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DEVELOPMENT OF AN INTERCHANGEABLE END EFFECTOR MECHANISM FOR THE RANGER TELEROBOTIC VEHICLE

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Abstract

The Ranger program at the Space Systems Laboratory (SSL) at the University of Maryland is a demonstration of an extremely low cost, space flight experiment. The Ranger vehicle is designed to perform teleoperated spacecraft maintenance. Completing the various tasks included in spacecraft maintenance requires several specific tools. This paper describes the Ranger interchangeable end effector mechanism (IEEM). Its design allows Ranger to change end effectors to utilize the appropriate tool for the various tasks.

The Ranger vehicle is designed with four manipulators. A seven degree-of-freedom (DOF) grappling manipulator securely attaches the vehicle to the work site. A 6 DOF camera positioning manipulator allows the operator to position a stereo pair of video cameras for visual feedback. The two remaining manipulators are the 7 DOF dexterous arms. They are the primary means by which Ranger accomplishes its required tasks. At the end of each of these dexterous manipulators is an IEEM.

This paper begins with a brief overview of the Space Systems Laboratory and the Ranger program. The constraints leading to the requirements for an IEEM are described. The following section then describes the design strategies and the down selection process resulting in two candidate designs, taper and pneumatic connector type. Next, the leading candidate design is described in detail, followed by a preliminary discussion of failure modes and planned testing. The paper concludes with a brief review and a section discussing future work.

Acronym List

EVA	Extra Vehicular Activity
NB	Neutral Buoyancy
NBRF	Neutral Buoyancy Research Facility

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NBV	Neutral Buoyancy Vehicle
RSIS	Robotic Systems Integration Standards
SSP	Space Station Program
TFX	Telerobotic Flight Experiment

Introduction

For many years the Space Systems Laboratory has studied how to do useful work in space with a particular emphasis on neutral buoyancy simulation of the micro gravity environment. The primary approaches are to understand how a person performs useful work in weightlessness, how machines operate in weightlessness, and how the two can work together. Neutral buoyancy was chosen as the weightless environment simulation for the Ranger program. This environment allows motion in all 6 DOF, but also introduces some new challenges. For example: the vehicle must be water tight, and the center of mass must coincide with the center of buoyancy to insure rotational neutral buoyancy.

The SSL has developed several telerobotic systems for operations in the neutral buoyancy environment. The Ranger neutral buoyancy vehicle (Ranger NBV) is the newest system to come on-line in the SSL. Ranger NBV, shown in Figure 1, is the development and test unit for the Ranger telerobotic flight experiment (Ranger TFX), shown in Figure 2.

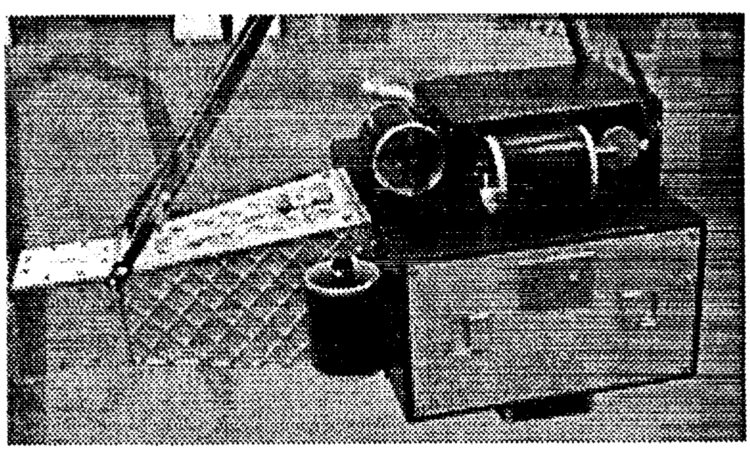

Figure 1. Ranger NBV

Ranger Background

Ranger is a telerobot designed to perform complete, end-to-end spacecraft maintenance operations. These include rendezvous and docking with a target vehicle, performing a specified task set and departing from the target vehicle. A specified task set includes, but is not limited to, structural assembly, orbital replacement unit (ORU) changeout, battery changeout and satellite refueling. These tasks represent some of the operational research aspects of Ranger. Some of the science and engineering data expected from the Ranger program include: a correlation of the neutral buoyancy environment with the space environment, advanced telerobotics design and control, remote telerobotic maneuvering, human factors of ground based control for space telerobots, and advanced small spacecraft technology (Reference 1).

