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Paper Session III-D - The Advanced Lift Support Automated Robotic Manipulator (ALSARM) Project

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The NASA/UCF
Advanced Life Support Automated Remote Manipulator Project

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OVERVIEW

The National Aeronautics and Space Administration (NASA) Biomedical Program Office (JJ-G), Design Engineering Advanced Systems and Analysis Division (DM-ASD), and the University of Central Florida (UCF) Department of Mechanical and Aerospace Engineering (MAE) are currently working together on the design, fabrication, and implementation of the Advanced Life Support Automated Remote Manipulator (ALSARM). Once completed, the ALSARM robotic arm will be integrated into the Controlled Ecological Life Support Systems (CELSS) Breadboard Project Biomass Production Chamber (BPC), located at the Life Sciences Support Facility (LSSF) at Kennedy Space Center (KSC). The goal of this collaborative effort between NASA and UCF is twofold: first, it provides undergraduate engineering students with the opportunity to gain vital experience in the “real world” of engineering design. Second, it introduces KSC’s next step in the development of a life support system to be used on a future human-tended mission wherein regular resupply from Earth would be impractical if not impossible.

The ALSARM Project grew out of a NASA grant awarded to Dr. Roger W. Johnson of UCF in 1993. Dr. Johnson formulated a project for the senior-level Aerospace Engineering Design class, the purpose of which was to design the electrical, mechanical, and control elements of the robot arm. Students were provided with a set of operational requirements for the arm, and the physical dimensions and environmental constraints of the BPC. The class was divided into teams, each team given a piece of the design problem to solve. After a series of internal design reviews and formal design reviews with UCF and NASA personnel in attendance, the final design of ALSARM took shape. Once the design was finalized, it was turned over to the NASA KSC Prototype Division (DM-DTL) for fabrication and installation.

To best understand how the final design of the arm was derived, a look at the physical environment in which the arm will operate and the purposes for which it will be used is in order.

2. SYSTEMS CONFIGURATIONS

2.1 CELSS Breadboard

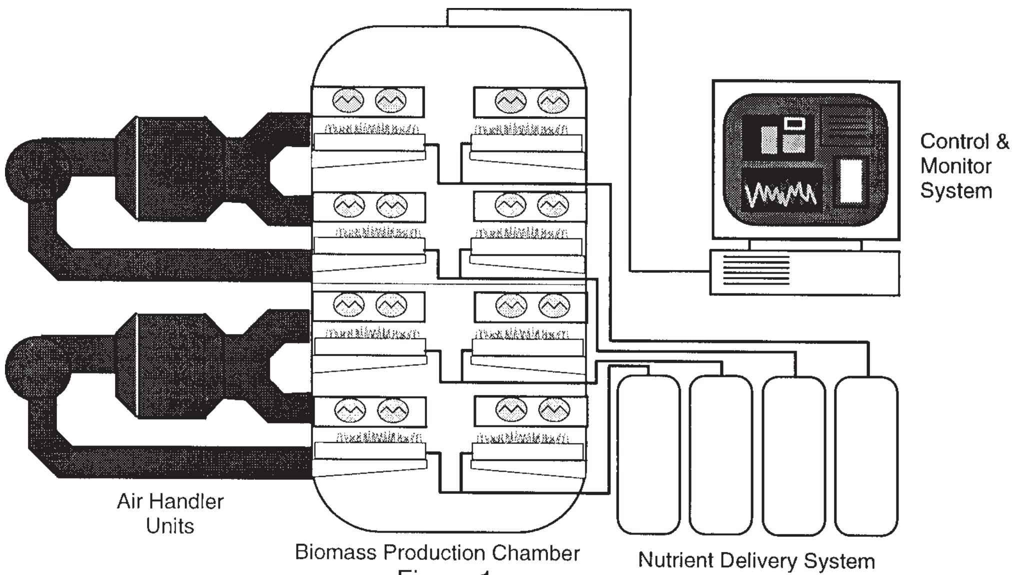

Figure 1.

The CELSS Breadboard Project (CBP) is a closed-loop plant growth environment consisting of the BPC, an approximately seven meter tall by three meter diameter cylinder, divided into upper and lower chambers; a Nutrient Delivery System (NDS) which provides water and nutrients to the plants; a lighting system; Air Handler Units (AHU); and a computerized control and monitoring system, comprised of a set of sensor/effectors connected to the system and communicating with a pair of Sun SPARCstations (see Figure 1). The two chambers in the BPC are configured identically, each containing two levels of plant growth trays, two levels of light banks and NDS piping, and AHU ventilation ducting. This configuration allows for a total of four levels of plant growth in two physically isolated chambers. The robot arm will be installed in the upper chamber of the BPC.

