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# LOGISTICS ISSUES IN AUTONOMOUS FOOD PRODUCTION SYSTEMS FOR EXTENDED DURATION SPACE EXPLORATION

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## ABSTRACT

To enable longer space missions, systems for production of food in space will be necessary. The Autonomous Life Support System (ALSS) program of NASA is an on-going research effort in this direction. This research uses intelligent agents to relieve the crew of substantial efforts relating to the food production tasks. In this paper, we propose a Contract Net Protocol approach to schedule transportation activities within this environment. A discrete-event simulation model using QUEST software (by Deneb Robotics, Inc.) is used to represent the flow of the transportation traffic within the system.

## 1 INTRODUCTION

Establishment of a long-duration human presence on the surface of Mars or the moon will require highly reliable and efficient systems to provide basic life support functions for the crews stationed at these remote locations. For long term missions, it will not be economically feasible to re-supply these life support elements from the earth. Humans will need to develop systems to produce food, purify water supply, and regenerate oxygen from the carbon dioxide they expel.

The Advanced Life Support System (ALSS) program at NASA has examined growing plants for food and oxygen regeneration, and use of physico-chemical and biological methods to process waste into usable resources, and has begun human testing within ALS at Johnson Space Center (JSC). ALSS concept, an on-going research project at NASA, seeks to develop a human life support system, supplying food, water, and oxygen, open with respect to energy but closed with respect to mass, that can operate for long periods in space without re-supply from the earth (NASA-JSC 1999).

Vertically Integrated Food Production System (VIFPS) is a model for supporting logistical issues relating to food production in the ALSS. The model seeks to address all activities ranging from planting to harvesting to food preparation. The model deals with scheduling of operations related to feeding astronauts in outer space assuming little or no re-supply.

The tasks included are planting, monitoring, harvesting, recycling, processing, and food production. The intelligent agent paradigm is well suited for implementing an approach to autonomous control in this production environment. A simulation model is used to visualize the results of the operations schedule obtained from the intelligent agents.

## 2 FOOD PRODUCTION LOGISTICS

The ALSS is developing a large-scale facility capable of long-duration testing of integrated life support systems. It will also offer a testing environment for the many existing regenerative life support technologies and for emerging technologies presently under development.

This test complex, referred to as BIO-Plex (Figure 1), and all of its components will be the basis for future long-duration human missions on lunar and planetary surfaces (NASA-JSC 1998).

BIO-Plex is comprised of a series of interconnected chambers with a sealed internal environment outfitted with a system of internally distributed utilities capable of supporting a test crew of four for periods exceeding one year. The full configuration calls for a habitat chamber, a life support systems chamber, two biomass production chambers (BPC1 and BPC2 in Figure 1), and a laboratory chamber; all of which are linked by an interconnecting tunnel with access through an airlock The BIO-Plex facility is located at NASA Johnson Space Center and all the activities addressed in VIFPS are performed there (NASA-JSC 1998).

