The Space Congress® Proceedings

1994 (31st) Space Exploration and Utilization for the Good of the World

Apr 28th, 2:00 PM - 5:00 PM

Paper Session III-C - Controlled Ecological Life Support System Monitor and Control System

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Scholarly Commons Citation

Krauskopf, Jan; Drysdale, Alan; and Hendricks, Dave, "Paper Session III-C - Controlled Ecological Life Support System Monitor and Control System" (1994). *The Space Congress® Proceedings*. 5.
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Controlled Ecological Life Support System Monitor and Control System

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NASA has plans for long-duration manned space missions, including a return to the moon, manned flight to Mars, and eventual colonization of the solar system from the moon, to Mars, the asteroids, and perhaps the Jovian moons. For such long-term voyages in space, a life support system will be needed to provide food, replenish supplies of water and oxygen, and remove carbon dioxide. Accordingly, NASA started the controlled ecological life support system, or CELSS, program in 1978 to develop the technology necessary to support life in space, and sponsors CELSS projects at various centers and other locations. Since 1987, Kennedy Space Center (KSC) has been operating a CELSS Breadboard Facility, to which McDonnell Douglas contributes under the Payload Ground Operations Contract (PGOC).

At KSC, the CELSS Breadboard Facility has been constructed from a sealable chamber used to test the Mercury capsules in a reduced pressure, or vacuum, environment. The chamber is located in Hangar L at Cape Canaveral Air Force Station, and was modified to accommodate trays, ducting, and plumbing in order to support plant growth research activities.

Eleven other plant growth chambers, used for specialized plant growth studies at KSC, are also located in Hangar L.

The current supporting systems provide conditioned atmosphere, nutrient flow, and lighting. Some specialized equipment and sensors were also acquired. A limited number of support systems are tied into the closed-loop system. Additional support systems will be connected to the future-generation Breadboard in Phase 2.

The CELSS components, shown in Figure 1, may be itemized as follows:

1. Primary production
2. Atmosphere conditioning
3. Water processing
4. Harvesting
5. Food processing
6. Crew provisioning
7. Supply/resupply
8. Waste/resource recovery
9. Dump system
10. Electrical power
11. Physical automation
12. Monitor and control

The first nine are primary components and the last three are components that support or control the others.

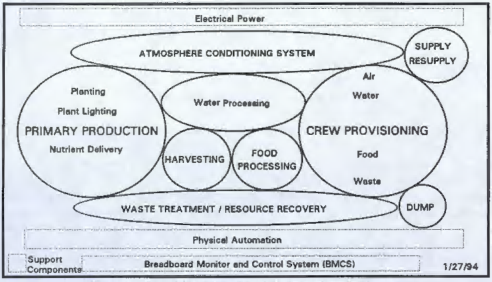

Figure 1 CELSS Primary and Supporting Components

The current breadboard functions in a semiclosed loop with six of the major CELSS components: primary production, nutrient delivery, plant lighting, atmosphere conditioning, water processing, and a second-generation monitor and control system.

McDonnell Douglas is currently involved in conceptual design for extensions to the Breadboard Facility, to be made in Phase 2, with well-planned and instrumented growth chambers and supporting subsystems. At the same time, the company is also developing concepts for the monitor and control system for the next-generation CELSS. This system will be a scalable, reusable, and cost-effective combination of hardware and software.

The monitor and control system is operational in the existing CELSS Breadboard Facility. The chambers and supporting supply systems are outfitted with sensors to monitor temperatures, pressures, airflow, nutrient flow, O_2 and CO_2 content, and relative humidity. The sensor data is analyzed by researchers to determine performance of the Breadboard and relate it to crop yields. The sensor data is also used to drive a system of control actuators that are programmed to compensate for out-of-nominal conditions.

The monitor and the control system is actually two different systems, designed to separate the functions as well as provide a degree of redundancy. These systems are currently used to track the activities of the plant growth chamber and the supporting components. Sensors and control devices are placed throughout the system on a limited basis, with some redundancy. The control devices are set for nominal values, like a household thermostat, to maintain the conditions perceived by the human to be optimal. The monitor system gives visual indications to the operator in the event of a problem so that the operator can manually set and adjust control system characteristics such as temperature and flows. The main function of the monitor system is to collect scientific data.

The monitor and control system is composed of five Sun workstations networked to a Hewlett Packard (HP) 9000-840 minicomputer with three HP X-terminals and two more Sun workstations. PCs are also connected on the network and operate in an HP terminal emulation mode for access into the system for data retrieval. Data are acquired with distributed, modular data collection assemblies consisting of a mounting chassis, power supply, a "brain board," and up to 16 conversion modules for the various input and output functions. These assemblies communicate with the controller by an RS-422 serial link at from 300 to 38400 bauds. This equipment is manufactured by OPTO22 under the name of OPTOMUX. Additional information on the system may be found in Bledsoe, Fortson, and Sager.

