HARDWARE INTERFACE UNIT FOR CONTROL OF SHUTTLE RMS VIBRATIONS*

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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

processing system (RTPS) which decouples the dynamics of the elevation arm from the force applied to the Shuttle tiles during rewaterproofing operations[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 necessary 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
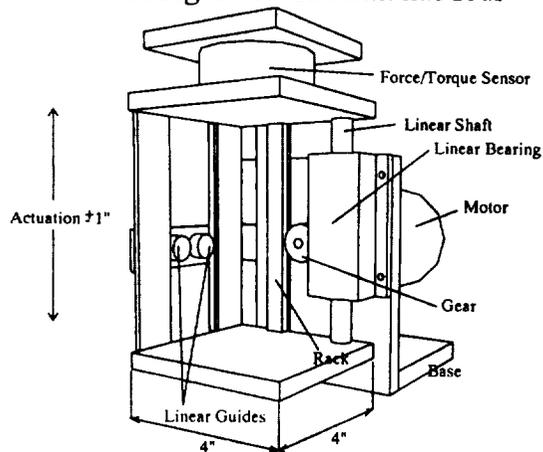

Figure 1: The Rockwell EPCU major subcomponents: 1) stepper motor drive mechanism, 2) constraints for linear motion, 3) force and position feedback sensors, and 4) controller hardware and software. The control software is described below. The EPCU is a completely self contained unit and needs no inputs 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 multiplied by a gain to command the EPCU
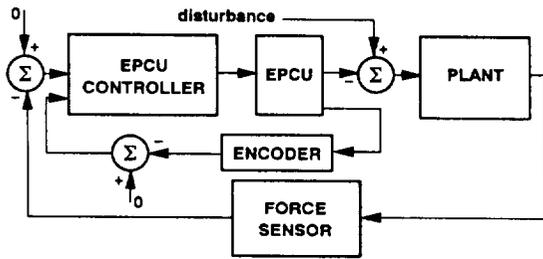
Figure 2: Control Structure Block Diagram

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
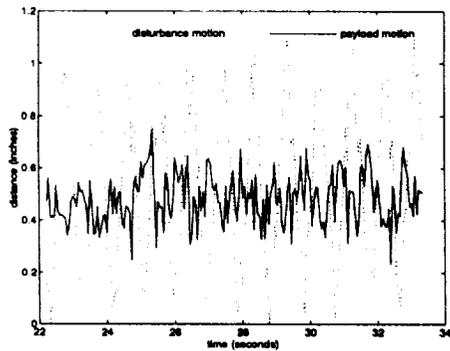
Figure 3: 1Hz Vibration Input and EPCU Motion in Rockwell Testbed

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.
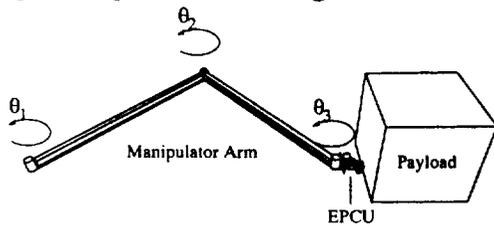

Figure 4: EPCU Integrated at Langley/Marshall Testbed

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 implemen-tation 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 addition-al application is in the suspension of automobiles, providing for a smoother ride and improved performance of the vehicle for a large range of loads.

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