HAND CONTROLLERS FOR TELEROBOTICS ON INTERNATIONAL SPACE STATION (ISS)

Jeffrey W Hegg, Senior Engineering Fellow
Marion P. Smith, Manager

Honeywell Inc, Space Systems, Clearwater Florida USA

Abstract: Multiple robotic manipulators on Space Station use common manual controllers for teleoperation consisting of two three degree-of freedom hand controllers. One is a Translational Hand Controller (THC) and the other is a Rotational Hand Controller (RHC).

A review of the latest technologies for input devices for teleoperation is conducted. Applicability of these technologies to space based manipulators is discussed.

The characteristics and parameters for the Space Station Rotational and Translational hand controllers are presented.

The methodology to the approach for the Space Station hand controllers which minimizes development cost by employment of space-proven hardware of the same basic design and configuration as those on the Space Shuttle Remote Manipulator System and Flight Control System is discussed.

These hand controllers are incorporated on the ISS as part of the Spar RWS and also on the JEM RMS.

Further operational aspects of teleoperation is discussed which permits rapid adaptation by the astronauts to unstructured tasks. *Copyright © 1998 IFAC*

Key Words: Hand Controller, Space Station, Space Shuttle, Man-Machine Interface, Robotics.

1. INTRODUCTION

The hand controllers on ISS represent one of NASA's implementations of 'faster, better, cheaper' approaches to equipment for the ISS.

The established heritage for operation of manipulator systems in space is to utilize manually operated hand controllers to generate commands for robot arm movement. The following are examples of robotic systems that have flown in space:

- Space Shuttle Remote Manipulator System (RMS)
- MIR Russian Robotic System
- Rotex Shuttle Experiment
- Japanese Flight Demonstration (JFD).

2. HAND CONTROLLER TECHNOLOGIES

Various robotic systems are used for terrestrial applications. Manipulator systems are commonly used to perform challenging tasks in environments such as:

- Nuclear Processing
- Electric Utility Power Lines

- Undersea Operations
- Hazardous Waste Clean-up
- Medical Applications.

These manipulator systems typically perform complex tasks utilizing manually operated hand controllers via telemanipulation.

The technology issues associated with the control devices for teleoperated space based manipulators have been studied previously. Such aspects as:

- force reflection versus force/torque displays
- modes of operation
- restraint systems for microgravity
- volumetric considerations
- time delays

have been evaluated as discussed in various References 1 through 7.

Research institutions both in Europe and the United States (e.g., Sandia National Labs) have built and demonstrated advanced methods of robotic control incorporating autonomous movements through a previewed virtual workspace. Autonomous control of robotic manipulators to space applications does not require manual input devices such as hand controllers. This type of system is being built for the ISS as part of the European Robot Arm (ERA) by Fokker Space Systems.

Also, on the ISS, dexterous manipulators are used that are to be controlled via telemanipulation using the common hand controllers located in the Canadian and Japanese Robotic Workstations.

3. SELECTION OF ISS HAND CONTROLLERS

The technologies used in modern hand controllers have advanced significantly. The options for the hand controllers for ISS were evolved from the hand controller prototypes that were available in the late 80's. NASA Johnson Space Center led an extensive study on the Space Station Freedom program involving international participation of the Canadian Space Agency, NASDA, European Space Agency and other NASA centers to select the hand controllers. The Joint Evaluation Test Team (JETT) performed extensive lab testing with the astronaut office on various types of hand controllers:

- 2 x 3 Degree-of Freedom (DOF)
- 6 DOF Passive
- 6 DOF Active
- Master-Slave or Replica Type Controllers.

The result documented in Reference 8 was the selection of the 2 x 3 DOF configuration that is very similar to that used on the Space Shuttle Remote Manipulator System. The use of this configuration for all the controllers on the ISS, assures the commonality necessary to provide operator familiarity with any set of controllers.

Honeywell is supplying these controllers for the ISS. The parameters for each of the controllers is discussed in the following section.

