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Automated Equipment and its Software for Mars: Leveraged Approach to Development

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ABSTRACT

During exploration and settlement of Mars hosts of automated systems will provide the needed services: processing materials, providing life support, as well as handling scientific research functions. Physical distance from Earth and the associated communication delays will make special demands on these automated systems. In addition, there are real unknowns; one cannot foresee all of the conditions under which this equipment will be used. There may certainly be a "creative" use that save lives of explorers and settlers. This paper considers the software required for such systems, and approaches to development that includes substantial leveraging from existing industry proven technology.

Programmable equipment will need to be programmed by those who use and depend on it. The equipment must empower the user. This characteristic is shared by some industrial systems used on earth today. This paper examines standards and practice of automation and communication in the semiconductor manufacturing equipment, where several decades of engineering work has provided a useful model for how many similar problems might be approached for equipment for Mars.

General engineering principles for embedded software for Mars will be discussed. Borrowing from the semiconductor manufacturing equipment industry, this paper examines:

- Generic Equipment Models,
- Equipment communications,
- Generation of "process programs" on site.

By starting with, and leveraging from excellent existing "industrial strength" technology, it will be possible to develop equipment destined for Mars that will exceed user expectations and even save development costs.

INTRODUCTION & PROBLEM STATEMENT

When Mars begins to be explored and settled a large array of equipment will be required on the planet's surface. Automation of equipment is an important issue; consider an individual's time as a most precious resource. Humans are also an asset in that they are flexible, creative and bring with them a wealth of experience upon which very good judgements can be made. Flexibility in the equipment will be required, if only to benefit from the presence of capable people. Since this is exploration, we expect the unknown and unforeseen as well. Designers and engineers on Earth cannot possibly anticipate all uses of the equipment they develop in advance. Instead of trying to anticipate everything, equipment must be engineered in reliable and robust ways so as to operate out-of-the-box, and additionally, operate from being programmed on Mars. Furthermore, provision must be made for reliable communication between equipment and complexes of computer systems. Data must be gathered, and operations and updates need to be made remotely. This is a big order, but good technologies already exist for this. Successful engineering models of this type of situation do actually exist already.

WHAT KIND OF EQUIPMENT ARE WE CONSIDERING?

For the purpose of this discussion, consider automated equipment that has sensors, and outputs control signals. It may control valves, current flow, or temperature. The equipment is intelligent, as in having a microcomputer along with embedded software. It has a LCD display, and means for manual entry, such as a keyboard. The equipment has an automated interface to a larger host computer that may passively receive streams of data, or engage in many types of automated services with the equipment. There are many other configurations, which are more complex in nature; these may be the subjects of further study. Figure 1 illustrates a general system of equipment interfaced to a central host computer system.

WHAT CAPABILITIES WILL BE NEEDED IN AUTOMATED EQUIPMENT FOR MARS?

Effective automation on Mars shares much in common with effective automation in demanding environments on Earth. While the exact requirements will vary depending on a specific machine or subsystem, the following is a good summary of basic equipment needs:

- Reliable, Continuous Operation: 7X24 (or maybe something better tuned to Mars),
- Reliable Communication Interface from equipment to host,
- Robust set of automation services, especially via the host interface,
- No unreasonable barriers to acquiring data and status information from the equipment,
- No unreasonable barriers to controlling any programmable part of the equipment,
- Efficiently integrated into larger systems,
- Excellent off-line tools for analysis and development,
- Reasonable development cost.

We will examine each of these areas in detail. Special consideration for equipment on Mars will be considered.

Reliable, Continuous Operation: 7X24

Equipment on Mars must work for the well being of the explorers and settlers. On Mars more of the environmental conditions will need to be generated artificially and need to function at all times. Their lives may depend on it. Furthermore, people there will be occupied, or may better have their attention spent on other activities than those amenable to automation. There is little point in bringing to Mars equipment requiring more human intervention than necessary.

