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SYSTEMS MODELING IN ALS: A SIMULATION-BASED OPTIMIZATION APPROACH TO MODEL AND DESIGN LIFE- SUPPORT SYSTEMS FOR MANNED SPACE MISSIONS

Dr. Seza Orcun, Dr. Selen Aydogan:

A life-support system for manned space missions is subject to many operating degrees of freedom. The choice of optimal values for these, e.g., values which would minimize the amount of re-supplies or would provide a safe environment for the crew members can only be made by considering the performance objectives of the integrated system. Furthermore, the system will be subject to many dynamic factors such as time-varying boundary conditions, system parameters that drift with mission time, and unplanned operating events. A novel approach, SIMulation-based OPTimization (SIMOPT), is proposed to design the life-support system for manned missions and understand the dynamics of it.

Development of the SIMOPT framework for studying the behavior of different life-support systems. The architecture includes an optimization module, which combines a diet optimization and crop-planting scheduler, a simulation module, which is used to determine the behavior of the system, and a time-series data-mining module, which scans the data. It is concluded that with the current technology levels, for no more than a 600-day mission to Mars, PC (physical-chemical) waste- recovery technology seems to be the most promising one.

Development of the SIMOPT framework for life-support system process synthesis. The main driver for a life-support system for manned space missions is the crew. Specifically, the life-support system should satisfy crewmember requirements or demands for basic life-support elements, such as O₂, H₂O and food. The conceptual design of the framework has been completed and it is implemented using Java. *A manuscript has been prepared with the detailed results of this study and is currently under review.*

Dr. George Chiu, School of Mechanical Engineering:

A control oriented model of the Plant-based Anaerobic-Aerobic Bioreactor Linked Operation (PABBLO) was developed based on first principles and validated with experimental data. An optimal control problem was formulated to find an input feeding strategy to maximize the net energy generation of the PABBLO process. Due to the bilinear structure of the system dynamics, the energy based cost function and the physical constraints; the optimal control exhibits singular characteristics. Numerical computation identified the optimal control strategy that will maximize the net energy generation for a given volume of input material. The optimal control strategy exhibits bang-bang control characteristics and the timing of the transition depends on the current system state and the operating constraints.

Jun Cai the graduate student working on this project has completed his course work and defended his thesis in October. We expect him to finish and deposit his MSME thesis by the first week of December.

Dr. Yuehwern Yih, Tze Chao Chiam, School of Industrial Engineering

Simulation of Control Policies for the Health-Monitoring System of a Closed System for Human Habitation of Space

A simulation and development of control strategies for a health-monitoring system is developed to assist decision-making in choosing control policies in a closed environment. This closed environment consists of a simplified representation of the water subsystem based on the documentation by the National Aeronautics and Space Administration (NASA). The water requirement (consumption) and generation are based on the crewmembers' demographics, activity schedules as well as intensity of each activity.

The health of this system is the result of the intricate interaction between the crewmembers as well as the water subsystem. The primary measure of the health of the system is the "state" representation of the system. This representation is a conglomeration of various hourly assessments of different aspects of the system. These aspects include the deterministic as well as the stochastic nature of the system. Due to the potentially vast number of possible states in the entire state space, state reduction techniques as well as assessments for infeasible states are applied for state reduction. A reward system is designed for allocating reward/penalty values to system states that satisfy predetermined conditions. Due to the strong stochasticity and the "memoryless" property of the system, the transition of system state can be modeled as a Markov process.

Transition probabilities are obtained through the simulation of the Markovian model. These probabilities, together with the reward values are formulated into appropriate mathematical representation and are solved by applying the Policy Iteration (PI) algorithm. The outcome from PI is an indication of the "best" policy to be applied when the system is in a given state. Several Artificial Intelligent techniques such as artificial neural networks, fuzzy logic, etc. can also be applied based on the outcomes of the simulation.

Various scenarios with different system design, magnitude of stochasticity and system modules such as the addition of a crop subsystem will be studied to evaluate the benefits of applying this methodology. Simulation was done in three stages: Data Collection/State space exploration, System Evaluation with Dynamic Policy and System Evaluation with Fixed Policy. The Data Collection stage was performed through 24000 ticks (simulation hours) of simulation time. With the use of the Random Walk (Drunkard's Walk) technique, 120 states were captured. Outcomes from Stages 2 are compared against a system that is not modeled as a Markov process and uses a different policy. Due to the use of a controlled input of common random number stream, a paired t-test is used to compare the outcomes of the simulation with best policies and one with a fixed

policy. Statistical analysis shows that the system with best policies performed at a level that is 34.7% more superior (in terms of reward value) than the system with a fixed policy.

Modeling and Control of Breathe I system. Two dynamic equations describing the mass balance of air/water treatment system (Breathe I) have been set up. Based on these two equations, we have developed a simplified bilinear plant model to analyze and synthesize appropriate control algorithms. We have developed a model predictive control strategy to maintain system output to within acceptable range under prescribed power constraints.

Control of PAABLO (Plant-based Anaerobic-Aerobic Bioreactor Linked Operation) system.

Conducting experiments to determine the amount of methane produced and thermal energy used with respect to temperature, residence time and moisture concentration from plant residues. We are using the data to characterize the response surface of the methane-production system to those 3 parameters. Based on these data, a control strategy will be developed to minimize energy while maximizing methane production. Based on our comprehensive literature review from different sources, under different conditions, and compared to each of their experiment setups, we have fixed our experiment plan, including variables to be measured, sample rate and number, equipment to be used, and thermodynamics of the reaction. We further refined our experimental plan in collaboration with Statistical Consultant Service at NASA. The plan uses the Central Composite Design to characterize the response surface.

System control and energy analysis. Model Predictive Control (MPC) formulation will be used to develop a subsystem level control strategy to maintain adequate life-support capacity but minimize energy consumption or maximize subsystem level efficiency. A phenomenological dynamic model for the NSCORT water/air treatment systems will be developed based on existing data and estimations. This model will be used to formulate and design the MPC controller. The result of the investigation will provide capacity and efficiency requirements and the associated control strategy to maintain adequate air and water reclamation for the crew. It will also provide the necessary dynamic response for other systems that are directly connected to the air/water treatment systems.

Impact of Plant Transpiration on Integrated System. From our detailed discussion with the Biomass Production group we realized that current estimates of plant transpiration (1400 Litres/day) meaningfully impact the sizing of condensing and water-treatment units. Given the lower radiative burden of the LED (Light-Emitting Diode) lighting systems, plant transpiration under LEDs could be significantly less than current lighting conditions. These potential savings further capitalize on reduced power and cooling requirements to operate the LED lighting systems. In collaboration with the biomass production project James

Russell conducted a literature search and evapotranspiration experiments to evaluate plant transpiration under different lighting conditions.

Publications in 2007:

Aydogan S., S. Orcun, G. Blau, J. F. Pekny and G. V. Reklaitis (in review). A Novel Approach for Life Support System Design for Manned Space Missions. Acta Astronautica.

Aydogan S., J. F. Pekny, and S. Orcun (2007). Effect of Different Waste Recovery Systems on the Overall Waste Generation Rates for Advanced Life Support System. International Journal of Environment and Pollution, 29-1/2/3, pp 232-253