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This instrumentation award funded the purchase of a strain gauge instrumentation system, piezoelectric actuator system, a pneumatic thruster control system and a digital AD/DA controller system (Systolic System, Inc., Optima 3 nonlinear robotics controller) for use in experiments in identification and control of flexible structures modeled by partial differential equations. This equipment, combined with existing vibration suppression, slewing control and testing facilities provides a unique identification and control facility for flexible structures. The piezoelectric devices combined with existing electric motors, proof mass actuators and accelerometers provide an excellent facility for examining the theory related to active structures. In particular, experiments have been design and initial testing begun on vibration suppression during slewing control of an active truss. (JES)

In addition, the experimental facilities funded by this equipment grant have serviced the AFOSR sponsored Center for Control Sciences at Brown Univesity through the AFOSR University Research Initiative Program.

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FINAL REPORT ON

CONTROL STRUCTURE INTERACTION INSTRUMENTATION

A Proposal Funded Under The

DOD University Research Instrumentation Program

Grant No. AFOSR-89-0143

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Introduction

The funds received for this equipment proposal were used to purchase equipment to support research in control structures interaction. This equipment purchased consisted of a nonlinear robotics controller which allows multi input/multi output control, via real time implementation by parallel processing. Several other associated instrumentation devices were also purchased including a digital oscilloscope, a 386 class PC to drive the nonlinear controller and piezoelectric actuators. Miscellaneous funds were also provided for strain gauge instrumentation as well as fabrication costs. The following describe several experiments that have been constructed and set up with these monies.

T - Truss

A 1.5 meter long truss in the shape of a "T" was constructed in a cantilevered configuration as illustrated in figure 1. This truss was then instrumented with accelerometers and a proof mass actuator. The actuators and sensors can be conviently placed at any of the nodes of the frame. This truss is constructed of space realiazable links and joints and is lightly damped. It is made of aluminum alloy and has a total mass of 5.335kg. The first natural frequency of the truss is 1.07. Each of the 7 bays is a .5 x .5 meter square.

This facility can be used to test multi input/multi output (MIMO) control laws. An excellent finite element model is available that matches the measured experimental frequencies of the structure quite well as reported in reference 1, 2. Control is provided by either analog or digital computer and MATLAB files can be loaded through our IBB 386 class machine. Other configurations of the truss are possible using free-free or cantilevered mountings. The truss can be actuated by either reaction mass actuators and/or thrusters. A variety of sensors are also available, i.e. linear accelerometer, rotational accelerometer, strain gauges and piezoelectric films.

Slewing Experiments

A large variety of beams and electric motors are available for performing slewing experiments. In addition a planer truss (frame) of extremely light weight is available (see figure 2). The beams and truss can be fitted with a variety of sensors (strain gauges accelerometers, rotational accelerometers and piezoelectric films and ceramics). Several motor and gear configurations are also available. Hence, a variety of multi input/multi output control configurations are possible for examining the slewing manuever and required vibration suppression.

The slewing truss system provides a new experimental facility in testing the control of flexible structures because it has substantially coupled rotational and translational degrees of freedom. Past modeling of beams actuated by DC motors have been limited to small (approximately 24 inches in length) beams constructed from sheets of thin flexible material such as aluminum. Although simple, these experiments yield useful information and allow a broad range of applications of the results. Information from larger and more sophisticated structures yields results, that although may not be as generally applicable, are of a more realistic nature and hence of great interest. This was the motivation behind constructing an experimental apparatus of a slewing truss structure.

The truss element type was chosen since it is a basic component in almost every space platform. It is a prime candidate to suffer increased vibrational motion from the current trend in design which is to increase space structure size and minimize weight. The experimental apparatus developed for this task consisted of a slewing rig and truss (see figure 2).

The truss rig is unique for its size and flexibility of use. It is constructed of 6061-T6 aluminum. Mounted on the top is an Electro-Craft 670 DC motor. Coupled to the motor is a Berg 7 to 1 high precision gear box. A stainless steel .5 inch shaft is attached to the gear box. The system has a 10 turn potentiometer attached to the bottom. The rig can be used to slew (or rotate about an axis) a variety of structures by changing the shaft component clamps.