2.2 ALSARM

The ALSARM unit consists of six elements: the Vertical Telescoping Assembly (VTA), Rotational Actuator (RA), Horizontal Telescoping Assembly (HTA), the Sensor Array/End Effector (SA/EE), video cameras, and a personal computer (PC) based Electrical & Control System (ECS) (see Figure 2). It is a two-link, three degree of freedom system that will allow CBP investigators to collect environmental data in the BPC via the SA in sets of preprogrammed protocols or manually collect and retrieve biomass samples with the EE for offline investigations.

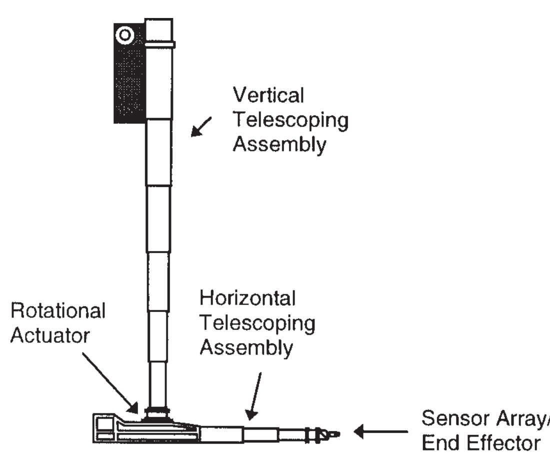

Figure 2.

3. DESIGN

The VTA consists of five major components: an aluminum six-link telescopic boom, a DC brushless servo motor, a 104-to-1 ratio worm gear, and a 40 mm steel rigid chain and chain housing (see Figure 3). Each of the boom link casings is 600 mm in length with a stroke length of 488 mm. When fully extended, the VTA has a maximum stroke length of 2,438 mm, which will allow it to extend from the ceiling of the chamber, where it is mounted, to the level of the lower growth trays. When fully retracted, the VTA is at its home position above the upper light bank, and out of the way of anyone needing access to the chamber. The motor/worm gear/rigid chain assembly drives the boom to position. The chain design constrains it to bend in only one direction, thus causing the chain to act as a rigid drive device when moving the VTA to position, yet allows it to coil into the housing, retracting out of the way of other moving parts. The majority of the VTA components are commercially available products, each of which were evaluated by student designers for their capabilities to meet arm requirements and integrate with each other with a minimum of effort. Where custom fittings such as mounting brackets and chain couplings were required, students did the design work, and the DM-DTL shop did the fabrication.

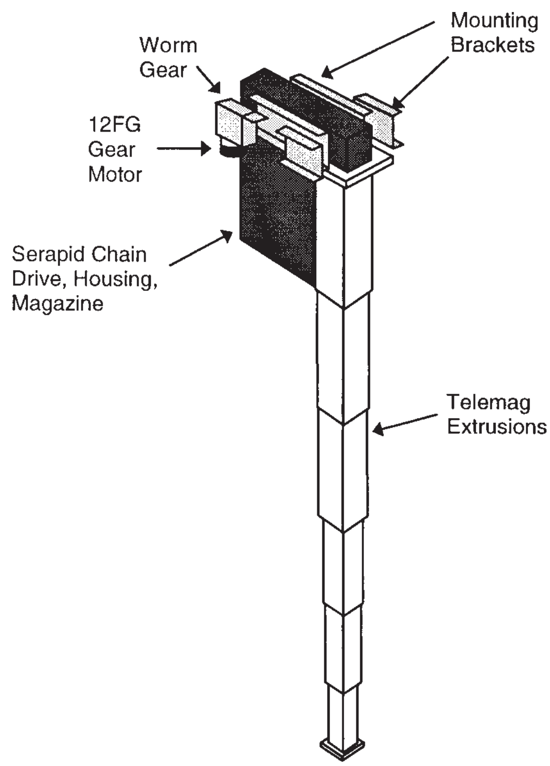

Figure 3.

