N90-27333

ROBOT DYNAMICS IN REDUCED GRAVITY ENVIRONMENT

Gary L. Workman and Tollie Grisham
University of Alabama in Huntsville
and
Elaine Hinman and Cindy Coker
Marshall Space Flight Center

ABSTRACT

Robot dynamics and control will become an important issue for productive platforms in space. Robotic operations will be necessary for both man tended stations and for the efficient performance of routine operations in a manned platform. The current constraints on the use of robotic devices in a microgravity environment appears to be due to safety concerns and an anticipated increase in acceleration levels due to manipulator motion.

The robot used for the initial studies was a UMI RTX robot, which was adapted to operate in a materials processing workcell to simulate sample changing in a microgravity environment. The robotic cell was flown several times on the KC-135 aircraft at Ellington Field. The primary objective of the initial flights was to determine operating characteristics of both the robot and the operator in the variable gravity of the KC-135 during parabolic manuevers.

This study demonstrated that the KC-135 aircraft can be used for observing dynamics of robotic manipulators. We also observed the difficulties associated with humans performing teleoperation tasks during varying G levels and can provide insight into some areas in which the use of artificial techniques would provide improved system performance.

Additionally a graphic simulation of the workcell was developed on a Silicon Graphics Workstation using the IGRIP simulation language from Deneb Robotics. The simulation is intended to be used for predictive displays of the robot operating on the aircraft. It is also anticipated that this simulation can be useful for off-line programming of tasks in the future.

INTRODUCTION

Most texts and papers dealing with kinematics and dynamics of robots assume that the manipulator is composed of joints separated by rigid links. However; in recent years several authors have published papers dealing with the dynamics of flexible manipulators, particularly for the application of robots in space.[1,2] Additional concepts which have to be worked out in any robotic implementation for a space platform include teleoperation and degree of autonomous control.[3-5]

Lightweight arms are necessary for space, primarily for the costs benefits derived from their reduced weight.[6] However, lighter weight arms have to necessarily flex during movement. Flexure of the arms performing a task requiring precision requires some control mechanism to insure that the end-effector is at the proper place and orientation with respect to the workpiece. Flexing motions of the arm will cause (1) accelerations to feed back into the base support of the robot, (2) transmit accelerations into the sample being transported, or (3)take forever to perform a task. The first effect will obviously destroy the microgravity environment of the Space Station, while the second will impact experiments such as the delicate protein crystals which are to be grown in space. In some cases slow movements may be acceptable for (3); however it certainly will not be suitable for all tasks aboard the Space Station.

One must also include the reasoning that for man and robots to co-exist in the space environment, the robot must be non-threatening to man. Lightweight arms are the only ones which satisfy that criteria. For space applications, a Cincinnati-Milacron T3 is not only over-weight, but also may be threatening to humans trespassing in its working volume. Artificial Intelligence will also have to provide a major role for robots to enter into the space activities. Current systems such as the Flight Teleoperator System (FTS) and the Orbital Manuevering Vehicle (OMV) will certainly develop some intelligence with time.[7] Allowing some degree of autonomy due to time delay communications for teleoperation over large distances is necessary. The robot controls then will have certain motions embedded in the control software that do not need explicit operator communication, except for emergency control, such as ABORT. AI will have to be part of the embedded software control. Time delays make for precarious situations in performing teleoperation from large distances. Tasks may be accomplished in a more reasonable manner and more success using some AI techniques.

This study was initiated in response to the need to determine the adverse parameters which might exist for robotic/telerobotic operation in a microgravity environment. The first part of this study has been to build up hardware to perform reduced gravity observations on a small robotic arm and to develop a graphical simulation of the robotic workcell. We anticipate combining these two efforts at a later time for predictive display capability in a remote control environment. Also at that time we will begin to develop control strategies using AI for remote teleoperation. The initial experiments will be performed on the KC-135 aircraft since TDRSS satellite telemetry will soon be available to onboard experiments.