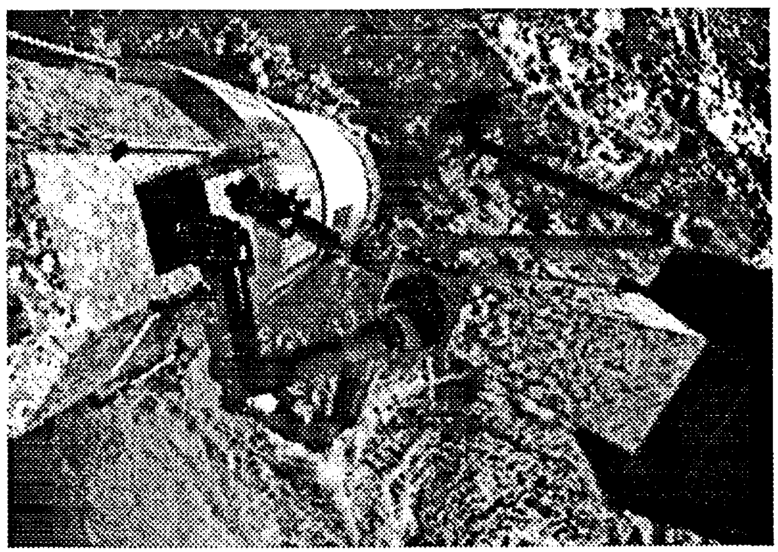

Figure 2. Ranger TFX

The Ranger program's objective to perform spacecraft maintenance operations is realized with the dexterous manipulators. These are 7 DOF, serial, revolute manipulators, designed with a similar work envelope and force exertion capabilities as those of a human. The envelope and force capabilities come from the requirement to operate EVA-type interfaces per NASA STD-3000. See Reference 2 for a more complete discussion of the Ranger manipulators.

In pursuit of the spacecraft maintenance goal, the SSL has accumulated a knowledge base using the Beam Assembly Teleoperator (BAT). BAT has demonstrated the capability to service the extra vehicular activity (EVA) crew training mock-up of the Hubble Space Telescope (HST) at Marshall Space Flight Center's (MSFC) Neutral Buoyancy Simulator (NBS) as shown in Figure 3. During this series of tests, the limitations of BAT's 5 DOF dexterous arm and a fixed end effector became apparent. These tests contributed to the requirement for an IEEM on Ranger.

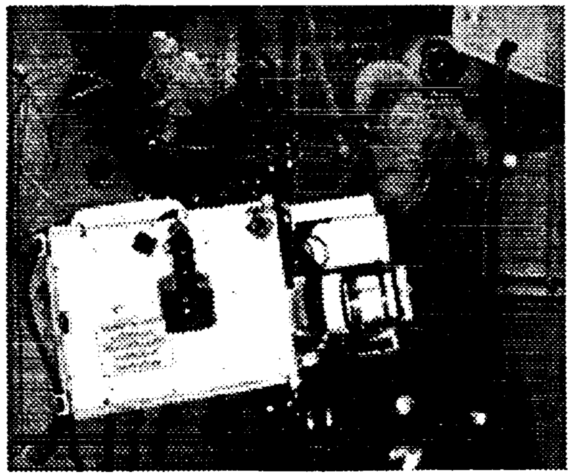

Figure 3. BAT servicing HST

Requirements

During launch, the arms will be configured with the nominal end effector for the initial flight task set installed. This reduces the risk of failure due to a missed end effector exchange early in the mission. The end effectors must be securely stowed in the storage rack for launch. A pyrotechnic or a similar type device will remove the launch restraints allowing the end effectors in the storage rack to engage and release.

The end effector selection for Ranger is based on the accepted robotic interfaces for space hardware as defined in NASA Robotic Systems Integration Standards (RSIS), NASA - SSP 30550 as well as SSL experience. This document requires Ranger to actuate H-handles, micro-conical interfaces, etc. The H-handle interface requires the end effector to have 2 DOF. Therefore, the IEEM shall have two mechanical drives to provide power.

During any kind of exchange, whether an ORU or end effector, there is a possibility of a missed exchange. This is particularly important in space as a missed exchange can easily result in loss of the ORU/end effector. The IEEM requires safeguards such that "no new satellites" are created.

Due to power, size and complexity constraints the latching mechanism shall be passive, requiring no electrical power to latch or release the end effector. The mechanism for Ranger NBV must be as similar as possible to the mechanism for Ranger TFX. Since the Ranger NBV version of the IEEM will operate in the NB environment, it must be waterproof. Therefore, electrical connectors between the end effector and the wrist are inappropriate.

Design Strategies

A method of identifying options for candidate designs was employed for the down selection process. The method chosen was the development of an options tree (Figure 4).