The RA acts in two capacities: as a load bearing connection point between the VTA and the HTA, and as a means for rotating the arm about an approximately 350^{o} arc in the BPC. Of all the components of the arm, the RA required the greatest student and NASA custom design effort, as no commercially available assembly exists that can fulfill all the linkage, rotation, loading, and environmental requirements placed on it. It consists of machined aluminum housing components, a stainless steel VTA attachment plate, stainless steel upper and lower split shafts, a 160-to-1 ratio harmonic drive gear assembly, a DC brushless servo motor, roller and needle bearings, and an optical encoder for precision placement (see Figure 4). Limit switches mounted in the RA housing determine its full rotation limits and home position. In order to minimize the possibility of environmental contamination from lubricants, silicon based grease is used, and grease stops have been incorporated into the RA design in order to prevent leakage.

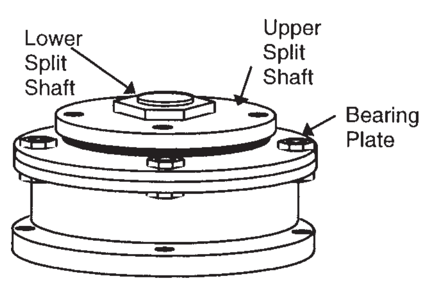

Figure 4.

The HTA is comprised of a NASA/UCF MAE designed Base Link structure, a telescoping assembly, a rigid chain, chain guides, a DC brushless servo motor, and an electronics housing (see Figure 5). The telescoping assembly consists of four anodized aluminum links, much like the VTA. Each link is 593 mm in length, with a total HTA extension of 1,575 mm. Magnetic reed switches are positioned in the HTA to determine full extension, full retraction, and home positions. The electronics housing at the end of the HTA arm acts as an attachment point for the SA/EE components, and provides a protective covering for SA/EE electronics circuitry.

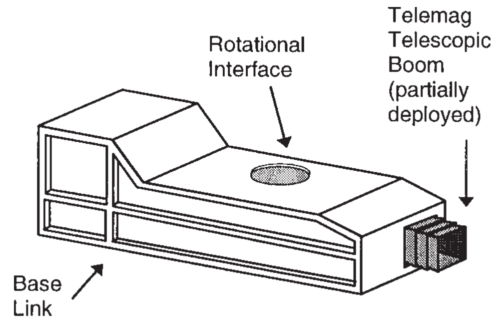

Figure 5.

The SA/EE assembly provides users with a set of sensors to gather data at any given point near the growth trays, and a means for collecting biomass specimens. The SA consists of five sensors:

- air temperature (0 - 50°C);
- relative humidity (0 - 100%);
- Photosynthetically Active Radiation (PAR) (400 - 700 nm range; 0 - 2000 mmol/m^2/sec);
- air velocity hot needle anemometer (0 - 5 m/sec);
- infrared radiation (0 - 100°C).

Figure 6 shows a drawing of the SA with its outer aluminum skins removed. The SA will attach to link 4 of the HTA. It is an aluminum housing comprised of endplates attached via support rods. The center plate divides the housing into two compartments, and is movable along the rods, allowing for mounted circuit boards of varying sizes. The plate is also drilled to accomodate signal, power, and video cable connectors. On the outer endplate is a sensor mounting plate which will act as the platform for the sensors.

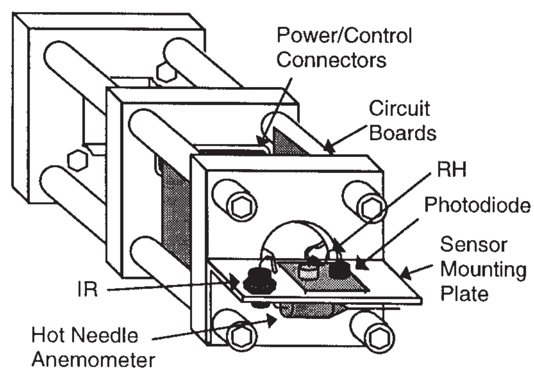

Figure 6.

In its current form, the SA is an interim step in the integrated SA/EE design. The design and fabrication phases of the majority of ALSARM are complete; the NASA team is currently involved in assembly and validation testing at the Advanced Systems Development Laboratory (ASDL). Once testing is complete, the arm will be disassembled, the aluminum pieces anodized, and reassembled in the BPC to begin final testing and operations. The EE is, at this time, still in its conceptual design phase as a continuation of the UCF senior design class. The EE current design, as discussed below, will not be complete in time for installation and testing with the rest of the arm. It is a design concept that has not yet fully matured. Therefore, in order for the arm to be at least partially functional when it is installed in the BPC, the SA was designed and built.