Reliable Communication Interface from equipment to host

As an interface to relay data, as well as control commands, the interface needs to be reliable. Protocol for errors in transfer of information is essential, as all interfaces have some probability of a transient data failure.

Robust set of automation services, especially via the host interface

Given a reliable interface, many possibilities exist for using it. In the case of equipment placed outside a habitat on Mars, many automation services may be utilized without the cost and energy of becoming suited-up for work out of the habitat. The more robust the set of services are through the interface, the less the need for time consuming procedures.

No unreasonable barriers to acquiring data and status information from the equipment

As a general rule, if and item of data or status exists in the equipment, it must be must be readable via the interface. Software should not provide a barrier to this, but rather facilitate an open port to useful information. There are some important implications of this that will be discussed in some detail later, and could be the subject of subsequent papers.

No unreasonable barriers to controlling any programmable part of the equipment

There may need to be safety protections here, but nothing unreasonable. The point is to allow control of the equipment through **the interface**. Consider the case of a well-designed piece of equipment with a LCD display, and a brightness/contrast control for that screen on the instrument itself using the screen. If the screen is invisible, control cannot be handled through normal means, the equipment user could verbally request someone in the habitat to bring up a control screen for that equipment and change the screen conditions remotely via the interface to the host. No action would be needed right at the equipment to make this change.

Efficiently integrated into larger systems

The cost of configuring equipment for integration with other computers is expensive and difficult on Earth. On Mars the cost in terms of personnel time and effort must be accounted for, an minimized. Standards help here, keeping costs and efforts minimal.

Excellent off-line tools for analysis and development

No point in tying up important equipment to do statistical analysis, or edit a new process program. Equipment is generally placed on-line for a productive purpose. Furthermore, off equipment computers will be more suited for statistical calculations. Process programs intended for download to the equipment may be developed off-line and even simulated off-line. Good simulators with the addition of some Artificial Intelligence (AI) techniques can do the job better, and with less risk to people or equipment.

Reasonable development cost

This last point is serious. The amount of development budget one can consume in a mostly software effort is probably infinite. Given the potential financial costs of a poorly managed cost for development, this one point deserves consideration. Anecdotal evidence suggests that development projects where the requirements appropriately constrain and focus the development result in delivered projects. Unconstrained development may never deliver.

WHAT TYPES OF EQUIPMENT? WHAT CATEGORIES?

This paper considers equipment to operate on Mars. Specifically equipment which may do one or more of the following:

- Processes Materials,
- Transfers/Transports materials or manages material flows,
- Monitors, measures or inspects.

To elaborate on these three categories, equipment which **processes materials** may refer to environmental, agricultural or materials processing for experimental or industrial purposes. Processing may be mechanical, thermal, or chemical in nature. The material so processed may be gas, liquid, or solid state.

Equipment to **transfer/transport** includes robotics or hard-wired automation equipment. **Material flows** include both gas and liquid the equipment would control pumps and valves for example.

Equipment to **monitor, measurement** equipment may be research equipment, environmental monitoring of a habitat, or perhaps some form of automated microscope. **Inspection** equipment may employ a variety of techniques to detect and classify anomalies in material, an object or a process.

It should be clear that this discussion applies to a wide variety of equipment types. The categories above relate to existing, well-defined equipment types in semiconductor manufacturing; for these standards exist, and we may make use of them. Applicability of this paper to other areas, outside of the above categories, such as guidance and control systems are possible, though will not be considered as a topic in this paper.

Clearly, examining industry based standards can provide a wealth of useful technology for the design team. We will examine one example standard in detail, though many useful industry standards do exist.

