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Toward a Reference Model Architecture for Real-Time Intelligent Control Systems (ARTICS)

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INTRODUCTION

This position paper is a condensed version of a paper titled "Concept for a Reference Model Architecture for Real-Time Intelligent Control systems (ARTICS)", [Al 90], which advocates the development of a reference model open-system architecture as a means to accelerate the pace of technological development in automation and robotics. We believe many of the major bottlenecks in the development of intelligent machine systems could be alleviated, if not eliminated, by the development of a set of ARTICS guidelines.

The pace of commercial and military technological advancement in the fields of robotics, intelligent machine systems and automation is falling short of expectations. Problem complexity is one of the major contributors to this problem. Intelligent robot systems projects typically require bringing together teams of technologists with a broad mix of engineering disciplines and a high level of expertise. Robotics and automation manufacturers must make large investments in both developing custom test-beds and in recruiting and training competent engineering teams in order to compete in this market area. A second problem is the lack of a widely accepted theory, or system architecture model that ties together the many disciplines involved in intelligent robot systems. This limits the dissemination of intelligent machine systems technology developed in different parts of the robotics community. This prevents new projects from building upon the foundations laid by previous efforts.

A set of ARTICS guidelines would reduce the impact of problem complexity and would provide an efficient means of transferring technology between projects. Manufacturers will adopt ARTICS guidelines if they believe that their potential profits would be enhanced by an expanded market. This must be driven by traditional market forces (user demand). We need a way to create automation building blocks so that more complex systems can be developed without making the technologies more difficult to understand and to apply and without "reinventing the wheel" each time a new project begins. We believe that a common hardware/software shell structure would facilitate the incremental improvement which would produce rapid advancement in automation and robotics technology.

To summarize the goals advocated by this paper, we suggest that an Architecture for Real-Time Intelligent Control Systems (ARTICS) is needed to:

* reduce the impact of problem complexity in the development of robotic applications

* expand the market for intelligent control system components through open-system interface guidelines and protocols.

* promote portability, inter-operability and modularity of intelligent control system software and hardware

* facilitate technology transfer between intelligent control system projects

* reduce the time, cost, risk, and initial investment required in bringing new, world class, intelligent machine systems and control system products into the market place

2. ARTICS VISION

ARTICS guidelines would specify a reference model infrastructure of hardware components, software components, interfaces, communications protocols, and application development tools. Such a set of guidelines would make it possible for industry to develop and market a diverse line of control system components which could be interchangeable and realizable on many different vendors' control systems platforms.

ARTICS would be designed to facilitate technology and component transfer among the various users and developers, taking advantage of commonalities among otherwise disparate applications such as manufacturing, construction, environmental restoration, mining, space exploration telerobotics, medicine, and military applications of air, land, space, sea-surface, and undersea robotics.

A commercially manufactured ARTICS implementation product would come with libraries of algorithms for planning, task execution, sensor processing and world modeling. These libraries would be user expandable and replaceable. An ARTICS implementation would be fully documented so that users could easily modify or replace any module with a minimum of effort. It would also be commercially maintained, so that users would be able to get help in fixing bugs and making system modifications. In addition, vendors would offer training services to help the user community apply ARTICS products to their applications.

Widely available ARTICS off-the-shelf products would include a target computer system with a backplane and bus configured as a card cage, a local area network to link distributed applications and interface workstations for human/computer interface and software development, a real-time multi-processor/multi-tasking operating system, compilers, debuggers, and CASE tools. ARTICS compliant products could be integrated into an extendible open-system architecture with complete documentation of all hardware and software components.

The ultimate goal would be for ARTICS to evolve into a set of standards for real-time intelligent control systems. Figure 1 illustrates a possible common system configuration for a Version 1 ARTICS system. It would be organized into three levels.

The top level would consist of a number of workstations on an Ethernet for off-line software development and testing. A number of Computer Aided Software Engineering (CASE) tools, shell programs, simulators, debugging and analysis tools, and compilers for at least C, Ada, and Common LISP would be available.

These workstations might include one or more SUNs, LISP machines, VAXes, Butterflys, Connection Machines, graphics engines and display and image processing machines.

One or more of the workstation machines might also be used for on-line real-time control of processes where response time can exceed 1 second, and in situations where weight, power, and other environmental requirements permit. A real-time, multi-computer, multi-tasking operating system such as real-time UNIX, or MACH would be provided to support this type of operation.

The top level would also support an interface to a gaming environment such as the DARPA SIMNET. This would provide a low cost means for testing and evaluating the performance of intelligent machines in a war gaming environment against manned systems, or other unmanned systems. It would also provide an environment for developing tactics and strategy for using large numbers of intelligent vehicles and weapons systems in large scale battle simulations.