REDUCED GRAVITY EXPERIMENTS

A major goal was to evaluate a small robot system, such as the UMI RTX, for materials processing applications in low gravity and determine the characteristics of a robot arm in a space environment, particularly with respect to accelerations which might impact materials grown on a space platform.

A materials transfer workcell was assembled to simulate the changing of sample ampoules as might occur aboard a space laboratory. Accelerometer packages were included for determining the G levels of the workcell and the at the end-effector. Several flights were taken with the workcell, improving some data taking capabilities each time. One experimental concern was whether a short enough, but meaningful task could be developed. The task needed to take no longer than around 22 seconds to fit within the microgravity portion of the parabolas. However, on each flight somewhere between 25 and 40 parabolas are flown allowing a short task to be repeatedly run and measured, or a long task possibily to be broken into consecutive steps.

The task for the first flights was a simple ampoule exchange from one rack to another. During the higher gravity portion of the parabola the robot could be reset, and another task run readied. The human operator was able to train the robot to perform a materials transfer function within the 20 seconds desired. The first computer used with the experiment did not allow for both control of the robot and reading of the accelerometer package at the same time. The next upgrade was to a 386 based computer, which enabled some improvements in the data acquisition process; but the multi-tasking software used at that time still did not permit the I/O commands to the robot to operate properly. Consequently we never did get to control the robot and take acceleration data simultaneously in these flights. Future task upgrades should allow this to be done.

A number of lessons were learned with this series of experiments. The RTX robot uses plastic belts for actuation of the links and optical encoders for position and velocity control. The slippage and flexing of the belts caused excessive jitter and accelerations at the end-effector. We believe that the belt-driven actuation would not be acceptable for experiments such as the protein crystal growth studies due to the lack of control of accelerations at the end-effector. The control system; however, is PID and appeared to work well whether the task was learned in 1 G and performed in low G or vice-versa. However, it was tedious to teach the robot during parabolas, mainly because we had few visual aids to assist in the correct orientation of the end effector; particularly for inserting the sample ampoule into its holder. A borrowed fiber-optic borescope provided little depth perception and was not useful for this study. In addition teaching a robotic device for precision movements can certainly be improved through more innovative approaches using embedded sensors or vision systems with some autonomous local control.

A major concept which might be important in terms of promoting telescience experiments to use the KC-135 would be to implement the above experiments using remote manipulation from the ground. The KC-135 aircraft facility at Johnson Space Center has indicated interest in these types of experiments using the TDDRS satellite for transmission purposes. Teaching the robot remotely and then performing the task from the ground would be an ideal simulation for space teleoperation.

IGRIP SIMULATION RESULTS

The RTX robot workcell was modelled on a Silicon Graphics IRIS work station using the IGRIP off-line programming language and simulation tools developed by Deneb Robotics. The simulation was generated with version 1.0. Later versions offer some enhancements which were not available in our simulation. In fact no off-line programming is actually available at the moment; however, it can be performed with later versions and would certainly be a necessary tool for the space-based activities.

In IGRIP, a geometric model is designed using through the creation of individual parts. These parts are attached in relation to each other and saved as a device. As a device, several non=geometric properties are entered, such as kinematics, velocities, and acceleration. The final workcell consists of the robot model and the workcell model.

A PART is made up of one or more OBJECTS. Simple OBJECTS are created through the use of cad primitives. Examples of Cad primitives used on the RTX and workstation model are the BLOCK, WEDGE, and CYLINDER. Additional OBJECTS are made through the use of the MIRROR and CLONE commands. OBJECTS which are connected and move together are saved as a PART.

The PARTS are assembled in the CREATE DEVICE module by invoking the NEW DEVICE command and specifying the number of degrees of freedom. Beginning with the base, each PART is attached to the previous PART and translated (x,y,z) or rotated (roll, pitch, yaw) to its new position. Once all PARTS are in place, it is saved as a DEVICE.