BRIEF HISTORY OF APPLICABLE SEMI STANDARDS

Work began on a Semiconductor Equipment communication standard in the late 1970's. The basic idea was to define how existing technology could be used to allow semiconductor manufacturing equipment and a central factory computer. The SEMI E4 — SEMI Equipment Communications Standard 1 Message Transfer (SECS-I)[i] was first published in 1980 defined hardware/physical and data link information. Implementation could be accomplished given an RS-232 port on equipment and the factory host computer. Following this, SEMI E5 — SEMI Equipment Communications Standard 2 — Message Content (SECS-II)[ii] was first published as a standard in 1982. SECS-II defines the details of the interpretation of messages exchanged between intelligent semiconductor manufacturing equipment and the factory host computer. The messages defined in the E5 standard support typical activities required for IC manufacturing, though much of this is completely applicable to many other types of applications. The standard also defines means for extension: for the definition of equipment-specific messages to support those activities not covered by the standard message definitions.

Using the E4 and E5 standards enabled an advance in factory automation. Cost savings were often the result of simply reducing the need for people to enter and leave clean rooms to obtain data, or program process equipment; this could be done reliably and easily through the SECS interface.

In the 1980's advances in semiconductor technologies made the process of manufacture more complex and demanding, and the complexity of semiconductor equipment increased. Although the E4 and E5 standards provided a level of standards, the rich set of possibilities allowed for some unproductive creativity on the part of semiconductor equipment vendors. Often this resulted in expensive and unique engineering work on the part of semiconductor manufacturers when new equipment was integrated into the factory. Costs of up to many hundreds of thousands of dollars were typical equipment integration expenses. Most of this was software work requiring a long schedule as well.

In the middle 1980's the semiconductor manufacturers began work on a solution to this big cost together with the equipment vendors. From this work a standard model for semiconductor manufacturing equipment evolved to become SEMI E30 — Generic Model for Communications and Control of Manufacturing Equipment (GEM)[iii]. The process of making this standard work in the industry has taken time, but GEM is part of the basic automation technology used by semiconductor manufacturers around the world.

Standards work continued in a number of other technical areas including standards for more advanced physical interfaces beyond the venerable RS-232 interface. The communication standards can now be used over networks supporting TCP/IP, for example.

The work of the Information & Control committee, which has responsibilities for the above standards, continues to advance the work in numerous technical areas. The committee and its technical task forces meet on a frequent basis.

APPLICABLE SEMI TECHNOLOGY FOR MARS

Let us consider some of the technologies used by semiconductor equipment we may consider for Mars equipment. We will consider each in detail:

- Machine Modeling techniques using Harel State charts,
- Communication Protocols,
- Data Content Standards,
- Design Philosophy and Practice**.**

Machine Modeling techniques can help to structure and organize the equipment software development process. There are many advantages to modeling the behavior of equipment as state machines: a good model rapidly communicates the nature of the system to engineers. In some cases, software tools are available to generate code directly from state models. Basic standards, as in a top-level standard for machine state behavior can help to focus the engineering and development work on the unique elements of the equipment.

When the basic standard state model is used in conjunction with a rich communication interface, more benefits are possible. Software in all forms is expensive, and while we primarily consider software in the equipment, it is very possible that software supporting the equipment at the host end of the interface will be a major development. Through the communication interface to the host, the host can determine the current state of the equipment. Consistent equipment state models can help with a virtual commonality from the point of view of equipment operation and communication. We assume virtually all but the most simple of Mars equipment will communicate with a host computer system. Figure 2 is a high level model which can be applied to virtually any processing equipment.

Communication Protocols for equipment from the SEMI standards offer support for a variety of physical interfaces from the venerable RS-232 interface to TCP/IP and OSI network protocols. Perhaps the greatest value of the **Communication Protocol** is from the SEMI Standards definition of higher layers of the interface.[iv] Communication protocols are an expensive item to develop.

Data Content Standards for equipment from the SEMI standards offer support for a variety of physical interfaces. The value of the **Communication Protocol** is from the definition of higher layers of the interface.

Design Philosophy and Practice for equipment from the SEMI standards offer support for a variety of physical interfaces. The value of the **Communication Protocol** is from the definition of higher layers of the interface.