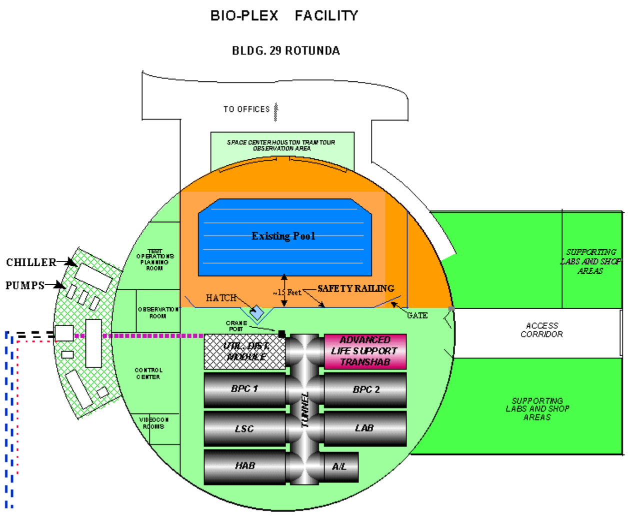


Figure 1: Bio-Plex Facility

The food production system, in the Bio-Plex, is contained in two chambers and the main tunnel. Farming procedures are performed in BPC1 and BPC2, the inventory, food processing and food preparation areas are in the main tunnel (Figure 2). Material must be transported from one area to another for different processes. Because the food production system is to be autonomous, several automated guided vehicles (AGV), capable of holding different capacities are likely to be used to transport material from one area to another. The AGVs may be responsible for picking up and delivering material to different areas. Therefore, the scheduling involves assigning vehicles to specific pick-up and drop off tasks without having to rely on human input.

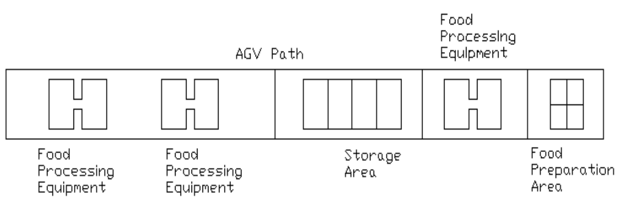


Figure 2: Main Tunnel in BIO-Plex Facility

## 3 AN INTELLIGENT AGENT –BASED FOOD PRODUCTION MODEL

The Vertically Integrated Food Production System (VIFPS) is a logistical system that is concerned with all activities that deal with producing food for the astronauts. VIFPS addresses the scheduling of food production as well as menu selection and is expected to alleviate astronauts from doing tedious food production tasks. Decision-making in VIFPS is handled via a multi-agent network consisting of nine agents assigned to specific tasks. The agents and their broad functions are as follows:

*LTRP Agent* - plans a list of required raw materials for the next year

*Farmer Agent* - creates a plan for planting the seeds, growing and harvesting the plant

*Food Processing Agent* - processes the harvested raw material into edible food

*Inventory Agent* - keeps track of the amount of seeds, raw material and ingredients in inventory

*Short Term Menu Agent (STM)* - plans the menu for the next week

*Cook Agent* - prepares the foods based on the menu given by the agent STM agent

*Material Handling Agent* – transports material between processes

*Facilitator Agent* - delivers messages between agents

*Astronaut Agent* - represents astronauts food preferences

The agents do not directly communicate with each other. Agents first send messages to the Facilitator Agent who keeps a list of registered agents. The Facilitator Agent then sends messages to appropriate agents. The use of the Facilitator Agent eliminates the chance that agents will not receive their messages (at times when the agent is "inactive"). A modified Knowledge Query Manipulation Language (KQML) message format is used for message passing between agents. KQML provides a structure for message passing. Messages include a performative, sender, item type, item quantity, time, astronaut, location, and receiver. Where the performative is the instruction code to be performed, the sender is the agent that originated the message, item type is a code for the item, item quantity is the quantity of the item to be moved or created, time is when it is to be moved or created, astronaut represents the astronaut, location is where an item is located (used mainly for the Farmer Agent), receiver is the agent that is to get the message (Ram and Smith 1999).

The food chain (Figure 3) within VIFPS is broken into different stages from plant growth to meal preparation. Seeds grow into plants, plants are harvested to become raw material, raw material is processed to become ingredients and ingredients are prepared into menu items. Each portion of the food chain is prepared in a specific area that relies on material handling support to transfer from area to

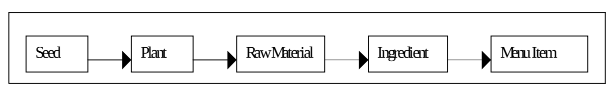


Figure 3: VIFPS Food Chain

area. Each area within the Bio-Plex has a principal agent that is in charge of all area functions.

All of the agents in VIFPS have a common framework. The agent architecture is adapted from the Bigus and Bigus (1997). The architecture class provides interfaces that allow agents to be added to the system, a method to give agent autonomy, and a communication system.