Future efforts involve the design and construction of a Phase 2 breadboard, along with the design and implementation of the monitor and control system. The remainder of this paper focuses on the plans and progress to date of the monitor and control system itself.

A systematic series of planning, analysis, and development activities is being performed on this project in order to specify detailed requirements for the design and implementation of the new system. Figure 2 illustrates the planned system development procedures.

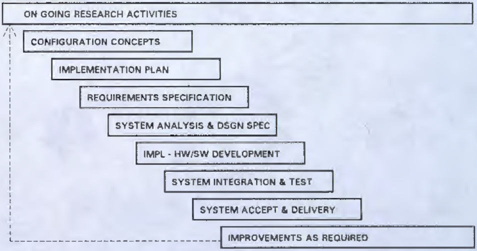

Figure 2 Phase 2 Monitor and Control System Development Procedures

The project team is currently finishing the implementation plan and designing the preliminary system architecture as part of specifying requirements. A real-time computer system will be used, based on industry standards, and with as much off-the-shelf hardware and software as possible. Well-established procedures and methodologies will be followed in design and implementation, and previous research and development efforts will be incorporated to the greatest extent possible.

The computer hardware and software used in the CELSS monitor and control environment will include the front-end interfaces to the CELSS sensors and actuators, the data processing computer system, the output devices (i.e., display terminals, workstations, and alarm consoles), and any additional peripherals required for real-time and posttest processing.

It is anticipated that typical monitor and control items will be used such as hardware interface utilities, generic system functions, specialized data processing utilities, and user interface utilities. The system architecture will be scalable, providing for subsequent system expansion. A potential system architecture currently under consideration is shown in Figure 3. Two or more processors will be utilized, with each assigned a designated processing function but acting as a backup to other processors in the event of a fault. This approach will provide scalability as well as fault tolerance, which is important to on-orbit, lunar, or other remotely located systems.

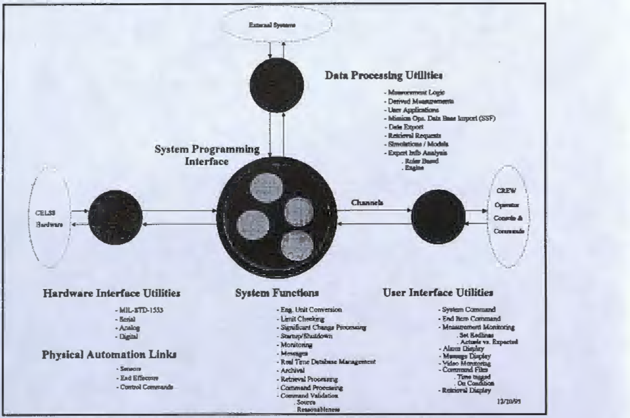

Figure 3 CELSS Breadboard Monitor and Control System Architecture

Industry standard hardware and software interfaces may be utilized to provide for compatibility of open systems. The hardware, software, and interface standards that may directly apply include the following:

- UNIX system V, or MS-DOS Version 6.2+ if PC-based
- POSIX 1003.1 and 1003.2
- ISO SC16 open systems interconnection protocol
- MIL-STD-1553
- IEEE 802 network standards (including Ethernet)
- DARPA TCP/IP networking protocol
- C-ISAM data structure
- ANSI X3.135-1986 SQL database interface
- IEEE 1014 (VME) bus interface
- IEEE 754 floating point number standard

The system architecture is derived from an MDSS-KSC project, the "RoadRunner" automated checkout system. The RoadRunner design team is composed of members of the teams that developed the partial payload checkout unit (PPCU) and real-time data system (RTDS). PPCU is currently used in the O&C building for integrating and testing payloads. RTDS was used in the checkout and flight of the Delta Clipper in White Sands, New Mexico in August 1993, under the Single-Stage Rocket Technology (SSRT) program.

This architecture is being considered for use on the monitor and control systems because it is a highly scalable design. RoadRunner can be tailored to systems requiring throughputs from low rates such as five-minute sample rates up to high rates such as 10 megabits per second without increased costs for the original kernel. This is a significant breakthrough in checkout system technology. The RoadRunner system architecture is based on an integrated approach, applying the following concepts and principles:

- Design based on lessons learned from PPCU and RTDS
- Major design goal is greater system and software simplicity
- 100% off-the-shelf hardware
- Architecture scalable to match throughput requirements for a wide range of applications.
- Evolutionary style software development

While the specific performance capabilities will depend upon the CELSS requirements as they are identified, the RoadRunner model has been evaluated for baseline throughput rates. These rates, as identified by the RoadRunner team for a generic checkout system, are given in Table 1.

