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Monitoring and Control for Artificial Climate Design

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ABSTRACT

The monitoring and control of an artificial climate is necessitated by the Mars Dome Project (MDP) [ref 1]. MDP is designed to grow plants in an enclosed structure under reduced pressure. This system includes a dome enclosure, an environmental control system, a plant growth system, a data logging system, and an external vacuum vessel [ref 2]. Each of these systems is integrated by the use of a solid-state control device located inside the base of the Atmospheric Tower Management System (ATMS). Details of the controller follow a short summary of the major components of the MDP.

INTRODUCTION

Plants have several basic requirements to grow, light, water, CO_2, nutrients, and thermal control plus additional requirements such as a base structure (soil), airflow, horticultural maintenance, and so forth. The environmental requirements for plant growth may be summarized by the following ranges: temperature 10 to 30 ° C; water vapor 2 to 3 kPa; CO_2 1 to 2 kPa; O_2 greater than (approximately) 5 kPa; light intensity 100 to 500 µmols; and air flow 0.1 - 1.0 m/s. The maintenance of these levels in a reduced atmosphere is not a trivial problem, especially when corresponding parameters display large swings outside the controlled environment. This would be the case on Mars. The investigations of plants cultivation in a closed volumes for space applications [ref 3] have been conducted [ref 4][ref 5] [ref 6] and provide the ideas for formal mathematical description of plant growth. A general equation to represent the development of plant growth in a closed system can be formulated by the following:

$$\frac{1}{X}*\frac{d}{dt}X = m*f(P,RH,T)*\frac{J}{K_J+J}*\frac{S}{K_S+S}*\frac{C}{K_C+C}$$

X = plant biomass
m = specific growth rate
J =intensity of illumination
S =limiting factors of plant growth nutrients
C =CO_2 concentration in the system
K_J,K_S,K_C = constants of plant growth
f(P,RH,T) = function of environmental parameters, that reflects the greenhouse microclimate influence on plant growth
RH =relative humidity
T =air temperature
P= air pressure

Attempts to generate a more detailed practical applicable expression for f(P, RH, T) related to Closed Ecosystems (CES) have been ongoing from the 70's [ref 5] till the present time [ref 6]. Climate parameters T, RH, P are closely interconnected in CES on the basis of the closed water cycle [ref 7][ref 8]. Environmental parameters presented in the general equation can then be further subdivided into corresponding equations that narrow in on their specific control algorithms. A general picture of these environmental relationships is shown in figure 1.

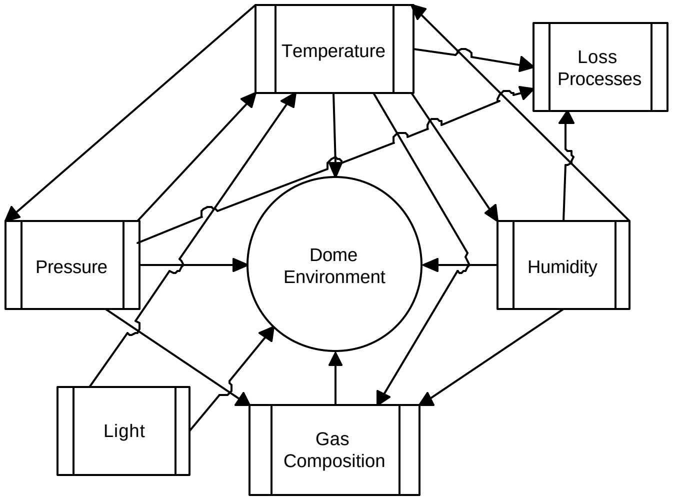

Figure 1 Relationships of parameters.

The ability to effectively measure and control these various parameters involves the use of sensors of which the reliability of measurement for use in feedback control is currently still in question at low-pressure. The Mars Dome Project is designed to test all the various combinations of climate design and control.

MARS DOME PROJECT

The Mars Dome (MD) is a half spherical lexan enclosure that is mated to a stainless steel base. The base is fitted with ports to allow access for instrumentation and to pass control lines for environmental control. A general layout schematic is shown in figure 2. A photo of the dome is shown in figure 3 [ref 9].

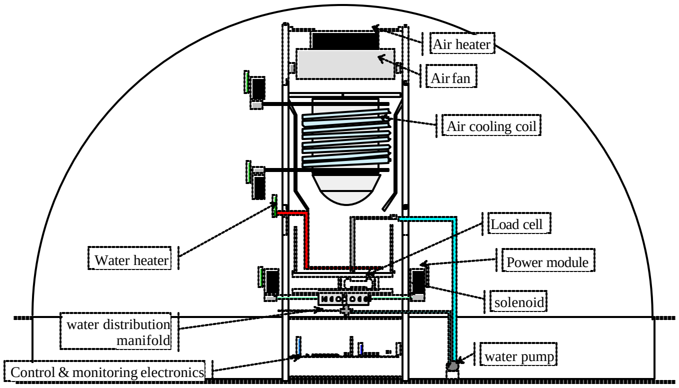

Figure 2 Dome Schematic

Based on the model and algorithms, the interior environment is kept within desirable limits by activating several control outputs at the appropriate times. The control outputs are comprised of an air heater, a water heater, an air cooler, an air pump, and a fan.

