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MICROGRAVITY MANIPULATOR DEMONSTRATION*

Andrew S. Brush
Sverdrup Technology, Inc.
(Lewis Research Center Group)
NASA Lewis Research Center

ABSTRACT

A test rig is being prepared that will be used to demonstrate and evaluate approaches to limiting manipulator base reactions in microgravity environments. The demonstration will include a 4-degrees-of-freedom (DOF) arm, control computing facilities, and a base reaction measurement system.

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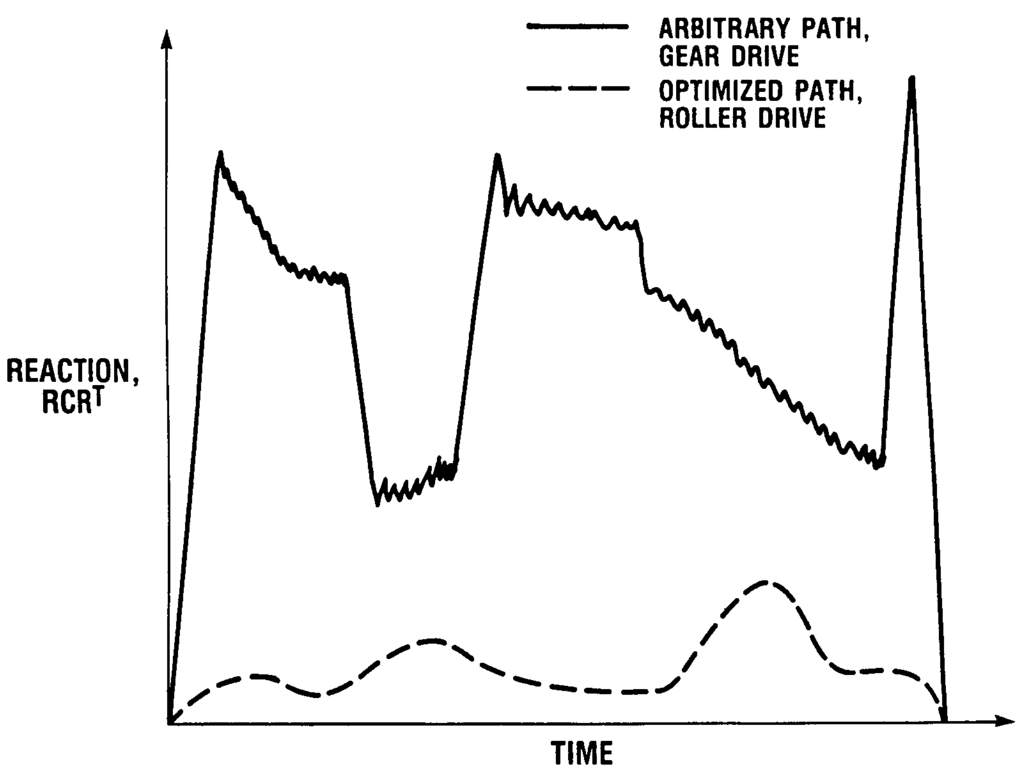
OVERVIEW

REACTION FOR SPECIFIED END-EFFECTOR PATH

In order to curtail the accelerations imparted to spacecraft by space experimental activities, schemes have been developed for reducing the reactions at the bases of robotic devices used for manipulation and motion on space platforms. These call for the application of robotic joints combining smooth operation with zero backlash, to reduce vibration, and the use of path optimization strategies to control base reactions due to gross motion. Although there is theoretical and numerical evidence that these concepts are valid, a hardware demonstration is desirable.



