TELEROBOTIC TENDING OF SPACE BASED PLANT GROWTH CHAMBER EXPERIMENTS

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ABSTRACT

The kinematic design of a telerobotic mechanism for tending a plant growth space science experiment chamber is described. Ground based control of tending mechanisms internal to space science experiments will allow ground based principal investigators to interact directly with their space science experiments. This will enable tending of space science experiments on unmanned platforms as well as off-load tedious tending chores from astronauts to allow them to focus on other important activities. The plant growth chamber apparatus is being designed for use on the Space Station.

INTRODUCTION

Space science is an important application domain for NASA missions such as Space Station. An important activity of Shuttle astronauts is to tend space science experiments. The astronauts are highly trained on the ground to accurately tend the experiments. But because astronaut time is so valuable, space science experiments often are not allocated the amount of tending time that a principal investigator desires. Ground based telerobotic tending of space science experiments is one solution to allow increased tending of space science experiments. Additionally, by putting tending mechanisms internal to the experiment apparatus, the apparatus does not have to be opened for tending which will allow more accurate experiment environment control and tending of hazardous environment experiments. The kinematic design of a robotic mechanism for tending a plant growth chamber apparatus is described. A more complete description of the design process and trade-offs is given in [)]. Ground control telerobotics for Space Station has been previously described in [2, 3, 4, 5].

PLANT GROWTH CHAMBER EXPERIMENT

A plant growth chamber is being designed for use on Space Station to study the growth of various types of plants in microgravity as part of the Controlled Ecological Life Support Systems effort. Plant growth on a spacecraft is used for life support, both for oxygen exchange and as a food source. Various types of plants will be grown under varying conditions. The plant growth will need to be monitored via visual inspection and environmental sensing utilizing a variety of different types of sensors. Also, the plants will need to be sampled, i.e., parts of the plants or whole plants will have to be removed and stored for later analysis. It is unlikely that there will be sufficient astronaut time to tend the plant chamber. Providing a remotely controlled