The MD is designed as a pressure containment device that will be placed into a large vacuum chamber built by Thermotron [ref 2]. The chamber is fitted with a water cooled lighting system and has multiple ports for interfacing both to instrumentation and for connecting to the MD interface system. The Thermotron has the ability to maintain Martain normal pressure (~1kPa) but cannot maintain normal Martain temperature. The main goal of this project is to test plants and systems at low-pressure.

There are three environmental control parameters to maintain the interior environment: temperature, pressure, and humidity. These three factors are not independent. A change in one affects the other two. Temperature and pressure affect each other as described in the gas laws. Humidity or vapor pressure is also related to temperature change by the gas laws.

Figure 3 Mars Dome at KSC

Plant Growth system

The MD system has a primary goal of growing plants for food with secondary goals of oxygen production, water purification, and CO_2 removal. Plants can effectively accomplish all of these goals when grown in the proper environment with the required water and nutrients. The main function of the plant growth system is to provide water to the plants at an optimum rate. The delivery of nutrients will initially be done with a time-release fertilizer. Later, a soluble nutrient solution will be added to the water delivery system. The water delivery system has four parts, a storage tank, weighing scales, a water pump, and a water distribution system.

A metered approach is taken to plant water delivery. Initially, the seeds are placed into pots with soil. The pots are placed on individual scales. The pots and plants are periodically weighed. The pots have individual irrigation lines fed by the water distribution system. The water distribution system is operated by the controller. When the weight of a pot and the plant indicates a deficiency of water, the pump is turned on and the valve to that particular pot is opened. Over time, transpiration and evaporation from the plants and pots will contribute water vapor to the chamber atmosphere. This causes an increase in the humidity and thus requires that water be removed from the system. The removal of water is done by passing the humid air over a condensing coil. The condensing coil is made of stainless steel tubing. Cold water is passed through the coil tubing. Condensation is collected into a storage tank. As each plant grows, its weight is monitored and its pot watered accordingly. This approach effectively establishes a feedback loop to implement a measurement-based allocation scheme, resulting in a dynamic water allocation policy. The water flow through the system is shown in figure 4.

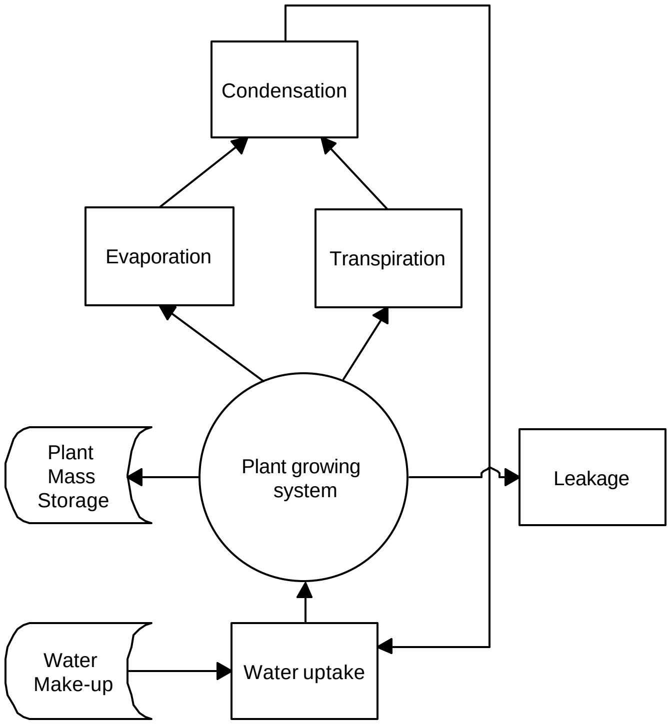

Figure 4 Closed system water cycle

The Controller Hardware

There are several challenges to the design and construction of the controls of such a system. First, it is desired that the controller hardware be small enough to fit within the chamber. Moreover, it must be flexible and scalable enough to accommodate various research configurations, while keeping the development cost and subsequent programming efforts low. The hardware design, developed by Rigel Corporation [ref 10], specifically for this mission is based on a distributed control system using multiple low-cost processors.

