WHITE PAPER

ROBOTICS TECHNOLOGY
AREAS OF NEEDED RESEARCH AND DEVELOPMENT

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KEY ISSUE

- What is meant by the term "robotics technology"?

POINTS

- Attempts to define a "robot" have been made by many organizations, including the Robotics Industries Association and the Naval Air Systems Command. None of these definitions are adequate for Navy-wide use in both the industrial and non-industrial sense.

  -- Industry definitions lack operational (non-industrial) orientation

  -- Service definitions do not adequately address military manufacturing and repair (industrial) applications

- The Joint Technology Panel for Robotics (JTPR), on behalf of the Joint Directors of Laboratories (JDL) has established the following definition of robotics:

"A system incorporating a computer controller to provide autonomy and reprogrammability, which employs an end-effector of some type (manipulator arm or mobile platform), which exhibits flexibility in the roles which it can perform or the equipment with which it interfaces, and which performs tasks of a complexity level that previously required human control."

- The issue, however, is not really the definition of a "robot", but rather what is meant by "robotic technology." The field of robotics (assume for now the JTPR definition) is supported by the disciplines of mathematics, computer science (to include artificial intelligence), mechanical and electrical engineering, materials, physics, psychology, and anatomy. These supporting disciplines required to construct a mechanical system, endow it with intelligence, and provide the necessary sensor data upon which to act, can collectively be termed robotics technology.

CONCLUSIONS

- There is no universally accepted definition of a "robot", but that put forth by the JTPR appears the most appropriate for this discussion. Revision of the JTPR definition will add confusion, but will not necessarily gain acceptance.

- All the supporting disciplines contributing to the successful fielding of an intelligent system as so defined can be considered "robotic technology" when thus employed.

RECOMMENDATION

- Use the JTPR definition of robotics to facilitate determination of technologies that should be pursued in support of robotics system development.

ROBOTICS TECHNOLOGY RESEARCH AND DEVELOPMENT NEEDS

BACKGROUND

For the increasing number of identified potential Navy applications, there are known deficiencies in the supporting technologies that will impede, if not preclude, successful implementation of robotic solutions. These can be subdivided into the two general categories of "Industrial" and "Non-industrial", and are summarized below.

NAVY UNIQUE INDUSTRIAL NEEDS

For the most part these needs reflect the fundamental differences between conventional high-volume assembly-line scenarios which pervade throughout industry, and the very low volume, unstructured environments of Navy applications in manufacturing, but even more importantly, maintenance and repair. It is this latter area where the major impact of robotics on the Navy is predicted to occur, and this arena has been virtually untouched by industrial developments. Examples of needed research and development:

On-line Programming Techniques - Acceptable methods must be developed to allow faster programming for low volume applications. Conventional teach pendants employed by industry are impractical in Navy scenarios. Options include laser-based target designation systems, six degree-of-freedom joysticks, voice input, etc.

Off-line Programming Techniques - Practical methods must be devised to provide three dimensional data describing part geometries for use in generating robot motion programs. This requires interfacing with and augmenting existing and future Computer Aided Design (CAD) systems, and the development of volumetric digitizing techniques and sensors. In addition, process control information depicting parameter values and the sequence of operations must be easily represented in the design database to allow intelligent robotic systems to address low volume, unstructured scenarios typical of Navy applications.

Path Planning for Industrial Robots - Appropriate algorithms must be developed to automatically generate the optimum manipulator and end-effector responses from the geometric and process control data discussed above.

Collision Avoidance - Specialized algorithms must be devised to ensure that robot motion trajectories and process sequences calculated in an offline mode do not create hazardous situations in terms of damage to the workpiece, the equipment, or operating personnel. This requires extensive dynamic modeling of the robotic systems, workpieces, and associated environments.

Sensors to Support Collision Avoidance - Three dimensional imaging sensors are required to ascertain part location and orientation for input to the collision avoidance software routines, as well as to identify discrepancies between expected and actual conditions.

Real Time Process Control Sensors and Algorithms - Automatic and adaptive process control is essential if robotic systems are to be employed in Navy industrial scenarios, due to the unstructured and changing working environments. Research issues include but are not limited to weld pool imaging systems, infrared thermography, paint thickness guaging, surface cleanliness sensors, non-contact measurement techniques, seam tracking systems, weld process control strategies. Typical applications include surface preparation and coating, gas metal arc welding, laser metalworking, application of flame sprayed coatings, grinding and polishing, non-destructive testing, etc.

Dynamic Control Techniques - This is a critical research issue needed to support the design of large robotic systems capable of dealing with massive workpieces as encountered in ship and weapons system manufacturing and repair scenarios. Conventional industrial robots have in comparison rather limited working envelopes. They can therefore assign constant values to control system parameters and mechanical properties such as moments of inertia, static and dynamic frictional forces, etc. In reality, however, these entities are not fixed values but functions of manipulator and end-effector position, velocity, and acceleration, and further affected by changing payloads. Accuracy, repeatability, and system response degrade measurably as real world conditions vary from ideal assumptions, and large systems will require real time calculation of servo control mechanism transfer functions (i.e., gains, damping coefficients, etc.) in order to compensate.