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MICROGRAVITY MANIPULATOR DEMONSTRATOR
LABORATORY SETUP

The Microgravity Manipulator Demonstration will contain four main elements:

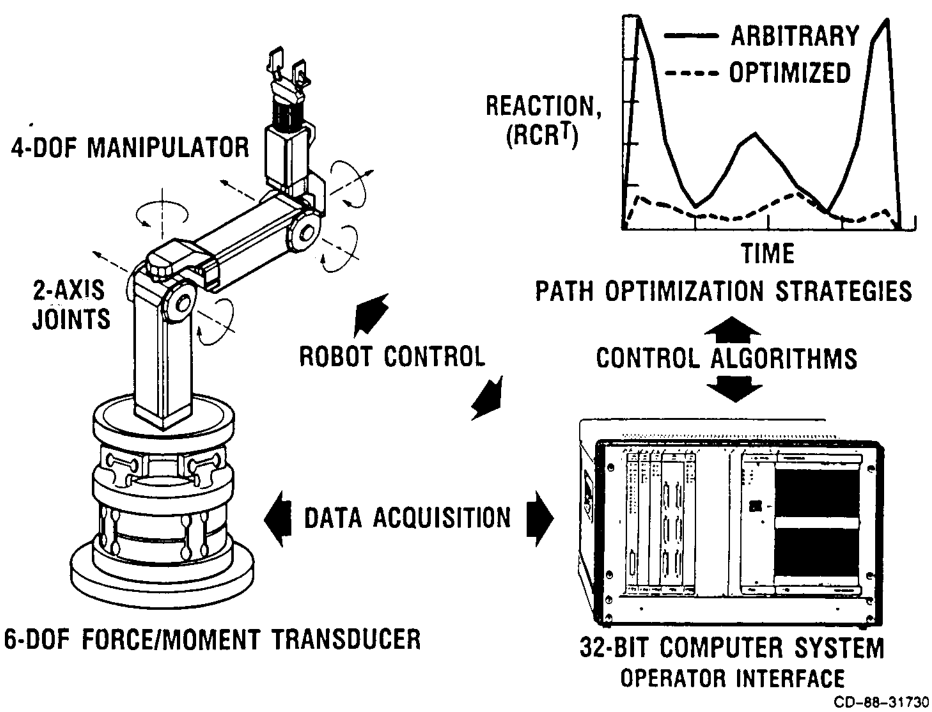
(1) A 4-DOF robotic arm utilizing traction-driven joints. These joints are expected to cause minimum vibration and have insignificant backlash.

(2) Data processing hardware based on VME bus architecture employing Motorola 68020 processors to implement arm control. In addition to providing closed-loop position and velocity control, processing capability will be available for path-optimization programs. Control software will be made as modular as possible to facilitate parallel processing. The bus architecture will allow future expansion through addition of processor or data acquisition boards.

(3) Optimization strategies that will select the best trajectory through joint space for a required end effector path in order to have minimum base reaction. These algorithms will be interchangeable modules in the control software to allow easy switching of optimization methods.

(4) A base reaction measurement system that will allow quantitative determination of the differences in reaction levels between optimized and unoptimized trajectories.

This demonstration will contribute valuable test data for developers of path optimization strategies, provide experience with programming techniques for integrating position control and trajectory optimization, and leave a reaction measurement test bed that will be useful to future microgravity robotics research.



POSTER PRESENTATION

OBJECTIVES

The Microgravity Manipulator Demonstration is being developed in order to facilitate assessment of hardware, software, and theoretical approaches to providing a manipulation capability for space microgravity experimentation.

The demonstration will provide quantitative evaluation of strategies for limiting manipulator base reactions and allow Lewis personnel to develop a knowledge base of experience with robotic controls for reduction of base reactions. Increased practical experience in this field is essential to the implementation of reaction-limited robotics in space.

The demonstration will also provide the opportunity to evaluate traction-driven robot joints.

- **DEMONSTRATE (PROOF OF CONCEPT) PATH OPTIMIZATION FOR LIMITING REACTIONS DUE TO MANIPULATOR MOTION**
- **DEVELOP AND EVALUATE CONTROL PROGRAMS FOR MICROGRAVITY MANIPULATORS**
- **EVALUATE TRACTION DRIVE JOINT TECHNOLOGY**

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APPROACH

The test rig must be able to provide all capabilities required to meet the objectives stated previously. This will require

(1) A multi-DOF robot arm

(2) Software implementing optimization strategies to reduce base reactions

(3) A data processing facility capable of providing full control of the arm, managing data acquisition, and running optimization programs under test

(4) A modular approach to control software that will allow easy substitution of different strategies for accomplishing the objectives of robot control

(5) A means of measuring the reactions at the base of the robot in order to evaluate the success of the reaction-limiting scheme