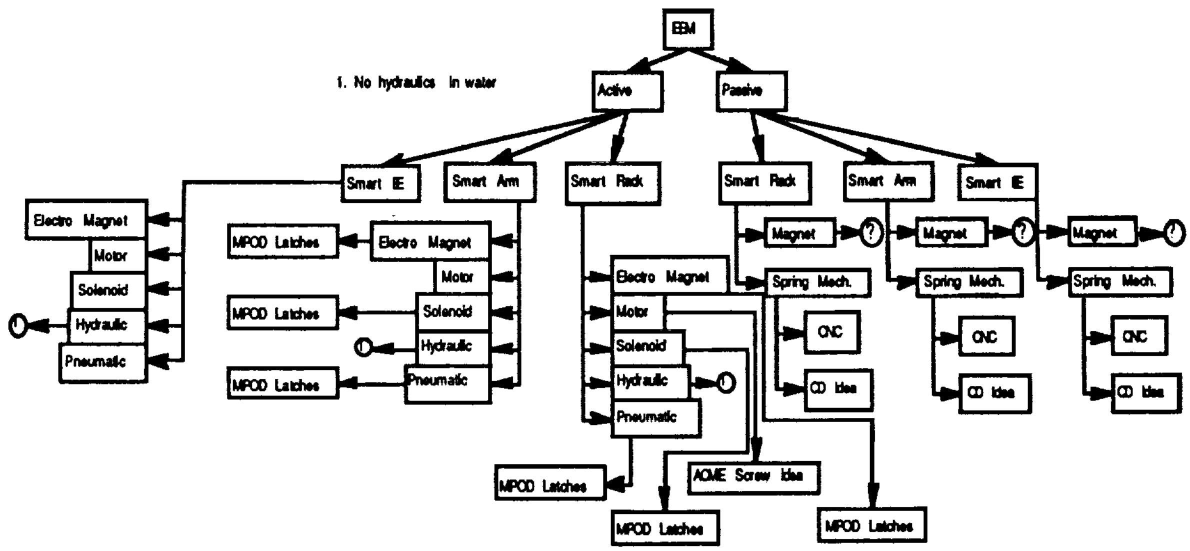

Figure 4. IEEM Options Tree

The options tree started from the general premise of needing a mechanism allowing Ranger to change the current end effector and flowed down to the specific candidates chosen. The process led to the selection of two candidate concepts, a taper design and a pneumatic connector-type design.

The first candidate IEEM is based on a torsional spring providing the force to rotate a cam and pin system (see Figure 5). The outer collar rotates relative to the inner post and the tool post, locking the tool post into the matching taper assembly. This provides the transmission path for the forces and torques to and from the end effector.

When removing the end effector, a set of fingers ride along a cam on the outside of the rotating collar forcing it to turn as the wrist is pushed forward into the storage rack. This turning action releases the end effector post from the manipulator and it is captured by a similar device on the storage rack side.

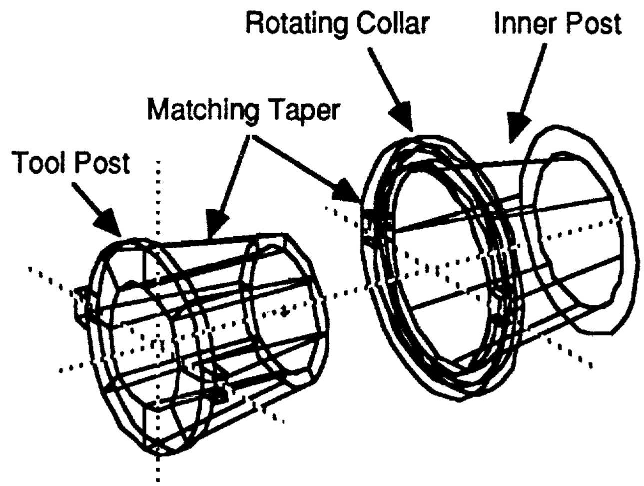

Figure 5. Taper Mechanism Description

The second candidate design is modeled after a pneumatic connector. This design applies a force using a spring loaded device to steel ball bearings in contact with the tool post (Figure 6).

A proof-of-concept article was manufactured demonstrating the functionality of this design. Due to cost considerations and ease of manufacture, some of the materials used were not those of the final design. The entire proof-of-concept article is made of aluminum. The prototype will include parts made from stainless steel for durability.