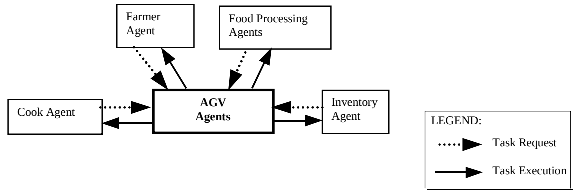


Figure 4: Principal Agent to Transportation Agent Communication

## 4 AGENT BASED SCHEDULING FOR TRANSPORTATION

We apply the Contract Net Protocol (CNP) technique to scheduling. CNP was first defined by R.G. Smith (1980) as a negotiation process between a collection of nodes. These nodes cooperate to determine a viable solution to a problem. The protocol consists of a manager agent, which is in charge of the tasks that are to be executed, and contractors, which are agents that execute the tasks. The manager has tasks that are to be executed and announces these tasks to the contractors. The contractors evaluate the tasks announced and determine if the tasks are plausible, and if they are, they will return a bid to the manager. The manager evaluates the bids, from the various contractors, and sends an award message to the best bidder.

It is very important to have a defined set of criteria for the contractors to determine whether to bid on a task and for a manager to select a bid.

The criterion is based on availability of the vehicle to pick-up and drop off at specific times. Each AGV is equipped with an intelligent agent that supervises its schedule and execution of tasks. Each AGV agent's main objective is to constantly be busy, so it tries to accommodate any task request that is sent. When it accepts bids, it is building an internal schedule and set of tasks for itself.

Figure 4 describes the areas that would need support from the AGVs. The Food Production, Farming, Inventory, Food Processing and Cook principal agents communicate tasks that must be executed. The AGV agents then perform these tasks for the agents.

Figure 5 illustrates the process of bidding and awarding tasks to AGV agents. When material is ready to be transported from one area to another, this principal agent takes on the role of the manager and sends a "Task Request Announcement" message, to each AGV agent, in the following format:

{Requester, Item, Quan, PULoc, POtime, DOLoc, DOtime, TN}

where: Requester is the principal agent that needs the task executed, Item is the material that needs to be picked up and dropped off, Quan is the quantity of the item, PULoc is where the material is originally located, Potime is when the material will be ready for transport, DOLoc is the material destination, DOtime is the deadline for the delivery of the material, TN is the identifying number for the task.

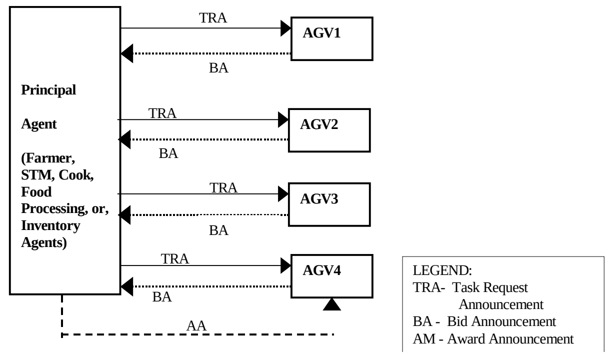


Figure 5: Sequence of Steps in Scheduling

When the task request announcement is received by the AGVs of the system, each AGV evaluates its current schedule and determines if it can accommodate another task at the specified. When determining if it can execute the task, it considers where it is currently located, how much time it would take to get to the pick-up and drop off locations and if it can handle the load. If the AGV can execute the task, it sends a "Bid Announcement " in the following format:

{AGV,TN, POtime, DOtime, Trips}

AGV is the AGV number, TN is the task number, POtime is the time the vehicle can pick up the material, DOtime is when it can drop the material off at the destination and trips is the number of trips it would take to drop off the quantity.