- **MULTI-DOF MANIPULATOR ARM UTILIZING 2-DOF TRACTION JOINTS**
- **STRATEGY TO OPTIMIZE JOINT TRAJECTORIES TO MINIMIZE BASE REACTIONS**
- **HIGH-SPEED, 32-BIT, MULTIPROCESSOR CONTROL HARDWARE**
- **MODULAR CONTROL SOFTWARE**
- **MEASUREMENT OF BASE REACTIONS**

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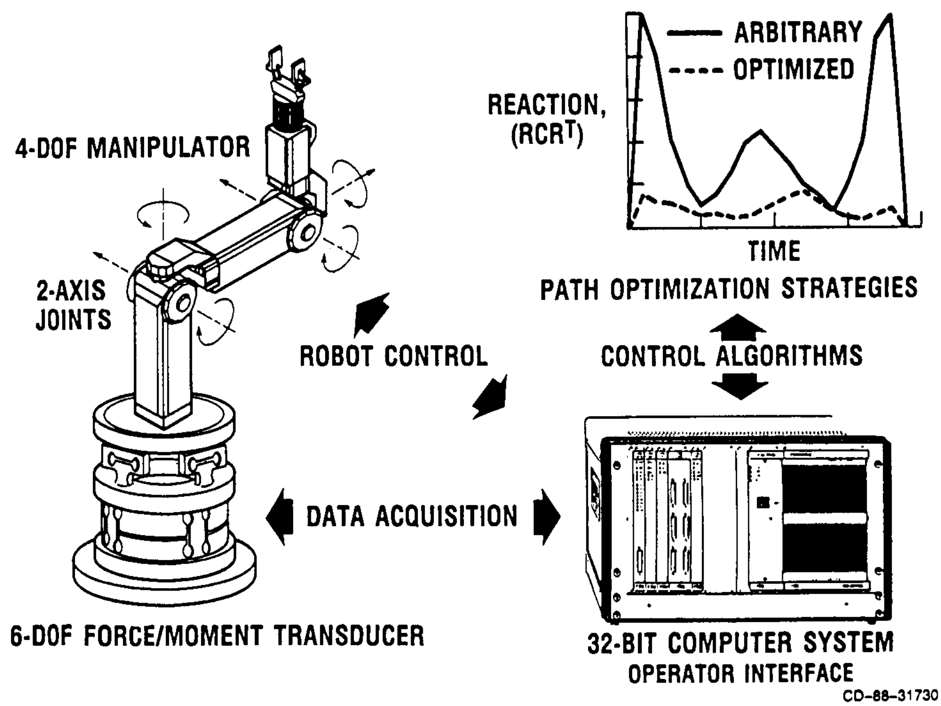
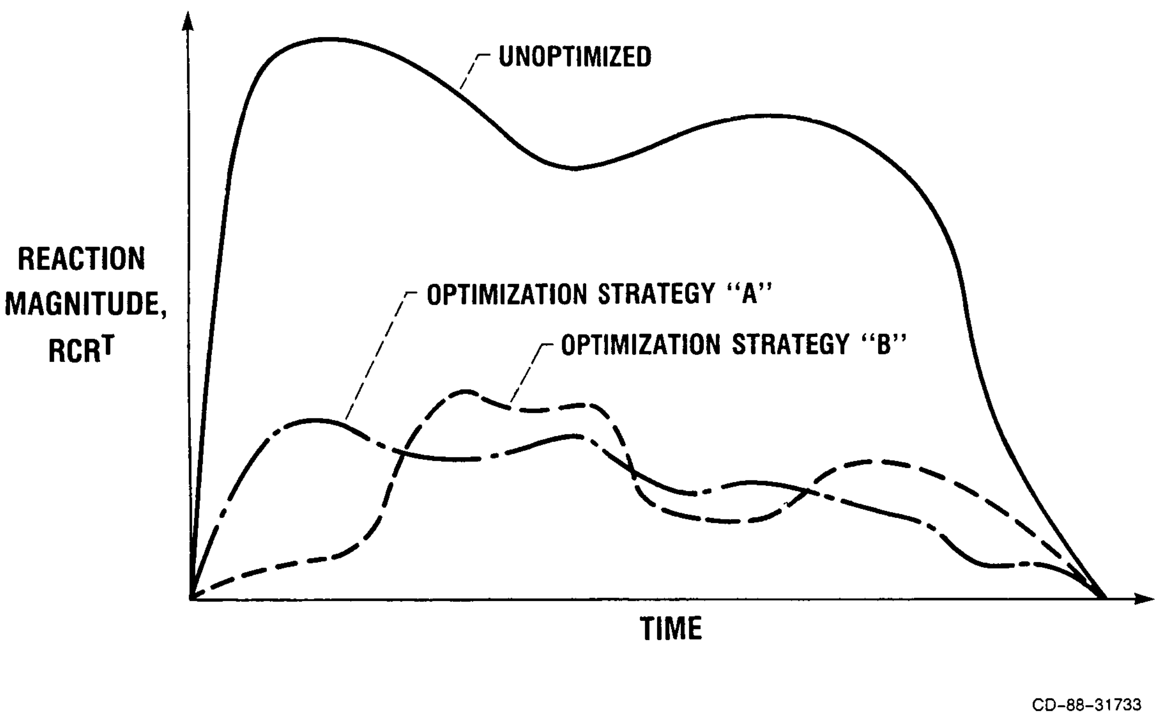