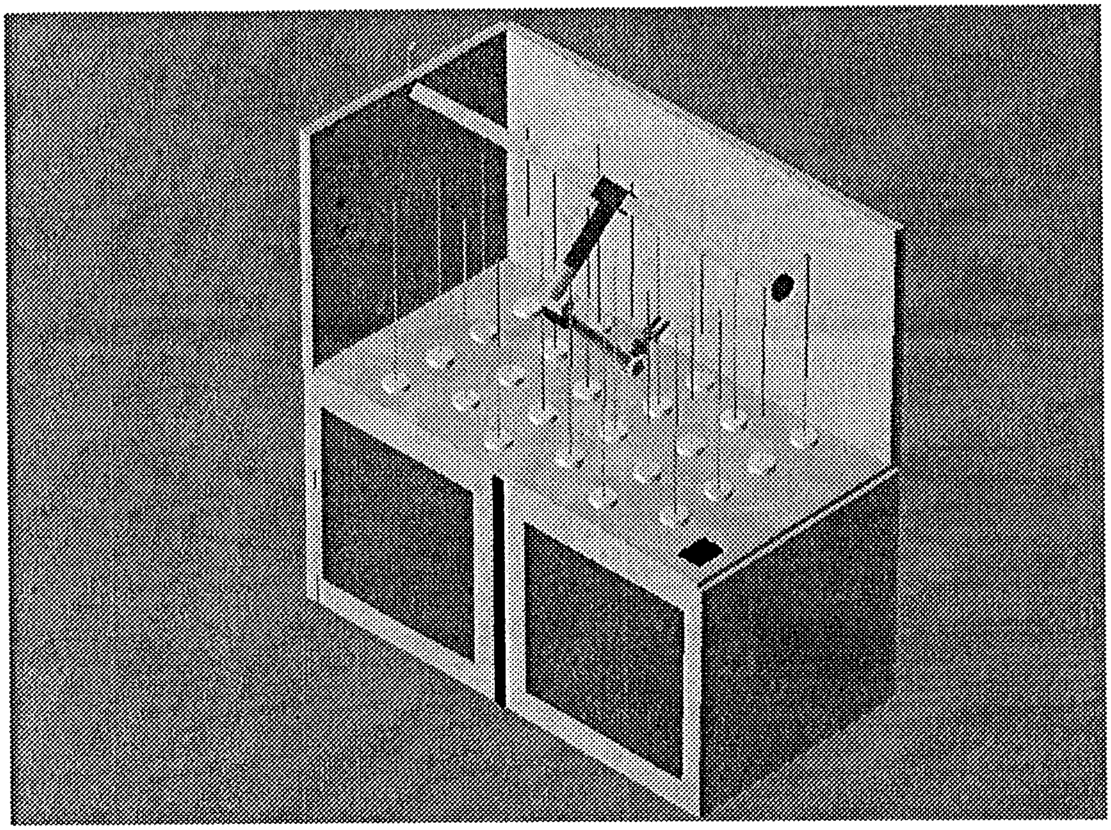

Figure 1: Plant growth chamber with tending robot

manipulator to tend the experiment will allow routine inspection and tending of the plant chamber.

It is valuable for the plant growth chamber environment, e.g., humidity, temperature, and airflow, to be well controlled. The environment internal to the plant chamber and the environment of the Space Station are likely to be quite different. For example, the plant chamber environment will likely be controlled to have high humidity to promote plant growth while the Space Station environment will likely be controlled to have low humidity to prevent organism growth on the Station internal surfaces. Mounting a manipulator tending device internal to the experiment allows inspection and tending to occur without opening the environment for access, thus preventing environmental exchange between the plant growth chamber and Space Station environment.

'l'he plant chamber is expected to utilize the volume of two Space Station racks. 'l'he volume is separated into an upper portion, where the plants grow, and a lower portion where the support apparatus is located. The plant growth area. where the manipulator will reside, will have a volume of approximately 1.5 m wide by 0.8 m tall by 0.8 m deep. The plants may grow out of disc shaped areas at the bottom of the plant growth chamber and grow up toward the ceiling where lights are mounted to provide the energy for photosynthesis. A graphic of the the chamber with the selected tending robot concept is shown in figure 1.

A possible scenario for planting, growth, and harvesting utilizing the internal manipulator is given below. A tray of plant cells is inserted into the chamber by an external device or astronaut. Each cell might have multiple seeds. The internal manipulator will be commanded to take the plant cells and insert them into the growth disks on the floor of the chamber. The seeds will be embedded in a felt-like material which will draw fluid from a nutrient bath below the growth disk. The plants will germinate and the stems will grow out of the tops of the disks. The plant cells fit snugly in the disk slots so that fluid cannot be released into the growth chamber. The material dots allow the trunk to expand as the plant' matures.

When the plants sprout, the manipulator is used to grasp a high magnification camera and then position the camera above the disks so that images can be taken of the seedlings. These images arc transmitted to Earth for analysis and specific seedlings arc selected to be removed from the chamber. The manipulator is then commanded from Earth to remove these seedlings by pulling them out from the roots, Some of the seedlings will break at the trunk while others will pull out by the roots. Some of the seedlings will be sprayed with a preservative and bagged (this is done automatically after the sample is deposited into a slot in the chamber, probably located on the floor of the chamber). Other seedlings will be discarded into a waste slot. The end of the seedling stage results in a thinned crop of seedlings.

The remaining stages of growth have the plants growing from seedlings into mature plants. At various stages of growth, specific plants will be selected (on Earth from images transmitted from the chamber) to be sampled, Either a part of a plant will be sampled or the entire plant will be pulled from the growth disk. The manipulator will be used to sample the plants. For example, the manipulator might pick up the camera and capture images of selected leaves of the plants. Specific leaves will then be selected on Earth for sampling and the manipulator will then pick up a cutting tool to remove the leaf, For the case of a grass such as wheat, the leaves are likely to be sampled from their base where they grow out of the stalk since that is where growth occurs. When the plants mature, the manipulator will be used to sample (cut and remove) flowers and fruit.

