HARDWARE INTERFACE UNIT FOR CONTROL OF SHUTTLE RMS VIBRATIONS

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KEY WORDS AND PHRASES
End point control unit, robotics, vibration isolation.

ABSTRACT
Vibration of the Shuttle Remote Manipulator System (RMS) increases the time for task completion and reduces task safety for manipulator-assisted operations. If the dynamics of the manipulator and the payload can be physically isolated, performance should improve. Rockwell has developed a self-contained hardware unit which interfaces between a manipulator arm and payload. The End Point Control Unit (EPCU) is built and is being tested at Rockwell and at the Langley/Marshall Coupled, Multibody Spacecraft Control Research Facility in NASA's Marshall Space Flight Center in Huntsville, Alabama.

INTRODUCTION
Robot manipulators with long flexible links, such as the Space Shuttle RMS, are susceptible to unwanted vibrations. These vibrations increase task completion times and reduce task safety. To reduce the vibrations, many arm controller architectures have been presented, including input shaping, adaptive control schemes, and fuzzy logic control. These methods show improved manipulator performance. This may be an acceptable solution for ground-based manipulators. For the Shuttle RMS, however, redesign of the controller would require a re-certification for space flight of both RMS software and hardware, an extremely expensive proposition.

Instead of redesigning the manipulator controller, a hardware device located between the arm and its payload can be used to physically decouple the system dynamics. Improved performance can be realized because the dynamics of the payload cannot adversely affect the manipulator arm, and vice-versa. A complete decoupling of the manipulator from the payload is not desired: the payload must still respond to desired motion of the arm. An intermediate level of isolation is desired.

Rockwell has developed an end-effector for the NASA robotic tile

* This work was partially funded by NASA Langley Research Center Contract NAS1-19243 to Rockwell Space Systems Division and was monitored by Dr. Raymond Montgomery of LaRC Spacecraft Controls Branch.
processing system (RTPS) which
decouples the dynamics of the elevation
arm from the force applied to the Shuttle
tiles during rewaterproofing oper-
ations[1]. The sections presented below
briefly describe the RTPS end-effector
and its derivative, the EPCU.

THE RTPS END-EFFECTOR AND
THE EPCU

The RTPS end-effector isolates the
damping of the RTPS elevating arm from
the shuttle itself. In this way, the nec-
essary constant force can be maintained
on the Shuttle tiles. The end-effector
uses a stepper motor for one degree of
linear actuation, and an encoder and a 6-
axis force/torque sensor for control
feedback. This end-effector has been
tested under numerous adverse
conditions such as attempting to maintain
a constant contact force with a Shuttle
tile while being subjected to vibratory
inputs [2]. Because the tests illustrated
the utility of this device, the next
generation end-effector (the EPCU) was
designed to meet a variety of vibration
isolation and dynamic decoupling
problems.

The current design of the EPCU is
shown in Figure 1. The unit has four

Figure 1: The Rockwell EPCU
major subcomponents: 1) stepper motor
drive mechanism, 2) constraints for linear
motion, 3) force and position feedback
sensors, and 4) controller hardware and
software. The control software is
described below. The EPCU is a
completely self contained unit and needs
no inputs from the manipulator
controller.

THE EPCU DECOUPLING
CONTROL PROBLEM

The EPCU control configuration is
illustrated in Figure 2. Unlike the
classical control problem of reducing the
effects of the disturbance signal, the
current system needs to react to certain
disturbance signals (the undesired
manipulator arm motions) yet allow
other signals to pass to the payload. The
disturbances to be suppressed are those
close to the natural frequency of the
RMS which are caused by structural
bending or flexibility of the manipulator
links.

The controller in Figure 2 consists of
two inputs and one output. Input signals
are from the force sensor and the shaft
encoder. The output of the controller is a
position or velocity signal which
commands the stepper motor driving the
EPCU.

Four control algorithms have been
developed and tested with the hardware
on a small-scale test bed in Rockwell's
Robotics Laboratory. The first controller
uses the force feedback to compute a
desired EPCU deflection based upon a
given spring stiffness value K for the
unit. The current EPCU position is
subtracted from this desired position to
compute an error signal, which is mul-
tiplied by a gain to command the EPCU

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motor as a velocity signal. The second controller uses this same algorithm but conditions the force feedback signal by subtracting the current value from the mean of the previous n values. This eliminates the effects of both static forces and force sensor drift. The third controller conditions the force feedback signal with a bandpass filter and a delay filter to allow only those frequencies deemed to be "problem" frequencies to be controlled by the EPCU. This feedback is used in a standard PD controller. The fourth controller uses fuzzy logic to determine the velocity output from force and position feedback signals.

Each of these controllers suppressed the undesirable vibrations and disturbances. Some gain adjustments were required for different payload weights. The adaptivity of the controllers can be managed via gain scheduling.

ROCKWELL TESTBED TEST RESULTS AND CONCLUSIONS

Figure 3 shows the results of a typical EPCU test run at the Rockwell testbed, illustrating the resultant payload motion from a 1 Hz vibration input. The payload motion response to the vibratory input is reduced by over 50% by using the EPCU. Other tests show the favorable response to a sinusoidal input superimposed with a constant velocity input. Test run data shows that the motion characteristics of the payload are improved, and that the unit can partially decouple the system dynamics, demonstrating a successful implementation of the EPCU to reduce the effects of unwanted system vibrations upon system performance. After testing at Rockwell, the unit was integrated into the Langley/Marshall flat-floor testbed, which is described below.

THE LANGLEY/MARSHALL TESTBED

The NASA Langley/Marshall Coupled, Multibody Spacecraft Control Research Facility contains a 2-link, 3-joint planar manipulator supported by air-bearings on a flat-floor test facility [3](see figure 4). The manipulator payload is a large sled supported by air bearings, controlled by onboard control motion gyros (CMGs) and air reaction jets. The system represents the Shuttle RMS docking with a controlled structure such as the space station. The links are 9.75 feet in length, and are designed to have a resonant frequency approximating that of the RMS. The payload weighs approximately 3700 lbs. Currently, the system shows vibrations and unwanted transient motions for a typical motion test run.

The EPCU is inserted between the manipulator arm and the payload, as shown in figure 4, and the same tests which showed unsatisfactory behavior were performed to determine if the EPCU unit improves the system performance. A fifth controller was developed to augment the first controller with the additional input of the desired velocity.
trajectory of the manipulator arm in the direction of EPCU actuation. Based upon this input, feedforward signals were generated to help the EPCU react faster to discontinuities in the velocity profile. Test results at the flat floor facility show improved performance both in terms of reduced forces on the payload and improved position tracking.

APPLICATIONS AND FUTURE WORK

The utility of the interface unit on the Shuttle RMS is evident from the above discussions. Further space applications of the device include isolation of antennas and solar panels from a satellite and isolation of payloads from Shuttle vibrations during ascent flight. Similar vibration isolation/control and dynamic system decoupling is needed for other applications of long manipulator arms, including Department of Energy waste cleanup as well as industrial uses. The device may also prove beneficial for reducing vibrations and impact forces in devices with less accurate control, such as cranes and winches. The implementation of a self-contained or near-self-contained active interface device for these applications will improve system performance without intelligent human interaction or advanced system control techniques. An additional application is in the suspension of automobiles, providing for a smoother ride and improved performance of the vehicle for a large range of loads.

REFERENCES

