's task coordinates (i.e., the center of the manipulation wheel), even if this means adding mass. Finally, physical and computational simulators should be used in conjunction during EVA training so that each may help compensate for the limitations of the other.

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Improved Method for Calculating Exact Geodetic Latitude and Altitude Revisited

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IN the Note published by the author titled "Improved Method for Calculating Exact Geodetic Latitude and Altitude,"[1] exact, singularity-free expressions for the geodetic latitude and altitude of an arbitrary point in space were derived. Recently, a numerical problem has been detected in the equations at points on and near the equator when q becomes very large. The author has modified the equations to neutralize the effect of large q, thus yielding equivalent, exact, singularity-free expressions that are also numerically stable everywhere and just as elegant. The revised algorithm follows.

Given a, b, x_0, y_0, and z_0,

$$e^2 = 1 - b^2/a^2, \qquad \varepsilon^2 = a^2/b^2 - 1, \qquad r_0 = \sqrt{x_0^2 + y_0^2}$$

$$p = |z_0|/\varepsilon^2, \qquad s = r_0^2/e^2\varepsilon^2, \qquad q = p^2 - b^2 + s$$

If $q > 0$, then

$$u = p/\sqrt{q}, \qquad v = b^2u^2/q, \qquad P = 27vs/q$$

$$Q = \left(\sqrt{P+1} + \sqrt{P}\right)^{\frac{2}{3}}, \qquad t = (1 + Q + 1/Q)/6$$

$$c = \sqrt{u^2 - 1 + 2t}, \qquad w = (c - u)/2$$

$$z = \operatorname{sign}(z_0)\sqrt{q}\left(w + \sqrt{\sqrt{t^2 + v} - uw - t/2 - 1/4}\right)$$

$$N_e = a\sqrt{1 + \varepsilon^2 z^2/b^2}, \qquad \phi = \arcsin\left[(\varepsilon^2 + 1)(z/N_e)\right]$$

$$h = r_0\cos\phi + z_0\sin\phi - a^2/N_e$$

The condition $q > 0$ implies that the excluded region is a closed prolate spheroid that is concentric with and contained within the Earth ellipsoid and whose semimajor axis is less than 43 km.

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