Experiment Tasks and Constraints

'1'here are three likely types of plants which may be grown in the plant chamber. Cereals and beans will provide fruit above ground. l'here may also be plants which have fruit among the roots, but the tending and harvesting of this type of plant is less well understood.

Some of the experiment tasks and issues related to kinematic design of the robot arc:

- Clip plant tops - This task will require up to 6 DOF at the end effector. Forces and torques necessary to perform the task will be minimal.
- Clip plant stems/leaves/flowers/fruit - This task will require up to 6 DOF and may additionally require kinematic redundancy for minimum disturbance to the plants during the procedure. Applied force and torque required for this task are expected to be minima].
- Pull out plant from roots - This task could be accomplished with 3 DOF if the tool is set to the proper orientation. Kinematic redundancy in positioning may be required to reduce disturbance with other plants during this procedure. This

task is expected to require the largest amount of applied force and torque, with the actual requirements dependent on the hydroponic growth technique used and the type of plant.

- Move sensors, e.g, camera, air - This task will require 6 DOF and may require kinematic redundancy. Minimal force and torque will be required for this task.
- Store plant samples - This task will require 6 DOF. Sampled plant materials will be deposited in a vent located at one corner of the floor in the plant chamber. Minimal force and torque exertion will be required for this task.
- Pick up and replace tools and sensors - Tools and sensors will be held at a storage area on one of the walls of the plant chamber. The robot must be able to pick up each tool and sensor and return them to the storage location.
- Other miscellaneous manipulation tasks - There may be other tasks necessary for the up-keep of the plant chamber. For example, cleaning the chamber of materials dropped by the plants may be necessary. In a weightless environment, this will mean the ability to grasp a floating object; or due to the constant airflow, dead plant material might collect at the air outlet vents and will need cleaning.

MECHANISM KINEMATIC DESIGN

Many design constraints were considered when determining the desired kinematic design of the mechanism including:

- Minimum weight - A requirement for space applications,
- Minimum power - A requirement for space applications. In addition, excessive heat generation would affect the controlled environmental conditions in the plant chamber.
- Minimum volume - Small size of components to reduce disturbance to plants.
- Reach all parts of the plant chamber volume - workspace of the robot should cover the plant chamber with sufficient dexterity.
- Travel speed - Tasks will not involve dynamic interaction so speed requirements are determined by the need to perform tasks in a specified time period and are expected to be moderate to slow.
- Minimize disturbances to plants - Reduce, as much as possible,. disturbance to plants during motions of the robot.
- No obstruction of camera views at the robot storage position and minimal obstruction during task performance.

The need for tool changeout was also an important consideration. It is assumed that quick change tools with electrical connections to the manipulator will be used, Inspecting, sampling and harvesting the plants creates a requirement for a 6 degree of freedom task space which results in a requirement for at least a six DOF manipulator. Because the plants will be grown in rows, the manipulator should be able to move the positioning links in a plane to minimize disturbance to the plants. Various kinematic configurations were considered inducting six and seven DOF manipulators. All of the designs considered had a translational joint along the top of the chamber. The configurations included Cartesian, single elbow, double elbow, and forearm translation. The two preferred designs were a Cartesian robot and a seven DOF single elbow robot.

The Cartesian robot with a roll-pitch-roll wrist is shown in figure 2. Its advantages are