The controllers and signal acquisition are implemented by a set of adapter boards, all of which plug into a baseboard. High current output drivers are placed at the loads distributed throughout the chamber. These drivers receive signals from the controllers as well as power from several chamber-wide power buses.
The baseboard houses the master controller and the power supply. Most of the control work is conducted by slave processors, placed on the adapter boards. The baseboard has a series of sockets for the adapter boards. Any combination of the adapter boards may be plugged into the baseboard. This provides much needed flexibility and extensibility.

The adapter boards also contain “smart” chips with on-board data processing capabilities. For instance, several analog-to-digital converters (ADC) contain on-chip intelligence to configure and condition the input signals. Such smart chips make it feasible to use the same hardware for the various analog inputs, such as load cells, humidity sensors, and light level sensors.

The digital inputs and outputs are implemented by a dedicated microcontroller running in a single-chip mode. That is, all the code and data memory, as well as the input and output ports are on the same microcontroller. These are called “deeply embedded” controllers. From the outside, they appear as specialized and dedicated “smart” chips. In this sense, these controllers are similar to the familiar application-specific integrated circuits (ASIC). However, they are fully programmable to allow future customization as the research needs arise.

The intelligent adapter boards perform many of the needed logic functions locally. Much of the data is processed into a higher level of abstraction before being passed on to the master processor. Ideally, the master processor simply requests processed information concerning the state of the chamber and issues the control commands. Many of the smart chips on the adapter boards use some form of synchronous serial interface, such as I^2C, MicroWire, or SPI [ref 11]. The dedicated microcontrollers on the adapter boards also implement synchronous serial port in software. This way, all inter-processor communications are conducted by synchronous serial communications.

One such adapter board uses the ADS1241 chip to read 24-bit analog inputs. The ADS1241 uses a delta-sigma ADC to implement up to eight channels of single-ended analog inputs or up to four differential pairs of analog inputs. A single adapter board houses four ADC1241 chips, capable of monitoring 16 load cells with minimal external circuitry. Next, we examine this subsystem in more detail.

The Load Cell Subsystem

Each load cell is a Wheatstone bridge, supplying a differential voltage proportional to the weight. Analog signals from the load cells are sent to the analog-to-digital converters (ADC). The ADCs are type ADS1241, manufactured by Burr-Brown, now a subsidiary of Texas Instruments [ref 12]. The ADS1241 is a precision, wide dynamic range A/D converter operating from 2.7V to 5.25V supplies. The delta-sigma A/D converter provides up to 24 bits of conversion values with no missing codes. Its effective resolution is 21 bits. Compared to the older generation ADCs, the ADS1241 is a "smart" chip. It has several modes of operation and a programmable analog front end for signal conditioning. It also performs self-calibration functions. The conversion values may be modified by a 24-bit offset. The offset determines the input voltage that gives a zero conversion result. Similarly, the conversion value per millivolt input may be programmed. This effectively determines the input voltage that generates the maximum (full-scale) conversion value.

The ADS1241 is controlled by a synchronous serial port, implemented using only three signal lines. The communications between the processor and the ADS1241 consists of commands issued by the processor and the data read from the ADS1241. More specifically, the processor writes to control registers in the ADS1241 to configure the chip and issue commands. The status of the chip as well as conversion results are read from the status and data registers of the ADS1241. Since differential inputs are used, each ADS1241 can read four load cells. The adaptor card houses four ADS1241 chips. Therefore, each adaptor card may read up to 16 load cells.

An accuracy of 100mg is chosen. A nominal pot weight of 2kg +/- 100g is assumed. When the seeds are placed, each ADS1241 channel is "zeroed out." That is, the ADS1241 is programmed with the appropriate offset value to return a conversion result of zero. Next, the ADC1241 channel is calibrated. We use a 100g weight, and program the ADS1241 channel to output a value of 2000. Once calibrated, the ADC conversion result has a resolution of 100/2000 g, or 50mg.

Although the differential inputs are relatively insensitive to common mode effects, we still experience some signal noise and load cell drift. A moving average methodology is implemented to further filter high frequency elements of the conversion data sequence. The method simply averages the most recent N observations. The parameter N is referred to as the window size, or the sample size. A new average is obtained each time a new conversion is performed. Let X(i) be the ith conversion result and Y(i) be the i-th average. Then,

$$Y(i) = Y(i-1) + \frac{X(i) - X(i-n)}{N}$$

The averages Y(i) are valid after the first N conversions. The method gives an accuracy of +/- 100mg, as desired.

CONCLUSION

This paper represents a small portion of the overall effort that is currently taking place to solve the problems of plant growth at low-pressure. Many of the same experiments are being conducted in a new facility at the University of Guelph, in Canada. It is very important to understand the physics involved with the measurement aspects so that reliable signals can be sensed for the control side of the problem. Intelligent control systems are being developed that will allow for the rapid interfacing to almost any sensor required.

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