The EE will be required to grasp and cut biomass samples from plants within the BPC and return those samples to an airlock mounted in the chamber hatch. The EE is comprised of six major parts: the socket, ball wrist, tweezer housing, tweezer motor, .tweezer assembly, and cutter (see Figure 7). The socket acts as a housing for the roll, pitch, and yaw motors, and as a mount for the ball wrist. The ball wrist, a commercially available polyethylene sphere, interacts with the motors to move the tweezer/cutter assembly on their three axes. The tweezer housing, tweezer motor, and tweezer assembly work together to grip and control biomass samples while the solenoid-activated cutter severs the samples from plants in the chamber. Once samples are cut away from the plant, the robot arm will move them to the hatch in the airlock door to be retrieved for inspection. The EE housing will also act as a platform for mounting the SA elements and camera.

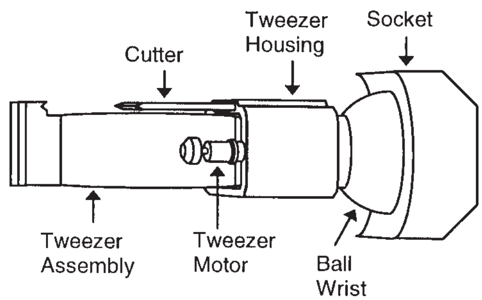

Figure 7.

The final component, the ECS hardware and software, is an Intel 80486-based microprocessor system using a Lab Windows CVI development environment with a C programming language interface. Initial work on the control software was done at UCF, then moved to KSC, where DM-ASD personnel completed it. The software design was created with the design goals of safety, flexibility, ease of operation, and maintainability in mind.The details of ECS functionality will be discussed in the following sections.

4 INTEGRATION

Prior to integration of ALSARM into its final duty station, it will undergo a full set of validation testing. Already complete is the initial software test environment phase, where the basic functionality of the control software was tested in a rudimentary simulation in order to check out nominal software control of robot behavior and exception handling. The next phase will consist of no-load motor testing, where the software test simulation will be replaced with ALSARM motors, and the motors will be exercised via ECS interface. In the third phase, the entire arm will be assembled on a test stand mockup of the BPC upper chamber at the ASDL. During this chamber mockup testing, the arm will be tested for its ability to operate properly in manual and automatic modes, motor tuning will be completed, and the first stages of operator training will take place. Once the tests are complete and the test team is satisfied as to ALSARM's basic capabilities, the arm will be moved to the BPC. Integrating ALSARM into the BPC will take place in three phases: installation, testing, and final operator training.

The arm will be physically installed by being bolted to the ceiling hatch of the upper chamber (see Figure 8). Power and control lines will be strung through an access panel in the hatch. The control system lines will be passed through the LSSF to the BPC Control Room, where the system's PC and control circuitry will be located. The control circuitry wiring will also contain a port near the BPC hatch for installation of a teach pendant, a mechanism for manually programming the arm movements.

Once installation is complete, DM-ASD and JJ-G personnel will complete validation and verification testing of basic arm functionality. This testing will include all phases of nominal and off-nominal operations, for both manual and automated arm functions. Operating conditions unique to the BPC and not checked out during the mockup testing phase will be noted and documented. Procedures will be developed to handle such contingencies. During this phase, selected JJ-G personnel will become familiar with the arm, and develop the protocols for training other experimenters in arm capabilities.

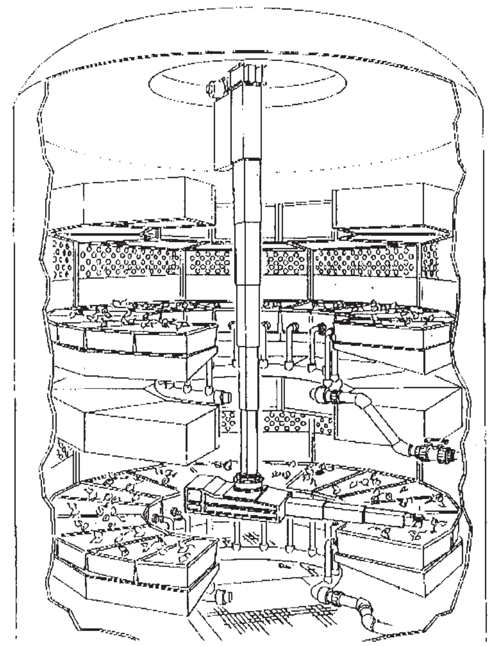

Figure 8

5. UTILIZATION

Software control of ALSARM is partitioned into three modes of operation: Main Mode, Auto Mode, and Teach Mode. The Main Mode is the startup in which the arm position is verified, and operator entry to the other modes is accomplished.