Computer Simulation of Robotic Devices - Much work is needed in this area to provide generic tools needed for off-line programming, collision avoidance, path planning, and dynamic control research.

Generic Rule-Based Architectures - The development of a generic system architecture for networking a modular collection of expert systems with the appropriate modular sensor and controller subsystems is viewed as necessary and desirable for complex Navy applications. Such an architecture would provide for inherent standardization as well as allow for evolutionary system upgrades in response to componentry improvements. The rule-based expert systems address the CAD interface, path planning, collision avoidance, and scheduling functions discussed above, and could be modified through rule changes to accomodate different system applications, without extensive redesign.

Expert System Development - Generic research in expert system development is mandatory for providing the required system intelligence to allow conventional robotic systems to address in a practical fashion complex Navy needs.

Ship Motion Effects - Research is needed to investigate the effects of ship motion on robot dynamics and equipment life.

NON-INDUSTRIAL NEEDS

The following research and development needs are required to support operational applications of robotics, embodied for the most part in mobile systems. Initial emphasis in prototype development will address hazardous operations (EOD, NBC scenarios) and performance of tasks for which man is incapable. As advances are made in the supporting technologies, there will be a natural trend from teleoperated to semi-autonomous and autonomous systems.

Collision Avoidance for Mobile Robots - Regardless of the application, an essential technological need for any system involving mobility will be the capability to avoid impact with surrounding objects. The problems associated with this need are two-fold: 1) the acquisition of high resolution geometric data describing the environment, and 2) the computational resources needed to interpret that data.

Sensors to Support Collision Avoidance - The acquisition of geometric data requires the development of high resolution, low cost non-contact ranging systems capable of real time operation. Ultrasonic ranging systems have served in this capacity, but suffer from problems associated with extremely poor angular resolution, temperature dependence, specular reflection, interference from adjacent units, and the relatively slow speed of sound in air. Conventional laser rangefinders are prohibitively expensive in terms of initial costs, physical size, and energy requirements. Practical units must be employed in sufficient numbers to rapidly acquire geometric data for use in modeling the robot's surroundings, to support decisions on terrain traversibility, and to address environmental "awareness" in general.

Navigational Planning for Mobile Robots - Mobile autonomous and even teleoperated systems must be capable of determining their exact location as well as their orientation at that location in order to effectively maneuver to a desired position, to circumvent known obstructions or hazards, or to avoid detection. Secondly, they must be able to calculate the optimum path for traversing from their current location to the goal, a task which is computationally exhausting.

Sensors to Support Navigational Planning - The task of ascertaining position and orientation will require the development of low cost, accurate, and reliable sensors and/or navigational aids currently unavailable.

Computational Resources - Improved data processing techniques as well as pipeline and parallel processing architectures must be developed to handle the massive amounts of data, calculations, and symbolic reasoning needed to emulate the required degree of intelligence for even the most primitive of systems. This is especially critical for a mobile system where space and energy resources are at a premium.

Application Specific Sensors and Controls - This is the non-industrial analogy to process control sensors in the industrial sense. For a given functional application (firefighting, sentry and security functions, explosive ordnance disposal, mine placement and neutralization, undersea search and recovery, airborne sensor platforms, underwater sensor platforms, weapons handling, material handling, nuclear maintenance, containment, surveillance, etc) there will be required an appropriate sensor suite and associated intelligence to effect the required actions of the system.

Motion Effectors - Research is needed to further develop various types of motion effectors (tracked, wheeled, legged, omni-directional) for optimal maneuverability, dexterity, traction, etc.

Energy Sources - Mobile systems will require a practical onboard source of energy to support drive mechanisms, actuators, sensors, and computational resources.

Man-Machine Interface - Considerable research is needed in this area to effectively enhance the human transfer function and allow efficient interaction between the operator and the complex teleoperated and semi-autonomous systems to be developed.

Training and Self-Diagnostics - The importance of this area cannot be overemphasized. Robotic systems of the future will by necessity be complex in nature, and not well understood by their users. Substantial gains in productivity, quality, or safety could be easily offset by problems associated with operator training, system integration, and maintenance and repair. It is impractical to attempt to provide the skill levels needed to support such equipment through conventional means. Such action would be prohibitively expensive, and even if theoretically possible would suffer from the almost certain loss of highly trained personnel to better paying jobs in industry. Therefore, proposed systems must be fully proficient in diagnosing their own problems. Video disk technology and expert systems must be developed for training and instruction to overcome this problem.

SUMMARY

Ongoing 6.3 development efforts have shown the requirement for more supportive 6.1 and 6.2 research. The examples cited above can be traced to specific prototype development needs in existing NAVSEA programs. The centralized development of generic technology in response to these issues will result in substantial cost savings to the Navy through avoidance of unwanted redundancy. Additional cost savings will be realized through the attainment of application goals otherwise not technologically feasible.