4. ISS HAND CONTROLLER DESCRIPTION

The hand controllers are mounted in multiple workstations onboard the ISS:

- Mobile Servicing System (MSS) – Robotics Work Station (RWS)
- Japanese Equipment Module (JEM) – Robotic Manipulator System (RMS)

The hand controllers provide a means for the IVA crew to manually control the manipulator motion. The International Space Station(ISS) hand controllers consist of the following components:

- Rotational Hand Controller (RHC)
- Translational Hand Controller (THC)

4.1 Rotational Hand Controller

The RHC is a three axis, crew-operated, passive hand controller weighing 9.5 lb and 7.5 x 4 x 8.5 inches (not including the grip) in size (see Figure 1).

The RHC contains 6 transducers: 2 redundant transducers sense pitch deflection, 2 sense roll deflection and 2 sense yaw deflection. The transducers produce a continuous analog electrical signal proportional to deflection of the RHC Grip. The transducer signals are demodulated internal to the RHC to provide a dc analog output proportional to grip deflection. The RHC requires separate electrical inputs of $\pm$12 Vdc and 26 Vrms 1500 Hz for each of the dual outputs requiring a total of 3.0W.

Each RHC has a maximum mechanical dead band of $\pm$0.25 degree in all three axes. Displacement of the RHC Grip beyond the dead band requires the application of a breakout force followed by a linearly increasing force until the mechanical hardstop is reached. Internal springs produce a continuous linear restoring force which will return the grip from any displacement to its neutral position when external forces are reduced or removed.

Max Displacement (Degrees)		Torque for Max Displacement (Inches-lb)	Pivot Location
Roll	$\pm$14.0	$\pm$15.5	Base
Pitch	$\pm$14.0	$\pm$10.5	Palm
Yaw	$\pm$10.0	$\pm$8.2	Palm

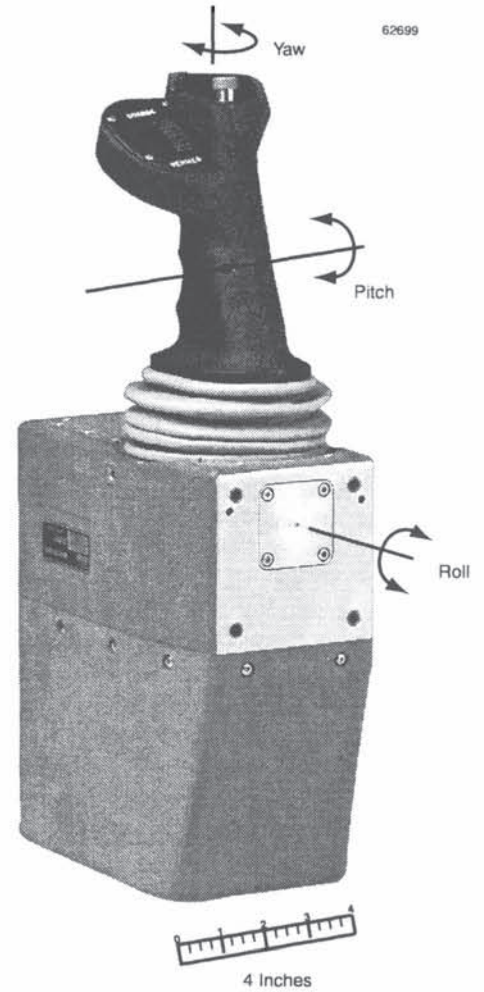

Figure 1. Rotational Hand Controller

Several switches are located on the RHC Grip. A thumb operated **rate hold switch** is used to maintain the manipulator velocities in all axes at the moment the rate hold switch is depressed. Grip displacements on the RHC and THC can be released and constant velocities will remain. Subsequent depression of the rate hold switch will deactivate the rate hold mode. A **vernier/ coarse** two position thumb operated slider switch selects tip/joint velocity ranges, either coarse or vernier. The reason for the vernier rate is to give greater control sensitivity when required. Annunciation of the vernier select is provided by the MIN RATE flag and the analog rate-meter display scale flag. A trigger switch is used for the payload **capture/release** function. The switch is a pivoting trigger where the lower portion is used to provide a capture discrete signal and the upper portion is used to provide a release discrete. The release motion is protected by a trigger guard that requires the astronaut to lift the guard out of the way prior to activating the release discrete. See Figure 2.

4.2 Translational Hand Controller

The THC is a crew operated passive hand controller that weighs 7.0 lb and is 7.8 x 4.3 x 5.5 inches in size (see Figure 3).