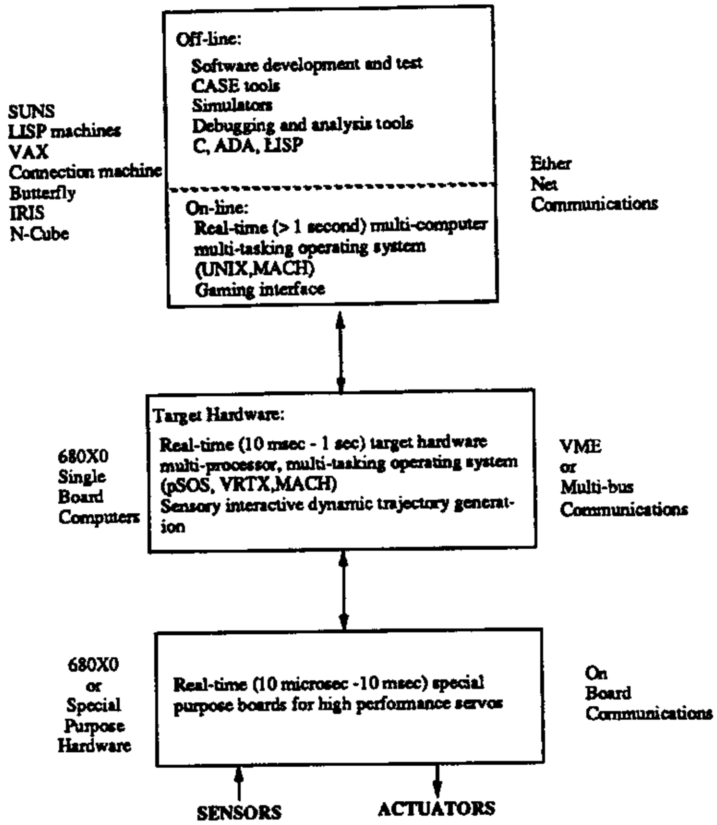

Figure 1: ARTICS Version 1 Common System Architecture

The middle level of the ARTICS system would consist of target hardware, such as single board computers and memory boards of the 680X0 variety, using VME or Multi-bus communications. More than one such bus might be connected via bus gateway cards. This middle level would have a real-time, multi-processor, multi-tasking operating system such as pSOS, VRTX, or MACH capable of supporting response times of ten milliseconds or greater.

The bottom level would consist of special purpose hardware which would interface to the VME or Multi-bus. This level would support high speed parallel processing for images, as well as servo controllers with response times between ten microseconds and ten milliseconds.

Figure 2 shows a possible reference model architecture based the Real-time Control System (RCS) concepts NIST has developed since 1980. These have been implemented in a number of applications including the Automated Manufacturing Research Facility (AMRF), the NASA/NBS Standard Reference Model for Telerobot Control System Architecture (NASREM) [Al 89], the Air Force Next Generation Controller for machine tools and robots, and the control system architecture research conducted for the NIST/DARPA Multiple Autonomous Undersea Vehicle (MAUV) project [Al 88].

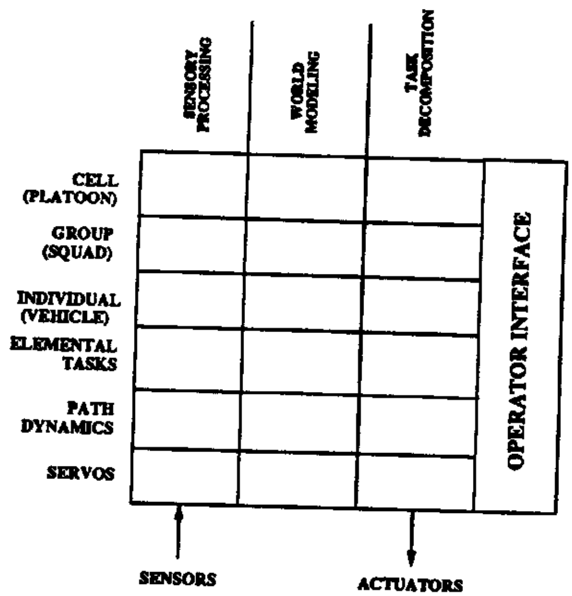

Figure 2: Reference Architecture for Real-Time Intelligent Control

The version of ARTICS shown here consists of six hierarchical levels: servo, path dynamics, elemental tasks, individual (vehicle), group (squad), and cell (platoon). The top (platoon) level of this reference model architecture would have interfaces to a higher (company) level in a battle management system. The bottom (servo) level would interface to actuators and sensors, and operator interfaces would be defined for all levels.