In Teach Mode, the operator will be able to develop the ALSARM movements, positions, and data collection protocols required. Using the desired SA position as a reference point for arm movement, the operator will specify horizontal extension, vertical height, and angular rotation to define points in the BPC (see Figure 9). The operator can also select the sensor readings to be taken at that point. By entering a set of SA positions into a data file on the PC, the operator can create a sequence of arm movements to predefined locations in the chamber. The operator can specify a file name and location on the PC disk drive where this position information can be stored for later use. Likewise, the operator can specify files where sensor data can be stored for later retrieval. In this mode, the operator has two means for entering position data. It can be entered via the Lab Windows Graphical User Interface (GUI) at the PC keyboard, using a full screen editor to input position coordinates, or the operator can use the teach pendant while standing outside the BPC to manually guide the arm to the desired positions.

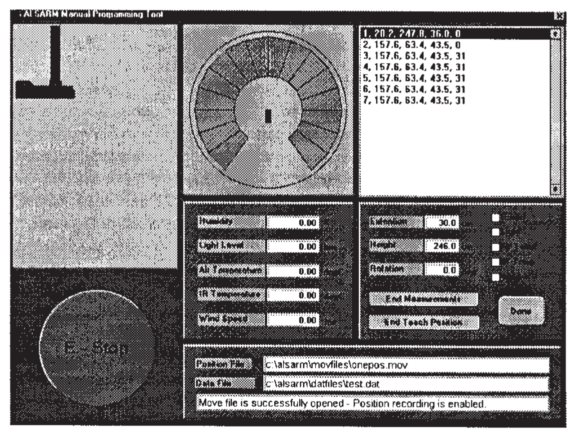

Figure 9.

Auto Mode is comprised of two operating states: Automatic Operation and Manual Operation. During Automatic Operation, the ECS uses the coordinate position files created in Teach Mode to move the arm to the set of predetermined positions and take measurements. The operator also has the capability to choose a continuous processing mode, which causes the arm to repeat the given set of movements for an extended period of time. During Manual Operation, the operator has the capability to suspend Automatic Operation and manually control the arm movements, either from the PC in the control room or at the BPC while using the teach pendant.

6. CONCLUSIONS

In our introductory statements it was pointed out that the ALSARM project has given undergraduate engineering students the opportunity to gain insight into how the skills they learn in school can be applied to real world situations. While no one involved in the project will argue this point, the process of translating an undergraduate design project into an operational device as was implemented in this project brought out many pitfalls. It is our hope that other groups wishing to embark on such a task will learn from our mistakes, and avoid the problems we encountered.

One serious problem we encountered in the project rests in the nature of contemporary undergraduate studies. The ALSARM project was presented as a class assignment involving many students over several semesters. This venue posed many disadvantages. First, students involved in the project had to divide their time between this project and the requirements of other classes. Second, as the project stretched across multiple semesters, many of the original team members graduated, changed majors, or were faced with other issues which caused them to be unable to stay with the project. As a result, the original design underwent several changes as new members got involved and brought in their own ideas. As the design changed, the schedule slipped.

Another problem which seems to be inherent in the traditional undergraduate system is the lack of a proper skilll mix among the participants. While the project was designed for electrical and mechanical engineering students, it seems that the bulk of student involvement came from the mechanical side of the house. While the students who worked on the electrical systems did a fine job, their presence in the project was lacking, which caused much of the arm’s electrical power and control system design work to fall into the hands of the NASA participants. Also, there was an almost total lack of student involvement from the computer monitor and control discipline. Once again, this glaring deficiency caused much of the work of designing and testing control software to fall into DM-ASD’s hands.

Coupled with these issues was the problem of communicating ideas into a form that could be used by NASA participants to fabricate parts. Through no fault of their own, many undergraduate students are unfamiliar with government and industry standards and requirements for producing documentation and drawings that can be easily interpreted by those groups and individuals tasked with turning designs into finished products. In many instances, documents and drawings had to be completely redone in order to put them in a useable form.

How can these pitfalls be avoided in such government/academia projects in the future? We hope the lessons learned from this experience will be used to make future projects run smoother or, at least, not fall prey to some of the problems we have encountered over the past three years.