The truss is constructed from 6061-T6 aluminum. This material was chosen for its strength, availability and light weight. Truss members were cut from extruded tubing with an outer diameter of .00635m and a wall thickness of 0.000889m. The truss members were attached to the truss joints using Duro Depend II adhesive. The truss joints were cut from piping with an outer diameter of .0155m and a wall thickness of 0.008m. The joints were 0.0092m wide. The global dimension of the truss are .2644 meters by 1.4 meters in a 5 bay configuration. The truss has a finite natural frequency of 1.75Hz and illustrates a first rotational mode at 10Hz (n=3).

The DC motor was chosen as the actuator because it is commonly used in control systems and can be modeled in a control law relatively easily due to its linear voltage torque proportionality. In addition, the DC motor's tachometer feedback can be adjusted to increase the control systems damping. This is useful to investigate the effect of damping on the system, and to design a servo controller with desirable performance characteristics.

Dish Antenna Experiemnt

Again in the spirit of moving the testing of large space structures into more realistic scenarios, we have created an antenna dish model (see figure 3). This antenna, modeled after a component of NASA's Evolutionary Model, consists of a rigid hub holding together 8 ribs which are prestressed by wire connecting the "free" ends. The ribs are made of aluminum of elastic modulus $E = 7.102 \times 10^{10}$ N/m^2 and density of 2700 /m^3. The global diameter of the antenna is about 1.2 meters. Its first natural frequency is around 4.259Hz. This structure is dynamically rich containing many repeated roots. The structure exhibits the beating pehnomena and provides an interesting control problem because it has a very low controlability norm for any single input/single output control law. The structure can be fitted with both passive damping and active damping devices. Strain gauges accelerometers and piezo films are available for sensing . Actuation is provided by piezoelectric ceramics.

Summary

Several fundamental structures are available for use in studying the interaction between control law, actuator dynamics and structural dynamics. The instrumentation provided by this award provides instrumentation to allow MIMO control laws to be designed on a variety of computering environments and implemented on these structures. The experimental test structures range from the dynamically simple to those with substantial dynamic complexity modeling space structures. This allows an excellent test bed facility, under academic control, to provide AFOSR supported researchers with an opportunity to test their theories and to train American graduate and undergraduate students. Photographs of the facilities and details of tests are available upon request by writing/calling the PI.

References

1) Minas, C, Garcia, E. and Inman, D.J., "Control of a Flexible Plane Truss Using Proof Mass Actuators"

2) Minas, C., "Modeling and Active Control of Large Flexible Structures," Ph.D. Dissertation, State University of New York at Buffalo