TEST PLAN

Once the control system is satisfactorily debugged, strategies for minimization of base reactions will be evaluated by executing point-to-point motions of the end effector using standard and optimized trajectories in the joint space. The measured base reactions will be compared to determine the extent to which dynamic forces are mitigated.



BASE REACTION MEASUREMENT - PERSPECTIVE

Until researchers became interested in experiments that take advantage of the low acceleration levels available in on-orbit spacecraft, there was no particular concern over the possible effects of small accelerations due to forces imparted by experiments or associated manipulators. Designers of the EURECA space platform discovered that they wanted to know the characteristics of the acceleration caused by each experiment that would fly on EURECA, so that they could asses the effects on other experiments. They were not able to develop a suitable 6-DOF force-moment transducer, however, so they recorded vibration levels at the attachment points of each experiment and calculated the forces using their knowledge of the dynamics of the experiment frame and the supporting structure. This was not an accurate method because of the estimation involved in determining the dynamic characteristics of the structures.

Some 6-DOF transducers have been developed that are apparently suitable for dynamic measurement of robot base reactions to the desired accuracy. The direct measurement of reactions is preferable and will be used in the demonstration.

- **SMALL SPACECRAFT ACCELERATIONS NOT A MAJOR CONCERN UNTIL THE ADVENT OF μG EXPERIMENTS**
- **REDUCING SOURCES OF FORCE IMPROVES μG ENVIRONMENT**
- **HOW CAN WE MEASURE SMALL DYNAMIC FORCES?**
  - **ACCELEROMETERS—REQUIRE PRECISE KNOWLEDGE OF DYNAMIC OF TEST ARTICLE AND SUPPORTING STRUCTURE**
  - **DIRECT MEASUREMENT OF FORCE USING 6-DOF TRANSDUCER**

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SIX-DOF TRANSDUCER CONSTRUCTION