NIST hopes to enlist the cooperation of experts from industry, academia, and government in developing and modifying these concepts into an agreed upon initial set of guidelines. NIST also intends to sponsor research and enlist others to sponsor research, into advanced concepts that will permit the ARTICS guidelines to evolve as technology advances.

3. REQUIREMENTS

The following "strawman" list of requirements is intended to encourage the robotics community to begin the discourse.

Functional and temporal extensibility; human/computer interface flexibility, levels of automation (i.e. teleoperation, remote control, computer-aided advisory control, traded control shared control, human override, human supervised control, autonomous control, sensory interactive control, mixed mode control), real-time andtemporal reasoning, distributed systems, graceful degradation, software portability, ease of use, cost effectiveness, software development environment, simulation and animation.

A discussion of these requirements can be found in [Al 90].

4. APPROACH

To implement the ARTICS concept a consensus must be achieved in several areas of the common control system architecture. Such a conceptual framework would provide developers with a common design philosophy to guide the development of new robotic applications and control system products. A number of control architectures should be considered and evaluated against some set of agreed upon common control system requirements and finally a common conceptual architecture must be derived from the results of the process. More than likely such an architecture would include the ideas of a number of researchers as well as strong input from the user community. The following is a list of recent research in this area:

- Action Networks [Ni 89]
- Autonomous Land Vehicle (ALV) [Lo 86]
- Automated Manufacturing Research Facility (AMRF) [Si 83, Al 81]
- Control in Operational Space of a Manipulator-with-Obstacles System (COSMOS) [Kh 87]
- COmmunications Database with GEometric Reasoning (CODGER) [Sh 86]
- Field Materiel-Handling Robot (FMR) [Mc 86]
- Generic Vehicle Autonomy (GVA) [Gr 88]
- Hearsay II [Le 75]
- Hierarchical Control [Sk 89, Sk 87, Ko 88, Ko 88]
- Hierarchical Real-time Control System (RCS) [Ba 84, Al 81
- Intelligent Control [Sa 85]
- Intelligent Task Automation (ITA) [Bl 88]
- Manufacturing Automation System/Controller (MAS/C) [Ho 88]
- Multiple Autonomous Undersea Vehicles (MAUV) [Al 88]
- NASA/NBS Standard Reference Model for Telerobot Control System Architecture (NASREM) [Al 89]
- Pilot's Associate [Sm 87]
- Robot Control "C" Library (RCCL) [Ha 86]
- Robot Schemas [Ly 89]
- Soar: Architecture for General Intelligence [La 86]
- Subsumption Architecture [Br 86]
- Task Control Architecture (TCA) [Si 89]
- Tech-based Enhancement for Autonomous Machines (TEAM) [Sz 88]
- University of New Hampshire (UNH) Time Hierarchical Architecture [Ja 88]

There are a number of government efforts under way that should be factored into the process of defining an initial set of common architecture components. Some of these include:

- The NIST Federal Information Processing Standard (FIPS)
- The NIST Government Open Systems Interconnection Profile (GOSIP)
- The Navy's Next Generation Computer Resources (NGCR) program
- The Air Force's Next Generation Controller (NGC) program
- The Army's Standard Army Vetronic Architecture (SAVA) program

In addition there is a Department of Energy interest in establishing guidelines for robotic systems needed in their Environmental Restoration and Waste Management Program, the U.S. Bureau of Mines Pittsburgh Research Center is conducting research in automation systems for coal mining and there are a number of DARPA programs (past, present and on-going) which are producing relevant technologies.

5. REFERENCE MODEL DEVELOPMENT PLAN

ARTICS must be able to evolve as technological progress is made. It will be important to create an organizational structure that can coordinate the process of evaluating change and update proposals and a process for achieving consensus on the release of new versions of the ARTICS guidelines. Such an organization will need a steering committee made up of leading experts in the field of robotics, intelligent machines and automation from industry, academia and government.

An ARTICS development effort could take the form of a voluntary organization much like the Initial Graphics Exchange Specification (IGES)/Product DataExchange Specification (PDES) organization [Ig 89] chaired by NIST. Alternatively the reference model could be developed by a major user of the technology such as the Department of Defense in the form of a military specification (MILSPEC). In either case working groups will be needed to steer the ARTICS development and to document and distribute the results. Once an initial set of ARTICS guidelines has been agreed to it can be submitted to one or more national or international standards organizations as a proposed standard (e.g., ANSI, EIA, IEC, IEEE, ISO, RIA, etc.).

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