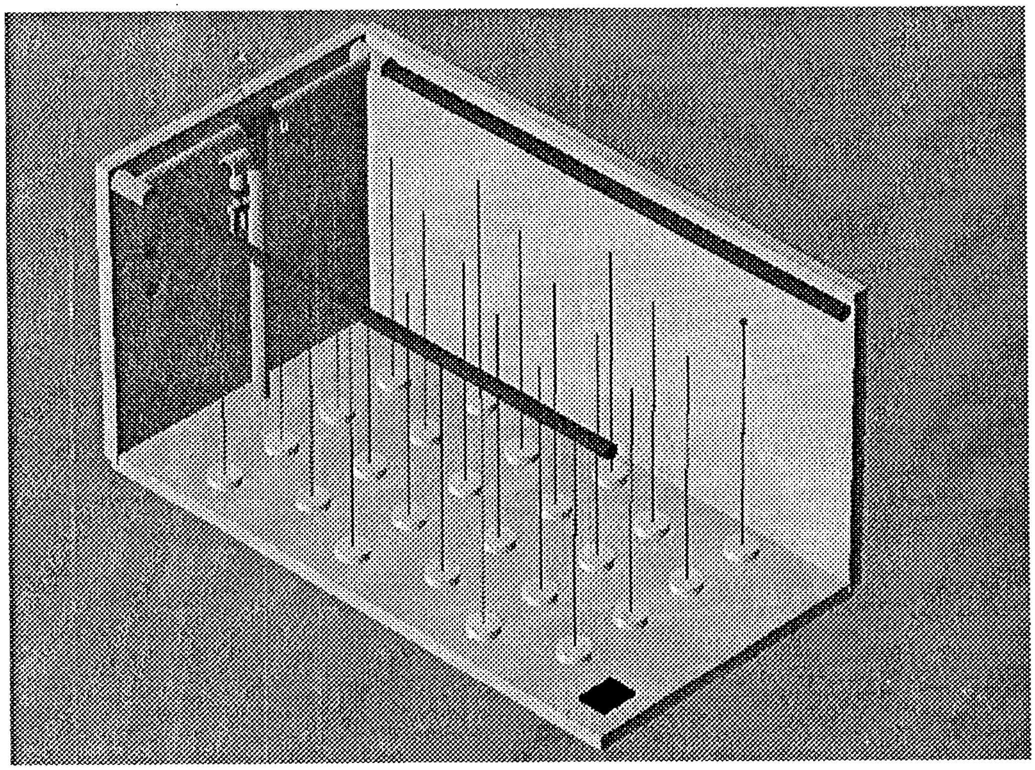

Figure 2: Cartesian configuration robot

its simple kinematics and dexterity over its workspace. In addition, due to support at both ends of the beams used for the first two translation joints, the stiffness of the robot will be greater for a given robot mass. The disadvantage is that there is greater likelihood of obstructed views. There are a number of ways of implementing the translation of the 3rd axis. One method is to have the translation link be mounted on a beam of fixed length so that the robot translates along lanes between plant rows to move the end effector between desired locations. This has a disadvantage in that the third link would cause significant disturbance to the plants as the robot moved. Alternatively, a telescoping third link could shorten itself and translate over the. tops of the plants. However, this would add complexity to the mechanical implementation.

The seven DOF single elbow robot is shown within the plant chamber in figure 1. In this design the first joint is a rotation joint which rotates the translation joint which travels along the top of the chamber. By putting the rotation joint before the translation joint, the actuators for both the rotation and translation joints can be placed outside of the chamber. The third joint is a roll at the shoulder. The fourth joint is the elbow. The wrist is in a roll-pitch-roll configuration for full dextrous orientation positioning. Motion over the tops of the plants can be performed by configuring the arm to lie in a plane parallel to the ceiling of the plant chamber. Elbow flip may be accomplished by positioning the arm in an almost straight line configuration, then rotating the arm in its self-motion workspace. Motion between points in different lanes can be accomplished by moving the arm up to the ceiling and translating to a position above the desired position and then lowering the arm. The selected design has the upper and forearm links in a plane. An alternative design with the links offset was considered, since this would allow a greater range of motion of the elbow, but was not selected since it would increase the arm profile between rows causing increased disturbance to the plants.

CONCLUSIONS

The kinematic design of a tending robot has been developed for potential use in the Controlled Ecological Life Support Systems plant growth chamber. The plant growth chamber is being designed by NASA for plant growth experiments on the Space Station. The baseline plan is for the chamber to be serviced by astronauts. Placing a robot internal to the chamber provides various benefits including off-loading valuable astronaut time for other important activities, maintaining a closed growth environment for better scientific study, and increased tending and inspection opportunities. A seven DOF kinematic design was selected for the robot. Electro-mechanical design, fabrication, and integration of the robot is now required to test the feasibility of the concept.

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