Figure 6 shows the second candidate IEEM in detail. The spring cavity is where the spring providing the holding force is located. The proof-of-concept version relies on 8, 3.175 mm (0.125 in) diameter springs in parallel to provide the holding force. The prototype version will have a custom-wound wave spring, 111 mm (4.375 in) in diameter. This approach ensures the candidate concept is valid before purchasing the custom wound spring. This provides a simple, low-cost method to evaluate the spring constant.

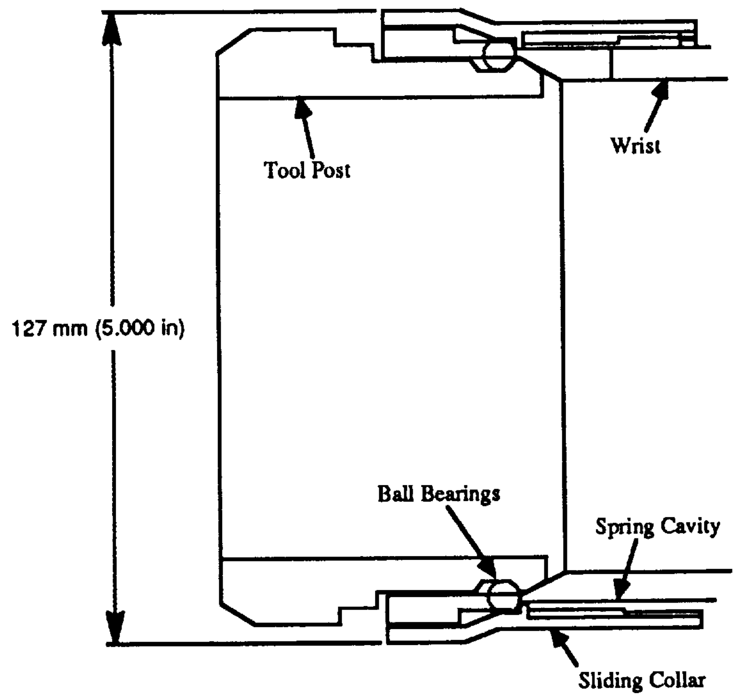

Figure 6. Latching Mechanism

The springs chosen for the proof-of-concept article are 110 kPa (16 psi). The sliding collar compresses 4.76 mm (3/16 in) during attachment and release operations. Applying the equation for a linear spring ($\vec{F} = k \cdot \Delta\vec{x}$) requires the arm to exert a maximum force of 13.3 N (3 lbf). The prototype version will have a spring constant of 55 kPa (8 psi). This softer spring will allow a greater range for the manipulator during the engagement process.

Figures 7 through 11 describe the engagement and release process:

Figure 7 shows the wrist aligned with the tool post and the sliding collar making contact with the retention finger.

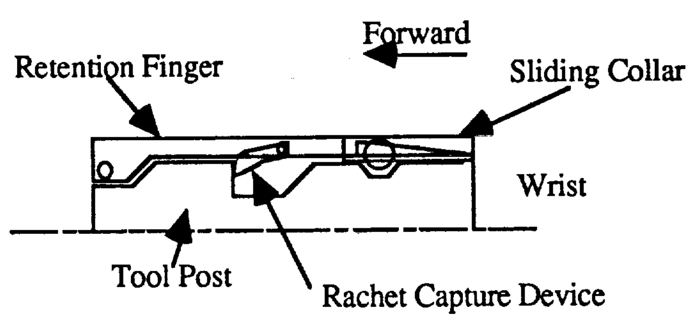

Figure 7. Latching the end effector

In Figure 8, the wrist has moved forward and the retention finger is compressing the spring inside the sliding collar. As the arm continues to push forward, the bevel at the end of the tool post engages the retention finger, pushing the spring loaded finger away. This motion allows the spring force in the sliding collar to move it forward. This wedges the ball bearings against the sliding collar and tool post, locking the end effector in place on the manipulator.

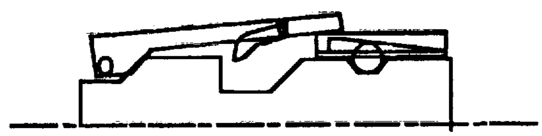

Figure 8. Latching the end effector

Next, the arm moves backward and removes the end effector from the storage rack as shown in Figure 9.

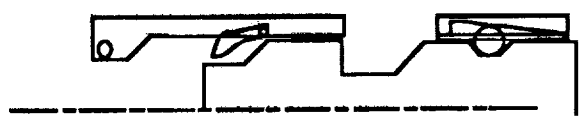

Figure 9. Removing the End effector from the storage rack

Figure 10 shows Ranger's wrist returning the end effector to the storage rack. As the wrist moves forward into the storage rack, the tool deflects a ratcheting capture device. When the arm moves the end effector far enough forward the capture device ratchets down. It now holds the end effector in the storage rack. During the forward motion, the spring in the sliding collar is also compressed by the retention finger. At the point of storage rack capture by the capture device, the spring in the sliding collar is compressed enough to free the wrist from the end effector.