TECHNICAL AND ECONOMIC ADVANTAGE OF LEVERAGE

In addition to the advantage to engineering a system by adopting SEMI technology, another important opportunity presents itself. Pros and cons through using Commercial Off-The-

Shelf (COTS) software have been discussed at the founding convention of the Mars Society[v]. The semiconductor equipment industry has vendors for software components for the equipment part of a SECS/GEM interface, as well as software at the host end as well. Thus there is the luxury of a buy vs. build decision for the development of equipment for Mars. Advantages and disadvantages to each approach can be considered for the specific situation.

CONCLUSION

Semiconductor equipment standards and technology as well as other industrial standards[vi] have much to offer the developers of equipment for exploration and settlement of Mars. Key benefits will be shorter development time for better and more robust designs that can better serve humans on Mars. Using the existing standards will also enable the possibility for use and evaluation of Commercial Off-The-Shelf software supporting the standards. Using and applying the SEMI standards will allow more work on the Mars specific technologies, and less on generic equipment technologies.

Given this opportunity, the next course of action is recommended:
An engineering project to:

1. Evaluate the applicable SEMI standards,
2. Develop actual equipment for analog studies,
3. Field Test in a Mars analog environment,
4. Evaluate and report results.

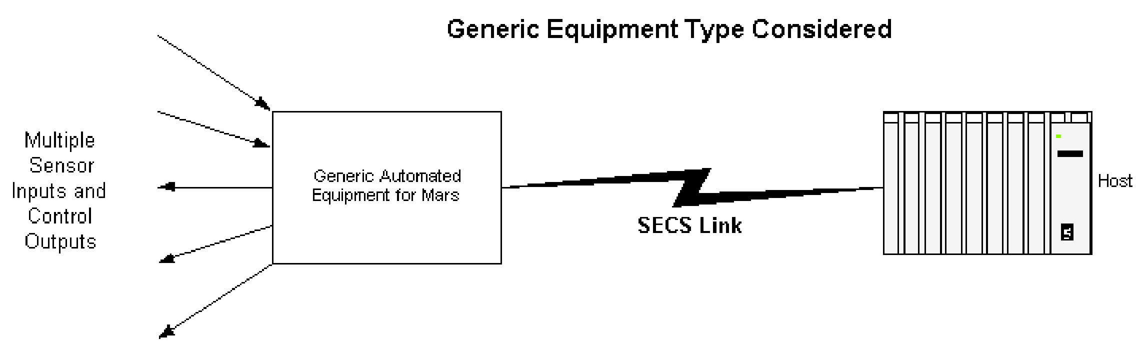

Figure 1