As we have pointed out earlier, involving undergraduate students in such a design project gives those students experience that they would otherwise not get in an academic environment. However, as we also pointed out, undergraduates tend to “come and go”, which is counterproductive to maintaining continuity in a project stretching across multiple academic terms. In fact, only one student among dozens has been involved in the project from its beginning, and that student is now pursuing a Master's degree at UCF. We agree that giving undergraduates an opportunity to participate in such a project only benefits everyone; however, we would recommend designing this type of project around a graduate thesis program, where the primary designers, i.e. the graduate students, are afforded the capability to focus more intently on the project, and maintain continuity. Undergraduate involvement may take the form of directed studies wherein they work with the graduate students and instructors on components of the project, or auxiliary classes wherein students study and evaluate the designs the upperclassmen produce.

Also, such projects need to be designed to be more interdisciplinary, so that the skills and talents needed to address every issue will be available. Whether this statement implies that students from other departments or colleges should be offered the opportunity to participate in this type of project, or undergraduate engineering curricula should be modified to include at least a basic understanding of computer programming, for example, is up to the university to decide.

Another impediment to progress can be easily avoided by improving communication between instructors and their NASA counterparts before the project itself is begun. A great deal of time and energy can be saved if both parties define and agree to requirements and standards at the beginning. Producing documentation and engineering drawings is a time consuming activity; it is doubly so if students are required to produce one set of documents that meet the instructor's criteria, then have to redo those same documents to meet NASA's. By agreeing up front on the set of deliverables expected and the format which they are expected to take, the university and NASA can assure that student products are useful on all fronts.

While the design and development of ALSARM has been a long, slow process with a steep learning curve and many problems, the arm is almost ready for installation and operations in the BPC. ALSARM's data collection features should enhance current environmental monitoring capabilities in the chamber and provide valuable information on the design of the next generation of robotic devices.

First, installation of the arm will allow the length of time the BPC is closed to be increased. Currently, scientists are required to enter the chamber on a regular basis to obtain environmental and crop measurements. By using ALSARM to gather data, the need for breaking the chamber door seal will be reduced. Increasing the closure period will allow a more realistic assessment of the effects of closed atmospheres on crop performance. Keeping the chamber sealed for greater periods of time will reduce gas leaks, thus improving calculations of production rates of CO_2, ethylene, and various other gases. Also, reduced human incursion into the chamber will result in fewer opportunities to introduce contaminants from the outside environment.

Second, the arm will help improve understanding of the chamber environment. As mentioned above, ALS personnel currently enter the chamber to take measurements. Using the arm to do this work will result in greater accuracy by better control over positioning and increased numbers of measurements throughout the chamber. By monitoring data at precisely defined locations on a regular, periodic basis, researchers will gain additional insight into the interactions of crops with their local environment down to the single growth tray, if not individual plant, level. Such knowledge will allow scientists and engineers to modify the current chamber to enhance crop performance, and improve the design of future growth chambers.

Finally, since ALSARM is scheduled to be installed in the BPC upper chamber only, scientists will have the opportunity to compare and contrast two otherwise identical plant growth environments wherein one requires more direct human intervention than the other. ALSARM will provide researchers with a tool to help begin to resolve the question of human resources required for bioregenerative life support systems during long term offworld missions. Can such future missions afford to incorporate a “hands off” design philosophy in their life support systems, or will the inclusion of crew members with extensive plant biology knowledge and experience be a fundamental requirement for mission success?

Appendix A: Acronym List

AHU	Air Handler Unit
ALSARM	Advanced Life Support Automated Remote Manipulator
ASDL	Advanced Systems Development Laboratory
BPC	Biomass Production Chamber
CBP	CELSS Breadboard Project
CELSS	Controlled Ecological Life Support Systems
DM-ASD	Design Engineering Advanced Systems and Analysis Division
DM-DTL	KSC Prototype Division
ECS	Electrical Control System
EE	End Effector
GUI	Graphical User Interface
HTA	Horizontal Telescoping Assembly
JJ-G	Biomedical Program Office
KSC	Kennedy Space Center
LSSF	Life Sciences Support Facility
MAE	Department of Mechanical and Aerospace Engineering
NASA	National Aeronautics and Space Administration
NDS	Nutirent Delivery System
PAR	Photosynthetically Active Radiation
PC	Personal Computer
RA	Rotational Assembly
SA	Sensor Array
UCF	University of Central Florida
VTA	Vertical Telescoping Assembly