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Automated Software Systems for the CELSS Project

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Abstract:

The National Aeronautics and Space Administration (NASA) Biomedical Operatons and Research Office (MD) at Kennedy Space Center (KSC), Florida, is conducting research in the design and development of Controlled Ecological Life Support Systems (CELSS) to enable long-term human exploration of space and colonization projects. One component of a computerized CELSS system is the Universal Networked Data Acquistion and Control Engine (UNDACE), the software element designed to monitor and control plant growth environments.

NASA has been conducting research in automated plant growth systems since 1978. The CELSS Breadboard Project was begun at KSC in 1986 to study the feasibility of recycling plant biomass to ensure crew survival in environments where regular Earth-based resupply would not be practical. To date, the project maintains a Biomass Production Chamber (BPC) and five Environmental Growth Chambers (EGC's) dedicated to plant growth studies.

The UNDACE software used on a UNIX-based workstation network to monitor plant growth, acquire and store data, and control environmental conditions within the BPC and EGC's is designed to be machine independent, portable, and configurable to any hardware architecture chosen. The design philosophy of UNDACE stresses the use of current computer industry standards: the C programming language, UNIX operating system, TCP/IP network protocols, and X-Windows.

Future plans for UNDACE include greater use of Artificial Intelligence, robotics, enhancements to software devlopment, and increased command and control capabilities of integrated ecological systems.

Automated Software Systems for the CELSS Project

W. L. Little, J. O. Bledsoe, M. S. Grysikiewicz

The National Aeronautics and Space Administration (NASA) Biomedical Operations and Research Office (MD), Life Sciences Group (MD-RES), at Kennedy Space Center (KSC), Florida, is conducting research in the design and development of Controlled Ecological Life Support Systems (CELSS) for use in long-term human-tended space colonization efforts. The project seeks to perfect the engineering systems required for maintaining food and oxygen recycling, replenishment, and generation for astronauts engaged in missions wherein regular Earth-based resupply would be difficult and economically infeasible, as in a lunar base or a Mars exploration mission. Major components of CELSS are crop production, resource recovery (waste management), and monitor and control. These components must be integrated to produce a reliable system with minimal mass and volume which requires that we minimize buffers (e.g. support equipment size and capacity) and optimize control. One element of the computerized control and monitoring component of the CELSS project at KSC is the Universal Networked Data Acquistition and Control Engine (UNDACE), the software designed to automatically monitor and control the operations and environments of the crop production and resource recovery components.

The Life Sciences Group at KSC has been conducting research on plant growth systems since 1978. The CELSS Breadboard Project was begun in 1986 to study the feasibility of growing food sources to ensure crew survival in environments requiring a high degree of reliability and self-sufficiency. The primary focus of the project has been to demonstrate the possibility of long-term recycling of food, water and air. Currently, the keystone for this research is the Biomass Production Chamber (BPC), a two-story, sealed and environmentally controlled chamber housed in Hangar L at Cape Canaveral Air Station (CCAS). Also maintained at Hangar L are five smaller Environmental Growth Chambers (EGC's) used for plant growth studies and laboratories used to develop resource recovery components. Scientists and engineers use the UNDACE UNIX-based computer workstation system in their laboratories to monitor and control environmental conditions within the BPC component and EGC's.

The UNDACE package performs system configuration and control, data monitoring and acquisition, and user interface. UNDACE is composed of modules dedicated to these functions. These modules are written in the C programming language to take advantage of that language's power, flexibility, and platform independance. Other industry standards for networking and data communication and human-computer interfaces (TCP/IP network protocols, X-Windows) are used to ensure flexibility, platform independance, and ease of portability. There are eight primary modules: OPTO, STORAGE, REALTIME, USERPANEL, CALIBRATION, SETPOINT, GRAPH, and UTILITIES. Other smaller, special purpose modules comprise the balance of the package. Each module consists of a set of C functions grouped to perform a task or series of tasks. Some modules interface with others. Many of the modules interact with the system's shared memory segments and data files stored on hard disks.

The OPTO module, named after the OptoMux data acquisition hardware (OPTO22, Huntington Beach, CA) used extensively throughout UNDACE, is the central element of the system. Its primary purpose is to initialize the Brain Board system, process messages, monitor data, control data, and output data gathered from various CELSS experiments.

The STORAGE module acts as an interface between the UNDACE realtime data acquisition modules and the UNIX file system. Data gathered from CELSS experiments is accessed and written to disk files for archive and data retrieval purposes.

The REALTIME module reads real time data values from public brain boards and displays them on the workstations in the control room and on any office PC in the network. An experimentor can, for example, call up REALTIME and check on the carbon dioxide levels and ambient temperatures in the upper and lower chambers of the BPC.

The USERPANEL module acts as an interactive management routine to allow users with the proper permissions access to functions which control the state of the EGC's and the BPC. Via USERPANEL, a user can execute functions which can view and graph data, calibrate conversion modules, manipulate alarm set points and data files, and modify system parameters.

The CALIBRATION module allows an authorized user to preview and update calibration constants for the conversion modules. CALIBRATION works in concert with OPTO to update the system's configuration disk files.

The SETPOINT module allows the user to interactively adjust setpoint and control enable data values. It is the UNDACE equivalent of a command processor.