Figure 1. Cantilevered Planer Truss

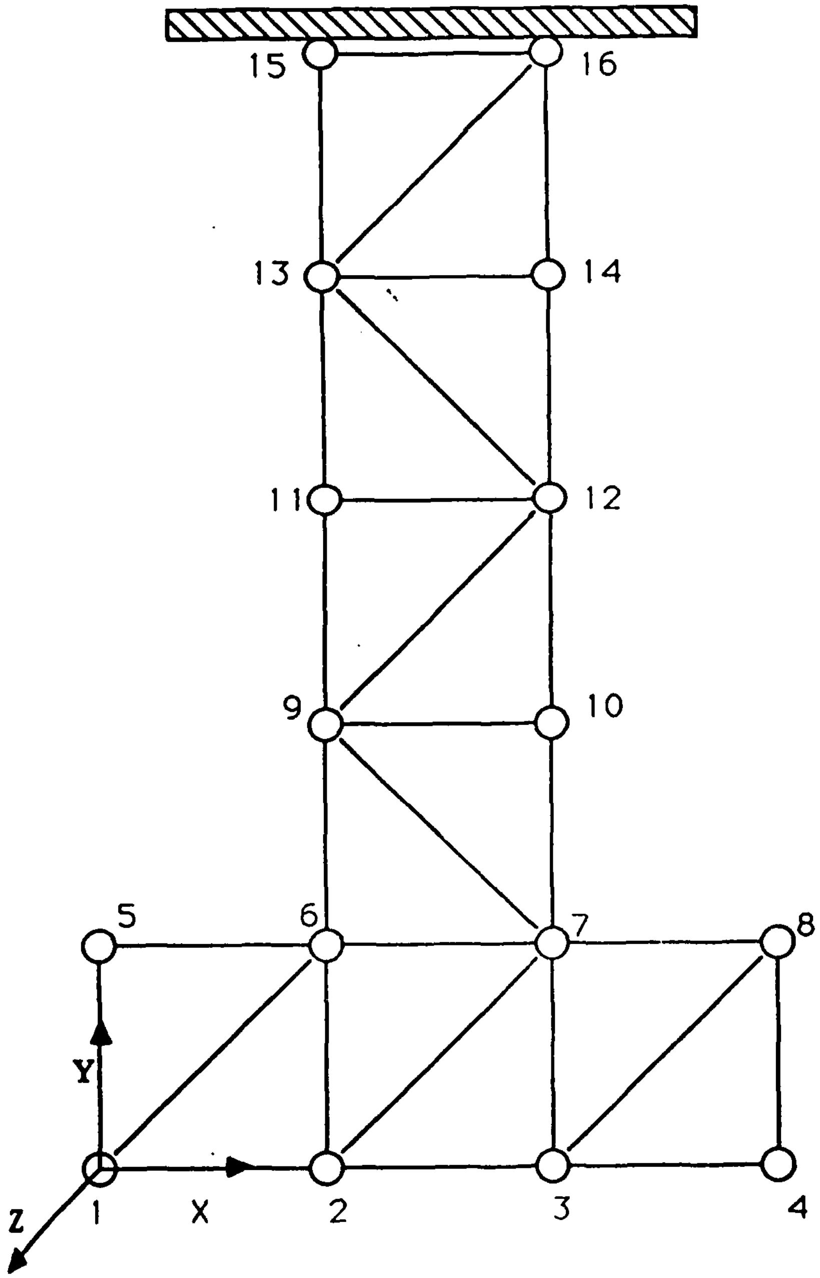
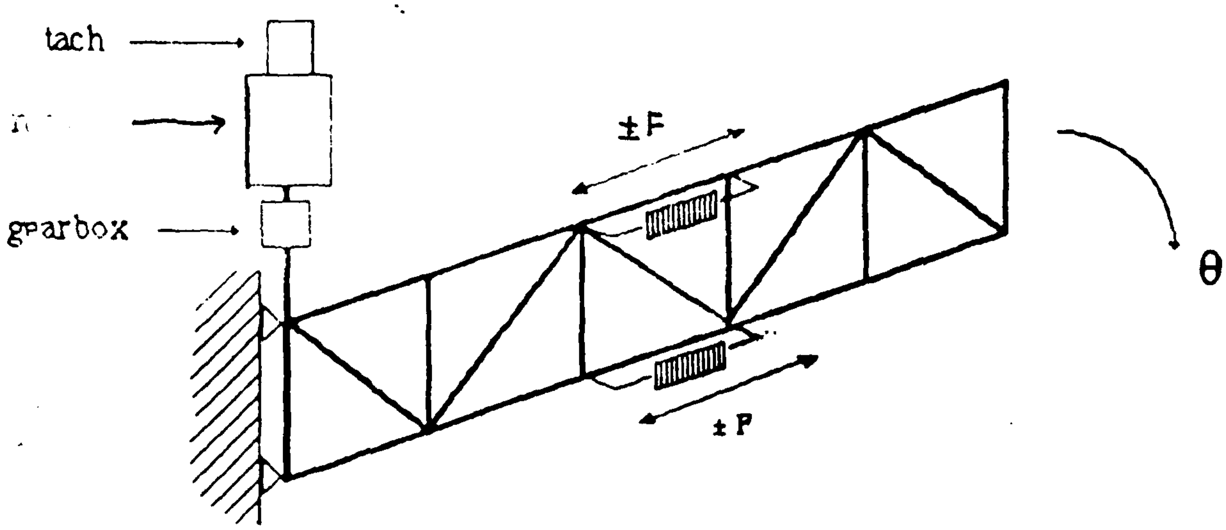


Figure 2. Slewing Truss Configuration Shown

with Piezoceramic Actuators

Slewing Truss Structure

- torsional modes must also be controlled, how?



- on-board piezo-actuators
- incorporate these actuators into a vibration suppression control law formulation

Figure 3. Experimental Aluminum Dish Antenna