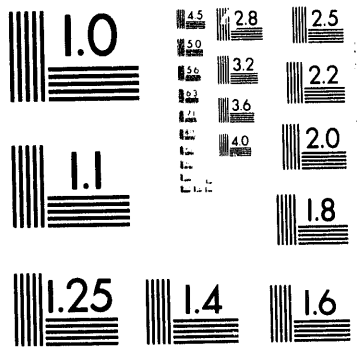
1.0
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Graphical Programming At Sandia National Laboratories†

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Sandia has developed an advanced operational control system approach, called Graphical Programming, to design, program, and operate robotic systems. The Graphical Programming approach produces robot systems that are faster to develop and use, safer in operation, and cheaper overall than alternative teleoperation or autonomous robot control systems. Graphical Programming also provides an efficient and easy-to-use interface to traditional robot systems for use in setup and programming tasks. This paper provides an overview of the Graphical Programming approach and lists key features of Graphical Programming systems.

Graphical Programming uses 3-D visualization and simulation software with intuitive operator interfaces for the programming and control of complex robotic systems. Graphical Programming Supervisor software modules allow an operator to command and simulate complex tasks in a graphic preview mode and, when acceptable, command the actual robots and monitor their motions with the graphic system. Graphical Programming Supervisors maintain registration with the real world and allow the robot to perform tasks that cannot be accurately represented with models alone by using a combination of model and sensor-based control.

Graphical Programming Benefits

- Interactive programming: Graphical simulation ensure efficient, effective and safe operations. Operators cannot command unsafe or collision-causing motions.

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- Task-based interface: Programming is simple – only high level operations, such as "Calibrate Part," are entered. Low level motions are automatically determined by the system's path planning algorithms.

- Real-time monitoring of operations: The operator can graphically monitor robot motions from any angle with any desired magnification.

- Real-time world modeling: Sensors automatically update the world model while the robot works.

- Automatic detection and compensation of world model inaccuracies: The robot automatically adapts to actual workcell part positions by using Sandia's calibration systems, mapping sensors, and sensor-based control.

- Modular software structure: The underlying software, built using a modular, object-oriented approach, allows new capabilities to be easily added.

Basic Operation

Sandia National Laboratories has developed this three-dimensional, graphics-based control environment to provide a unique operator interface for the programming and control of complex robotic systems. Graphical Programming uses 3D simulation systems; a graphical user interface (GUI) with pop-up menus; mice, spaceballs, and dials and buttons input devices; and real-time communications with robots in a seamless integrated system.

Currently, Deneb Robotics' IGRIP robot simulation package is used to model the robot and its working environment. The models include engineering knowledge of the overall system including dimensional information about known structures, robot end effectors and tools, robot geometry and kinematics, models of sensors used with the robotic system, and models of the tasks that the robot system must perform.

The operator uses the GUI to select robot tasks. Tasks, including moving to new locations, contact surveying nuclear components, grinding parts, and painting complex surfaces, can be commanded and controlled with a spaceball, mouse, or other intuitive input device. This contrasts with typical robot programming systems which require manual programming of all the points required to perform a given task. Using the Graphics-Based Control approach, programming is simplified by requiring the operator to only describe high level tasks, such as "Calibrate Part" or "Paint Surface." The lower level motions are automatically determined by the system's path planning algorithms.

Task motions are simulated and graphically previewed before the actual robot ever moves. Simulation and previewing ensures that the robot can move safely and efficiently by allowing both the operator and computer to "see what the robot is thinking." Simulation is also used to plan collision free motions and improve motion efficiency. All unsafe trajectories, such as those causing collisions, are detected and reported to the operator through the graphics interface. The supervisory program or the operator can modify proposed trajectories and verify new trajectory plans for safety. Only safe, collision-free robot trajectories can ever be transmitted to the robot.

As sensors develop additional information about the robot's working environment, the model is dynamically verified, refined, and corrected. Changes in the workcell are automatically reflected in the graphical model while operations are being performed. To date, tool force-torque sensing, touch-off probes, ultrasonic range finders, laser structured lighting, automated vision, and interactive stereo vision systems have been successfully integrated into the Graphical Programming environment for rapid world model building and updating.

Industrial Applications

Graphical Programming allows industry to increase its productivity by increasing the quality and flexibility of robotic operations while minimizing process downtime. New enabling technologies including task and motion planning and simulation are seamlessly integrated into these robot control systems.

This robust Graphics-Based robotic control system can detect changes within the robot environment and compensate where possible to produce the desired effect. For example, painting systems can detect and automatically compensate for changes in a paint gun's spray pattern. The flexible nature of Graphics-Based Control eliminates fixturing and manually measuring a part's location by automatically adjusting to the precise location of any part. System safety is enhanced by graphically previewing motions to ensure collision-free trajectories. Cost effectiveness is achieved by nearly eliminating downtime caused by robot reprogramming. Finally, efficiency is enhanced with path planning algorithms that optimize the motions required for a given task.

All of the above capabilities enable Graphics-Based Control to be applied to a variety of applications ranging from machining to assembly, in environments ranging from subsea to outer space to the factory floor. Graphical programming is the natural way for operators to plan complex robot motions safely, quickly, and easily.

Status of Capability

The graphical control environment described here has been implemented and demonstrated in several applications ranging from hazardous waste remediation to painting. Robotic systems from a variety of vendors, including GMF, Schilling, PaR, Spar, Puma, and Cincinnati Milacron, have all been integrated into this graphical environment. The underlying software, built in a modular, object-oriented approach, allows us to easily add to the existing capabilities. We are increasing the intelligence and adaptability of this system by adding new path planning algorithms, integrating new sensors, and enhancing the user interface.

Recent, Sandia has extended Graphical Programming by integrating it with network-based teleconferencing software to allow robots to be safely controlled over long distances. This extension is being pursued to allow Sandia to train personnel in robot operations at remote sites and to allow researchers to access Sandia robot facilities from university and other research sites.

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