The GRAPH module accesses data stored via the STORAGE module and plots it on the workstation CRT in stripchart format. The user can display current data being gathered in real time, or select historical data, given begin and end dates and times.

The UTILITIES module houses various functions designed to facilitate use of the system, synchronize planned activities, and troubleshoot and debug software problems.

As with any complex computer-based control and monitor system, UNDACE is not without problems and shortcomings. Some are inherent in the off-the-shelf technology, some are home-grown. Some have been successfully resolved, some are still in work.

When network errors and losses occur, the Network File Sharing (NFS) default is to halt all active processes and keep trying to reestablish communication essentially forever. While that effort is underway, all other data storage processes are hung until the network is back up. This condition could cause loss of vital data. We have resolved the problem by altering the network default configuration to force NFS to return a failed system call. We have defined a short timeout interval and a fixed minimum number of retries, after which UNDACE is to stop attempting to reestablish the broken communication link and continue other tasks.

Error logging of "hard" failures within UNDACE has also proven to be a challenge. When a "hard" failure occurs, such as an loss of power to an OptoMux board, the error is logged to a disk file whenever the failure is detected. The interval at which the error is reported is defined by the task which logs the error. If such an error occurs, it could possibly cause a hard drive to be filled with one file consisting of the same error message repeated over and over again. Currently, the resolution is to report the error five times, then not write it to the disk again. This resolution has not proven to be the most successful as yet. While we are confident that the design of the remedy is a good one, the implementation has yet to yield the desired results in every case.

Input errors caused by breakdown of CELSS hardware components can also cause spurious data to be input to UNDACE data structures. For example, if a thermocouple breaks, it will return a temperature reading of -3823°C. UNDACE would normally react to such an out-of-specification reading by attempting to dump heated water into the BPC to bring the ambient temperature up. In the case of such an abnormal temperature input, UNDACE would use the last valid value in the softmodule register for that thermocouple to do further processing.

The last major problem UNDACE faces goes to the very heart of the existence of the CELSS project. At its current level of maturity, the system requires linkage to a human 24 hours a day. Any hardware or software problems that occur during off shift hours are reported to the CCAS Range Control Center (RCC) by the ALARM module, and the officer on duty calls a member of the CELSS staff to report the problem. That staff member on call is then tasked with coming in and resolving the problem. The long term solution to this problem is one of the primary issues we continue to investigate. We will touch on one possible software solution, artificial intelligence, later in this paper.

UNDACE is a growing and expanding software tool. As new user needs are identified and defined, and the CELSS project at large matures, new capabilities are designed and added. Future plans, both near- and long-term, point to UNDACE's flexibility and capacity for better meeting the client community's requirements.

A statistical module which will allow experimentors to compare current data to archived data from any given point in the pest is in work. This module will allow experimentors to compare the current state of the system with earlier states, examine changes and trends in plant growth, and derive alterations in growth chamber environments to tailor those environments to the given crops.

One of the primary long-range goals of the CELSS project is to develop self-contained plant and animal growth environments that are essentially "hands off"; that is, environments that can maintain and sustain themselves with minimal intervention from the astronaut crew. On a mission such as a moon base or Mars colony, personnel numbers will be limited, and the time and energy dedicated to monitoring life support components, and optimizing their production could best be accomplished mainly by machine, freeing parsonnel to do other jobs. To this end, two projects currently in work are designed to enhance the capabilities of CELSS in general, and the robustness of UNDACE.

The Advanced Life Support Automated Remote Manipulator (ALSARM) project, a joint effort between NASA and the University of Central Florida School of Engineering, has generated a design for a robot arm to be installed in the BPC. The arm will act as a transport device for an end effector, which will be a sensor/effector arrey used to gather data on individual growth trays and plants. Once installed, the arm will be interfaced with UNDACE so that arm manipulation and end effector data collection will be under UNDACE software control. Future development plans to utilize robotic manipulation for crop planting and harvesting, and materials handling are envisioned.

Dr. Alan Drysdale of McDonnell Douglas Aerospace KSC Division has been studying Artificial Intelligence (AI) software development for Advanced Life Support (ALS). Over the next year, Dr. Drysdale and the CELSS group will define further ALS data system requirements and functionality, and develop an expert system prototype. Once these two tasks are complete, Dr. Drysdale and his team will integrate their command and monitor system prototype into the CELSS Breadboard Facility (CBF), using UNDACE as the backbone. This effort should result in operational expert system modules for each component in place in the CBF by the second quarter of 1998.

Implicit in the software development effort for UNDACE is the need for enhancements in the software development and testing environment. To date, the old tried-and-true "manual" method of design, code, debug, test, and implement has proven sufficient, but hampers rapid development of new modules and quick turnaround of existing code enhancements and fixes. CELSS personnel have begun using commercially available automated software development and rapid prototyping tools in an effort to solve this problem.

Ultimately, our long range goal is to build a software and hardware environment that can control and monitor integrated life support systems. UNDACE and CELSS today are limited to monitoring and controlling the BPC and other support equipment. Our current level of development and integration is limited; CELSS cannot act as a true life support system as yet. As we include more components, we will expand the capabilities of the system to a point where it can be truly self sustaining, and provide the essentials of food, water, oxygen, and waste recycling to future explorers and colonists of our solar system.

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