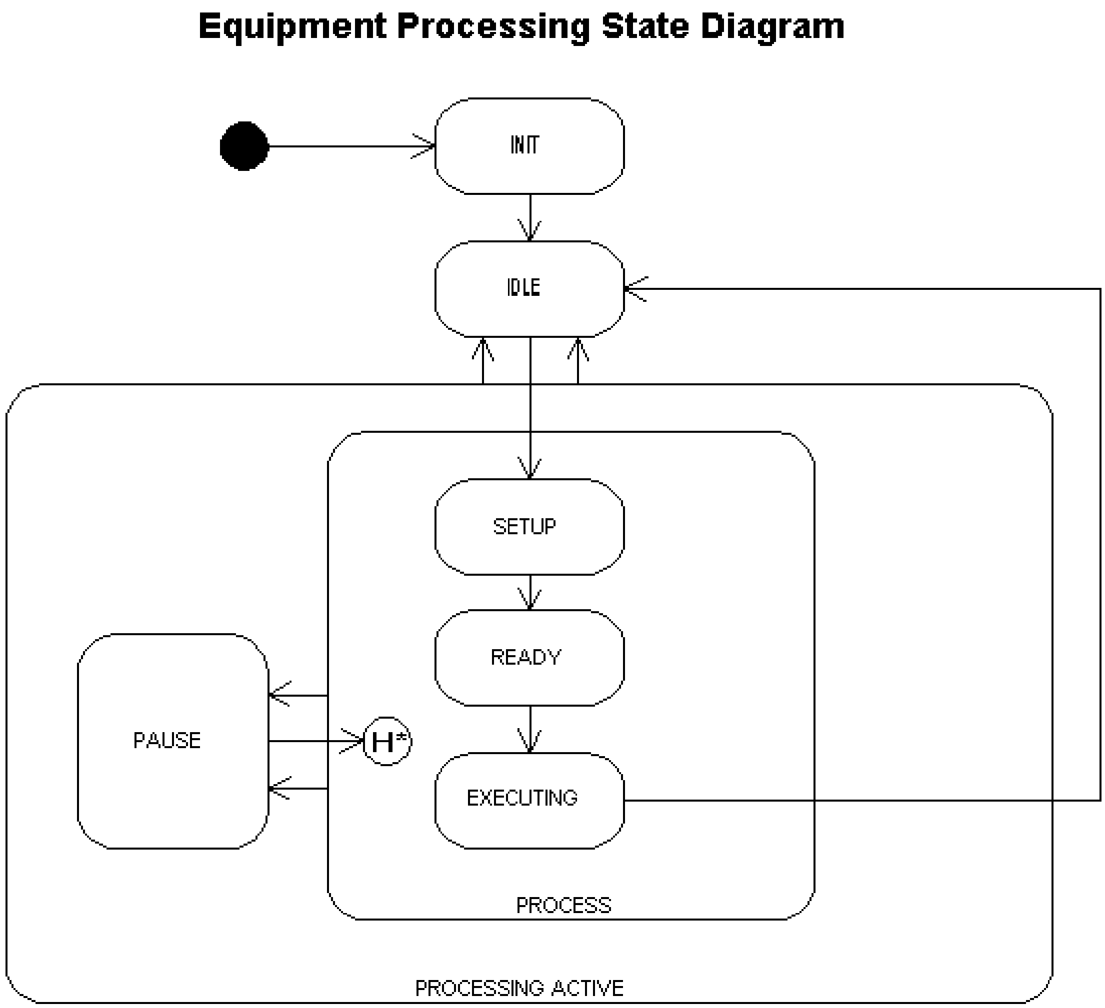

Figure 2

REFERENCES

[i] SEMI E4 — SEMI Equipment Communications Standard 1 Message Transfer (SECS-I), Semiconductor Equipment and Materials International, 3081 Zanker Road, San Jose, CA 95134, USA. Web: HYPERLINK http://www.semi.org www.semi.org .

[ii] SEMI E5 — SEMI Equipment Communications Standard 2 — Message Content (SECS-II), Semiconductor Equipment and Materials International, 3081 Zanker Road, San Jose, CA 95134, USA. Web: HYPERLINK http://www.semi.org www.semi.org .

[iii] SEMI E30 —— Generic Model for Communications and Control of Manufacturing Equipment (GEM), Semiconductor Equipment and Materials International, 3081 Zanker Road, San Jose, CA 95134, USA. Web: HYPERLINK http://www.semi.org www.semi.org .

[iv] A good reference on layered communication models is ***The OSI Reference Model*** by Day and Zimmermann in **Proceedings of the IEEE**, Volume 71, Number 12, December 1983, pp. 1334-1340. The entire issue of the Proceedings is devoted to this topic.

[v] N. Chapin, "Using COTS Software for Mars Missions*," Proceedings of The Founding Convention of the Mars Society Part II*, pp. 381-395, Zubrin and Zubrin, editors, 1999.

[vi] Another good example of a useful standard is from the telecom industry*: Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria,* Telecordia Technologies, GR-253-CORE, © 1995, 2000, Telecordia Technologies, Piscataway, NJ, 08854. This document describes requirements for potentially remote and highly reliable network equipment for communication. Further discussion is beyond the scope of this paper.