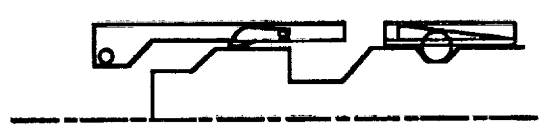

Figure 10. Re-inserting the end effector

At this point the manipulator can leave the end effector in the storage rack or to re-engage it, as shown in Figure 11.

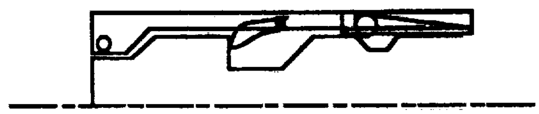

Figure 11. Latching the end effector and withdrawing the arm

Two motors and gear trains provide the required mechanical power to the end effector. The current motor design uses Inland motors attached to pancake harmonic drives to actuate the end effector. The prototype mechanism will include a candidate latching mechanism, as described above, as well as the motors and gear trains for the two tool drives (See Figure 12).

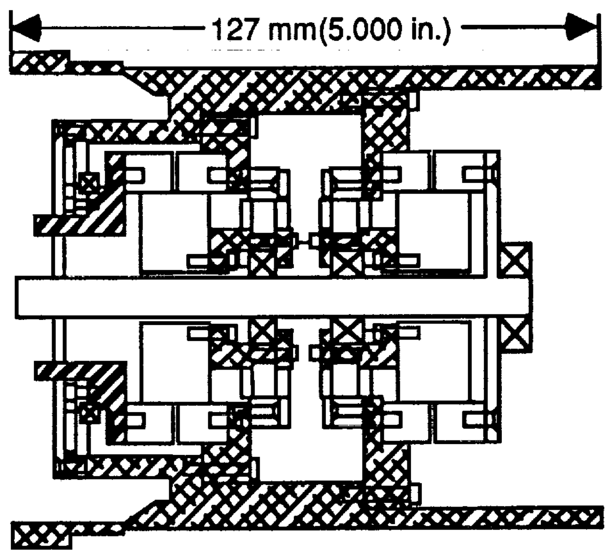

Figure 12. Concentric Tool Drives

Failure Modes

There are several possible modes that may cause complete failure of the candidate IEEM's. In the taper candidate design, the torsional spring performs all the work of engaging and releasing the tool. If the spring binds due to a temperature gradient or another reason, there is virtually nothing the operator can do to fix it.

The pneumatic connector-type candidate IEEM does not suffer from the spring reliability issue. It relies on the dexterous manipulator to provide the energy to make the engagement/release. It does, however, require the operator to maneuver the manipulator very precisely in order to place the end effector in the storage rack. If the wrist moves too far forward during the replacement operation, the retention fingers would disengage. The end effector would then be recaptured by the sliding collar on the wrist. If this occurs, the end effector replacement process would have to start again. Although not a concern in regards to losing the end effector or jamming the IEEM, the limited time in a single test session makes this a real problem, especially for Ranger TFX. Alleviating this failure mode, requires systems external to the IEEM. A force torque sensor upstream of the IEEM, along with visual cues, will determine when the engagement and release has taken place.

Testing

The testing the IEEM will primarily be accomplished in a fit and function manner. During assembly build up, the device will be thoroughly tested and then tested again during integration. Several load-bearing tests are needed to completely characterize he latching mechanism (Reference 3).

Conclusions

Although not complete, the proof-of-concept IEEM has demonstrated the feasibility of the chosen technology. The pneumatic connector-type candidate has several advantages over the taper candidate. These include: ease of manufacture, better packaging for the tool drives, and less reliance on a single point failure spring for all the engagement/release work. The manipulator provides the force to actuate the IEEM in the pneumatic connector-type design vs. a torsional spring in the taper design.

Future Work

The implementation of the IEEM for Ranger is proceeding rapidly. The schedule for the pneumatic connector-type candidate calls for a completed and integrated prototype on Ranger NBV by the end January, 1994. Results of the testing and integration will be incorporated into the presentation of this paper in May, 1994.

The taper candidate prototype design must be completed by February, 1994. Its fabrication and integration of the proof-of-concept article are scheduled for completion by April, 1994. The testing to determine which is the better mechanism should be completed by August, 1994. Two units of the chosen design should be available in October, 1994.

Acknowledgments

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