After receiving all of the bids from the qualifying AGVs, the manager selects the most appropriate AGV to handle the job. The manager makes its decision on which AGV can do the job in the least amount of trips and secondly, in the least amount of time. An "Award Message" is sent to the winning AGV in the following format:

{AGV, TN, Item, Quan, PULoc,POtime, DOLoc, DOtime, }

where: AGV is the AGV number, TN is the task number, Item is the material that needs to be picked up and dropped off, Quan is the quantity of the item, PULoc is where the material is originally located, Potime is when the material will be ready for transport, DOLoc is the material destination and DOtime is the deadline for the delivery of the material.

The winning AGV must send a "Reward Acknowledgement" message to the manager ensuring that it has received the task and has added it to its schedule.

Once a bidder AGV has accepted a task, it is committed to doing that task. Other tasks that the vehicle bids on are then scheduled around already awarded tasks.

## 5 SIMULATION ENVIRONMENT FOR THE FOOD PRODUCTION SYSTEM

A discrete-event simulation model using QUEST software (by Deneb Robotics, Inc.) is used to represent the VIFPS environment in BIO-Plex. This model uses 3D features of QUEST software to enhance the view of the environment The simulation model demonstrates the transportation traffic and flow within the system from growth chambers (BPC1 and BPC2) to food processing in the main tunnel (Figure 1).

The model here has been built upon the known components of BIO-Plex facility that is located at NASA Johnson Space Center (Figure 1). It consists of plant growth chambers as well as food processing and preparation areas in the main tunnel. Some components of this facility are still under development. Figure 6 shows the entire model that is built in QUEST. Figure 6(a) shows the food processing equipment layout. This figure illustrates the 3D model of Figure 2. The food preparation area is the first object seen in the front and the storage area and BPC1 (chamber with the tray) are seen in the back. This model is assumed to contain four AGVs to perform all the transportation requirements. The path for AGVs is set to allow access to BPC1 and BPC2 as well as the processing and storage area in the main tunnel (Figure 6(a)). Figure 6(b) shows the storage area and BPC1. Three AGVs are also shown in the figure.

The model will use the results of the scheduling decisions to test the feasibility of the model through the Simulation Control Language (SCL) that is imbedded in QUEST.

SCL is a powerful language that allows users to change the logic that drives QUEST while the simulation is running and provides much more flexibility in modeling. SCL makes it possible to automate the whole system by linking other applications with QUEST. Modifications made in the SCL file automatically change the behavior of the simulation model.

Figure 6(a)

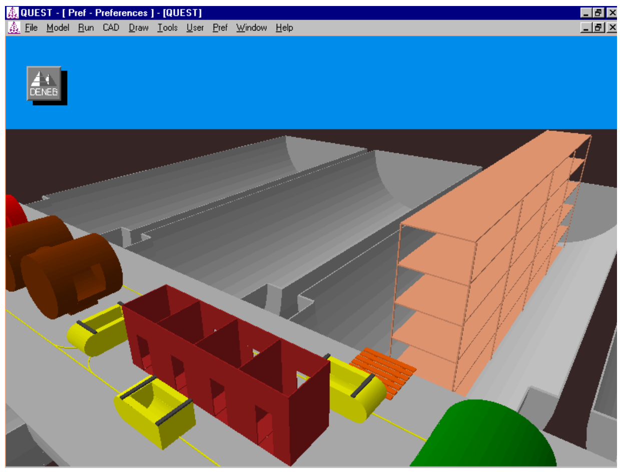

Figure 6(b)

Figure 6: BIO-Plex Environment in QUEST

Schedules are provided using Contract Net Protocol. This information contains pick-up and drop-off times for AGVs as well as the locations where they are needed. The information is stored as the input to the simulation model. An SCL program is attached to the AGVs and it uses the scheduling information in order to control the AGVs. An AGV picks up an item from a specified location at a certain time and carries it to a specified destination at a certain time as well. AGVs have unique agents associated with them that are also specified by the SCL program.

## 6 CONCLUSION

This paper provides an approach for scheduling material handling in an autonomous food production system. It consists of a CNP based method for scheduling and a simulation model to visualize the material handling operations in the system.

## ACKNOWLEDGEMENTS

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