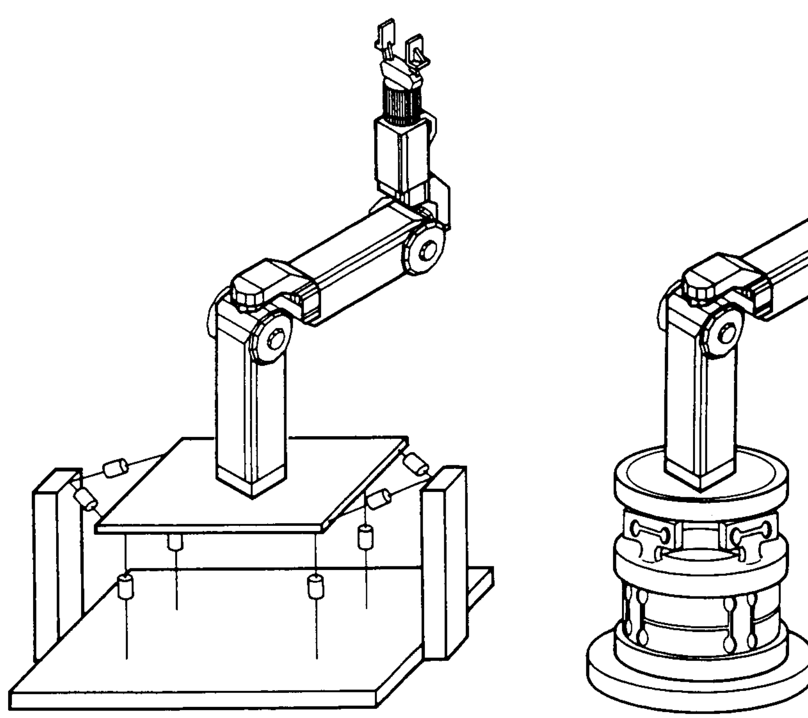
The construction of a 6-DOF transducer involves constructing a structure with predictable stiffness to forces applied at the attachment point and then instrumenting it to determine the strain or displacement in enough (six minimum) directions to fully determine the load.

Strut-type transducers attempt to resolve all forces and moments into purely axial loads in struts supporting an attachment flange (load application point).

One popular type of robust transducer uses eight flexures to measure the horizontal and vertical forces in perpendicular planes. This type may be stiff and strong but will have more crosstalk than a strut-type transducer.

Any shape of flexure may be used, as long as at least six orthogonal components of displacement can be measured with sufficient resolution. The previous types of fixtures are successful because they contain areas of high enough strains to allow use of electrical resistance strain gages.

High-precision displacement measurement techniques may present opportunities to use unconventional flexure designs.



STRUT TYPE TRANSDUCER **MULTIPLE FLEXURE TRANSDUCER**

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BASE REACTION MEASUREMENT - DATA REDUCTION

Measurement of forces arising from the motions of the manipulator and its payload are complicated in an earth-bound laboratory by the presence of static loads due to gravity. In the case of a manipulator, the static moments in the plane of the floor (M_x and M_y) are determined by a nonlinear function of the joint angles. This static component of the measured load must be subtracted from the total measured reaction:

$$R_t(t,\Theta) = R_d(t) + R_s(\Theta)$$

where $R_s(\Theta)$ must be known for all possible points in the joint space.

The interpolation error caused by using a lookup table with a reasonable number of points (<10 000) will be excessive, so we need to develop an equation for the $R_s(\Theta)$. This equation is a function of Θ, having as parameters the mass distribution of the arm segments. We will eliminate having to estimate the mass distributions by fitting an equation of the proper form to experimental data.

The present demonstration does not include real-time feedback of reaction, but this may be possible if processing resources are sufficient.

- **STATIC BASE FORCES DUE TO GRAVITY MUST BE IGNORED**
- **GRAVITY MOMENT IS A NONLINEAR FUNCTION OF JOINT ANGLES**
- **NEED TO KNOW GRAVITY MOMENT AT ALL POINTS IN JOINT SPACE**
  - **LOOKUP TABLE IS IMPRACTICAL**
  - **PARAMETERS IN EQUATIONS CANNOT BE EXACTLY DETERMINED ANALYTICALLY**
  - **ANSWER: USE PARAMETER IDENTIFICATION TECHNIQUES**
- **EQUATIONS ARE COMPUTATION INTENSIVE...**
  REAL-TIME REACTION FEEDBACK MAY REQUIRE ADDITIONAL PROCESSOR

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CONCLUSIONS AND BENEFITS

This demonstration will provide proof of concepts that will reduce robot base reactions by optimizing joint trajectory. Additionally, it will contribute experience with controls and hardware for microgravity manipulation to a knowledge base that will benefit designers of hardware for space experiments.

The force measurement system and computer system will be available after the 4-DOF demonstration for research using other types of manipulators.

- **KNOWLEDGE BASE WILL BENEFIT DESIGNERS WHO REQUIRE REACTION LIMITATION**
- **FORCE MEASUREMENT SYSTEM AND CONTROL DATA FACILITY WILL BE AVAILABLE TO TEST FUTURE MANIPULATORS AND ACTUATORS**

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