The RoadRunner system consolidates the RTDS/PPCU data acquisition processor, the application processor, data base subsystem, archival/retrieval subsystem, display processor, and the generic data acquisition software onto a single platform. The platform is the new multiprocessor DEC Alpha AXP system. A front-end VME interface attaches to the DEC 100 Mbyte/sec VME bus adapter (15 Mbytes/sec). The front-end interfaces convert the raw input data into generic 40-byte data packets and send the data to the RoadRunner kernel. In Figure 3, the kernel is the central bubble in the diagram. The kernel converts all engineering units, checks limits, and processes significant changes in the data from the front-end interfaces. The kernel also processes system boot and shutdown requests, health-monitoring, commands, and archiving and retrieval. Data are displayed to the user on X-Terminals or Unix Workstations.

Table 1 RoadRunner Performance Capabilities

Capability	RoadRunner
PCM Downlink Telemetry Rate	250bps-10Mbps (Note 1)
PCM Downlink Telemetry Channels	9/VME chassis
Input Data Latency to Display	< 5 msec
Command Throughput	72 kbps
Command Latency From Issuance	< 5 msec
Reactive System Response Time	< 5 msec
RF Uplink	72 kbps
Data Display Rate	20/sec
IRIG Time Accuracy	1 msec
ARS Storage Capacity, Short-Term	Configurable up to 40 Gbytes
Internal Data Bus Rates	150 Mbps
Discrete Input	32/card (Note 2)
Discrete Output	32/card (Note 2)
Analog Inputs	32/card (Note 2)
Analog Outputs	16/card (Note 2)
GSE Measurements	FDDI - 100 M

Note 1. A 20 Mbps COTS PCM card should be available by 1995.

Note 2. The standard VME chassis has 20 slots, 1 for CPU card, 19 for I/O boards

In this architecture, hardware interface utilities, data processing utilities, and user interface utilities are adjacent to the kernel. While the original RoadRunner team develops the kernel software, the Breadboard system development team uses the existing kernel, and develops the hardware, data processing, and user interface utilities. Off-the-shelf software is used to a great extent. The area of the user interface, discussed in the following text, has been considered in some detail by the Breadboard system team.

The graphical user interface will provide menus, icons, dialogue boxes, and other graphical interaction devices. This interface will be consistent, easy to use, reliable, and concise. The interface will have the same user dialogue constructs, appearance, and procedures for similar functions across various aspects of the system, and extensive external documentation or training will not be needed to use it. Being reliable, the user interface will exhibit identical behavior and uniformity between screens and levels of detail as the user migrates through the applications. And being concise, the interface will reduce or eliminate superfluous color, motion, dialogue, graphics, and input actions.

The display console software will provide the man-machine interface for CELSS. This software will provide windows for displays, utilities to build and modify displays, pop-up-window management, user-initiated commanding, system health and status monitoring, access to viewing and modifying database tables, access to posttest data analysis, and access to the expert system and simulation software functions.

Displays may be created and modified at any time during system operations. Operations typical of this capability will include:

Power-up and initializations
Setting data input and output formats
Sending commands to the control devices
Changing displays
Building displays
Editing displays
Modifying data in any database
Viewing configuration data
Modifying configuration data
Monitoring acquired data

Through the above functions, the system will provide effective use of sensor data, specialized instrumentation, data analysis, and user displays to ensure that the various CELSS components are performing correctly. One can use a wide variety of hardware and software in a system to customize the functions and user interface through high-level graphics-oriented application software.

In addition to displays of sensor and instrument information, analyzed data may be displayed, both current and historical. With graphical user interfaces, specified users will be permitted to customize and dynamically change the software-driven displays to provide multiple levels of detail. Provision will also be made for audio, voice input and output, and video. This approach permits equipment to be optimized by implementing generic hardware components for a variety of functions. Each type of display is equally easy to identify, use, and integrate into the system. System equipment should be optimally chosen to achieve the flexibility and performance benefits required of the CELSS applications.

The hardware interface and data processing utilities have not yet been considered in much detail. The sensors and effector requirements must first be analyzed to define the hardware interfaces. Many of the data processing utilities can be provided by off-the-shelf tools such as LabWindows or DADiSP. Again, a great deal of requirements analysis must be done first.

As stated earlier, the Breadboard monitor and control system for Phase 2 is still in the conceptual phase. We expect that the project will move into analysis and design in the middle of 1994, and that by next year's Space Congress, we will have begun the actual design work.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions made by others on the CELSS Breadboard Facility research team at KSC. Funding is provided by NASA headquarters, while KSC sponsors the local CELSS activities, including the use of Hangar L at Cape Canaveral Air Force Base. The Bionetics Corporstion also conducts research and support activities related to the Breadboard Facility.

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