The ATTRIBUTES of the DEVICE are defined next. LINK TYPES, LINK LIMITS, Max Velocity, and Max acceleration are then entered. The Degrees of Freedom are specified by choosing the axis for rotation or translation corresonding to teach link. Selecting the KINEMATICS command gives the option of jogging by links or through a kinematics routine. The RTX model has a user-kinematics routine defined.

In the CREATE WORKCELL module, the models of the robot and workstaion are placed together in relation to one another and saved. It is here in the workcell that a device is programmed. With the user-defined kinematics specification, a sequence of entered link movements are saved in a program. The MOVE command enables the selection of a link and input as to the translational or rotational distance. An option is available as to whether or not the link movement will be simultaneous with other link movements. The program is then saved for later recall.

To view the program, one uses the LOAD command. The DEVICE must be activated before simulation can occur. Simulation time step size (SIM STEP SIZE) is an option adjusting the time icrement between simulation updates. This alters the speed of the simulation.

During a simulation, it is useful to check for collisions. A primary DEVICE is selected. ADD TO QUEUE puts the devices selected into the Collision Queue of the primary DEVICE. Checks for Collisions and Near Misses are available. The primary DEVICE has the option to stop or not upon detection of a Collision, Near Miss, or both.

As these studies continue, we hope to be able to upgrade to a newer version of IGRIP and continue with the development of the predictive display capability for the teleoperation experiments on the KC-135.

Future plans call for the incorporation of a lightweight video camera placed on or near the arm to provide viewing of the workspace. Graphic overlays, giving supporting information, or command cues may be added. An on-board operator could try using primarily the video view to attempt to alter the robot's task. Simple task altering commands such as "go to rackspace x" would be pre-programmed to allow easy, and fast, task modification. This would also be necessary for remote telescience experiments in general, as there may be no on-site person to implement or program complex command sequences.

CONCLUSIONS

It has been demonstrated that the KC-135 aircraft can function appropriately as a testbed for robotic tasks in reduced gravity environment, provided that simple and short duration tasks are used. In many cases, larger tasks can be broken into several short tasks, allowing relevant test measurements to be made over a short period of time. For space tasks, the advantage is the ability tp view and study manipulator actions in a low gravity environment before going into space. Simple PID controllers designed for ground-based operation do work in reduced gravity, although low cost robots, such as the UMI RTX exhibit excessive jitter and accelerations due to the actuators used in their construction. However, the possibility of using off-the-shelf, or slightly modified labortory manipulators in the pressurized modules may still provide access to affordable remote experimentation opportunities.

Much can be learned by performing teleoperation demonstrations on the KC-135 aircraft. However, improved sensing is needed for precision training of tasks performed in the reduced gravity of the aircraft. With time, a testbed for remote microgravity simulation could be developed, which combines both the graphic simulation and on-board manipulation. While the UMI RTX is not suitable for precise work, other laboratory robots, which have have been designed for precision motion, can be tested.

BIBLIOGRAPHY

1. Toshio Fukuda, "Flexibility Control of Elastic Robotic Arms," Jour. of Robotic Systems, 2 (1985) 73-88

2. W.H. Sunada and S. Dubowsky, "On the Dynamic Analysis and Behavior of Industrial Robotic Manipulators with Elastic Members," Trans. ASME Mech. Transmission Automat. Design 105, (1983) 42-51

3. E. Heer and A.K. Bejczy, "Control of Robot Manipulators for Handling and Assembly in Space," and Machine Theory 18, (1983) 23-35

4. R. A. Clift, "Program Plan for the Astronaut's Apprentice, "Robotics 1, (1985) 251-264

5. D. R. Criswell, "Robotics and the Space Station," Robotics 1 (1985) 205-222

6. M.M. Clarke, "Recent Advances in Teleoperation: Implications for the Space Station," SPACETECH 85

7. J. Varsi and D. Herman, "Space Station as a Vital Focus for Advancing the Technologies of Automation and Robotics", Conference on Artificial Intelligence for Space Applications, 1986, p 1-6.