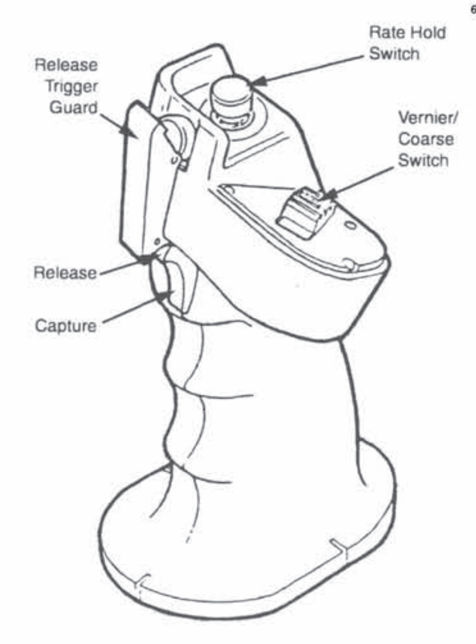

Figure 2. Grip Switch Configuration

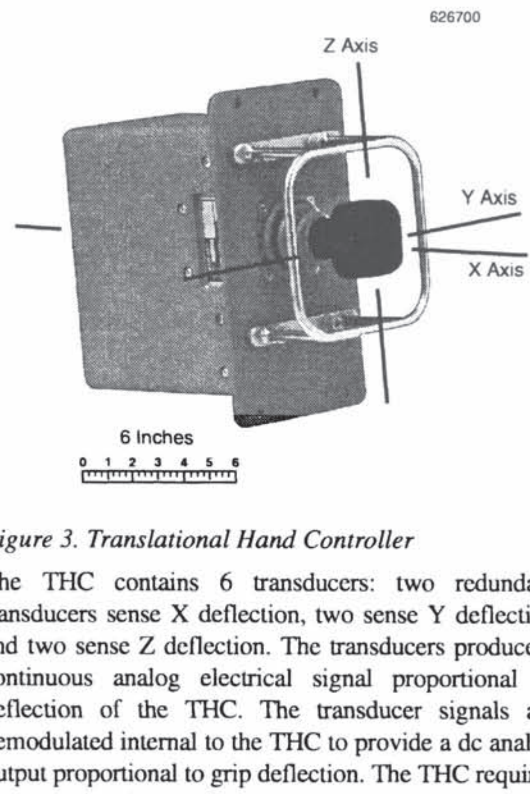

Figure 3. Translational Hand Controller

The THC contains 6 transducers: two redundant transducers sense X deflection, two sense Y deflection and two sense Z deflection. The transducers produce a continuous analog electrical signal proportional to deflection of the THC. The transducer signals are demodulated internal to the THC to provide a dc analog output proportional to grip deflection. The THC requires separate electrical inputs of $\pm$12 Vdc and 26 Vrms 1500 Hz for each of the dual outputs requiring a total of 3.0W.

Each THC has a maximum mechanical dead band of $\pm$0.05 inch in all three axes. Displacement of the THC Grip beyond the dead band requires the application of a breakout force followed by a linearly increasing force until the mechanical hardstop is reached. Internal springs produce a continuous linear restoring force which will return the grip from any displacement to its neutral position when external forces are reduced or removed. The pivot axes are configured to minimize interaxis cross coupling.

Max Displacement (Inches)		Force for Max Displacement (lb)
X	± 0.5	1.2-2.5
Y	± 0.5	0.8-1.5
Z	± 0.5	0.8-1.5

The THC grip is a cube shape surrounded by an index ring. This grip configuration allows operation by either hand but is intended to be primarily for left hand operation while the RHC is being operated by the right hand. The index ring allows the THC motion to be achieved with finger operation rather than requiring the grip be grasped by the hand.

5. OPERATIONAL CONSIDERATIONS OF SPACE BASED MANIPULATORS

The migration of terrestrial robotics to space based robotics has not occurred because of the unstructured work site environments the manipulators typically encounter. Environments where the work site is unstructured require manual control of the manipulator system with hand controllers. Autonomous manipulator movement works best in a structured work site environment.

5.1 Space Shuttle RMS

For Space Shuttle RMS operation, the work site is not defined well enough to allow autonomous manipulator movement thereby requiring astronauts to manually perform the robotic operation portion of tasks such as the repair of the Hubble Space Telescope using hand controllers.

As described in reference[9], the RMS has the following control modes:

- Manual augmented
- Automatic
- Single joint drive
- Direct drive
- Backup

Manual augmented modes of control enable the operator to direct the end-point of the arm using the RHC and THC to provide end effector translational and rotation rate commands in selected coordinate frames. The manipulator control algorithms process the hand controller signals into a rate demand to each joint on the arm. The operator can carry out manual augmented control on the arm using one of the following coordinate systems:

- Orbiter unloaded
- End effector
- Payload
- Orbiter loaded

When the manual **Orbiter unloaded mode** is selected, rate commands through the THC will result in motions at the tip of the end effector that are parallel to the Orbiter body axis coordinate system and compatible with the up/down, left/right, in/out direction of the THC. Commands from the RHC will result in rotation at the tip of the end effector, which are about the Orbiter rotation at the tip of the end effector, which are about the Orbiter rotational axis coordinate system.

When the manual **end effector mode** is selected , rate commands from the THC will result in motions at the tip of the end effector that are parallel to the axes of the end effector whose origin is located at the point of resolution (the end of the end effector) of the resolved rate algorithm. The purpose of the manual end effector mode is to maintain compatibility at all times between axial rate commands at the THC and RHC and the instantaneous orientation of the end effector. The end effector mode is primarily used for the grappling operations. The end effector mode is used in conjunction with a wrist-mounted TV camera which is oriented with the end effector coordinates and which rolls with the end effector. The scene from the TV camera, presented on the TV monitors, will have viewing axes that are oriented with the end effector coordinate frame. This results in compatible motion between the rate commands applied at the hand controller and movement of the background image presented on the TV monitor. Up/down, left/right, in/out motions of the THC result in the same direction of motion of the end effector as seen on the TV monitor, except the background in the scene moves in the opposite direction. Therefore, the operator must remember to use a "fly to" control strategy and apply commands to the THC and RHC that are toward the target in the TV scene.

When the manual **payload mode** is selected , a coordinate system is established (called the payload coordinate system) whose origin is within the payload and which is fixed with respect to the payload. In this system a point within the payload is the point of resolution of the resolved rate algorithm. Rate commands from the THC will result in motions at the center of the payload that are parallel to the payload coordinate system, and rate commands from the RHC will result in motions at the center of the payload which are rotations about the payload coordinate system. The purpose of the manual payload mode is to maintain compatibility at all times between axial rate commands at the THC and RHC and the instantaneous orientation of the payload axes with respect to the Orbiter referenced frame. The manual payload mode is intended to enable the operator to translate the payload in directions that correspond to the orientation of its axes, and to rotate the payload about its own axes, rather than those of the Orbiter or the end effector.

When the manual **Orbiter loaded mode** is selected, the rate commands from the THC will result in motions to the center of the payload that are parallel to the Orbiter body axis coordinate system. Rate commands from the RHC will result in motions at the center of the payload that are rotations about the orbiter rotational axis coordinate system. The manual Orbiter loaded mode is intended to enable the operator to translate and rotate a payload about the Orbiter axis with the point of resolution to the resolved rate algorithm being within the payload. This allows for pure rotations of the payload, which is useful for berthing operations.

The **manual augmented modes** of control are used to perform the following tasks:

- Grapple a payload
- Maneuver a payload into/out of payload retention fittings or handling aids
- Grapple or stow a special purpose end effector on-orbit

5.2 International Space Station Robotics

Telerobotic operation will be similar to Space Shuttle RMS operation.

For Space Station, the work site will be relatively structured allowing for utilization of autonomous manipulator movement for many tasks. However, there will be circumstances where unplanned events require the manual interventions of the astronauts. This manual control is accomplished with minimum program risk by incorporation of the proven 2 x 3 DOF hand controllers configuration as part of the Intervehicular Activity(IVA) workstation. Coordination between manual IVA manipulator operation without direct viewing and EVA astronauts is accomplished with operating procedures already developed and established on the Space Shuttle program.

The utilization of pre-planned (previewed) autonomous manipulator movement on Space Station is feasible because of the structured work environment. In the likely event that manual control is needed, utilization of IVA hand controllers common between all the IVA robotic work stations on the ISS results in minimum program risk.

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