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APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Embedded Software and Pervasive Computing PE 0602302E, R-1 #15

COST *(In Millions)*	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost To Complete	Total Cost
Total Program Element (PE) Cost	47.876	65.561	60.000	50.966	48.520	47.444	44.384	Continuing	Continuing
Networked Embedded Systems Design AE-01	8.850	18.191	22.000	25.443	24.746	27.676	24.658	Continuing	Continuing
Software for Autonomous Systems AE-02	13.757	23.896	26.000	10.926	9.906	9.884	9.863	Continuing	Continuing
Software for Embedded Systems AE-03	17.288	23.474	12.000	14.597	13.868	9.884	9.863	Continuing	Continuing
Gigabyte Applications AE-04	7.981	0.000	0.000	0.000	0.000	0.000	0.000	0.000	N/A

(U) **Mission Description:**

(U) Embedded computing provides the connection between the physical world and computation realm. Embedded computing impacts the superiority of a multitude of DoD systems from avionics to smart weapons. Virtually all-new weapon systems from the F-22 aircraft to National Missile Defense and from the Future Combat System to Unmanned Combat Air Vehicles depend on embedded software technology. The level of software complexity in these systems is unparalleled. The goal of the Embedded Software and Pervasive Computing program is to greatly extend the reach and effectiveness of computation from mainframes and desktops into the physical world. These embedded programs pursue the software and systems research to facilitate a new emerging application of computers, and conduct research to greatly increase the autonomy of those systems, so as to promote the human role from that of operator to supervisor thereby reducing the mission demand for intensive manpower. Embedded system advancements may revolutionize system and software technology to facilitate the efficacy of the integrated battlefield.

(U) The Networked Embedded Systems Design project will extend DoD's ability to monitor and control the physical environment and will require a much "deeper" approach to information systems – one that manages the vast quantities of "physical" information that can be accessed by sensors and actuators in direct contact with real world processes. To enable this transition, both the network and embedded software infrastructure must be extended to deal with: challenges created by a wide diversity of embedded devices dealing in physical world information which must be

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addressed by network research; vast increases in the numbers of nodes with real-time transmission requirements; and operating regimes in which network-based nodes must host services on behalf of embedded clients. Research on embedded software creation must radically extend the technology to enable the composition of software systems subject to physical constraints.

(U) The Software for Autonomous Systems project develops software to enable predictable, safe, and cooperative operation of free ranging, autonomous systems. This effort includes software for selected mobile robots performing tasks in dynamic, unstructured (physical) environments without the need for synchronous, operator control inputs or high quality communications links. This effort also includes the development of advanced computer-based control systems to improve the capabilities of manned and unmanned aircraft. Advanced control system development will exploit recent breakthroughs in hybrid systems research, which combines continuous-time systems with discrete event systems.

(U) The Software for Embedded Systems project develops a new class of software to deal with the processing of physical world information by embedded devices. The convergence of processing power, vanishing size and decreasing cost of today's microprocessors has created new devices and micro-sensors that enable a new wave of DoD applications. The effort includes new algorithms and software that enable distributed micro-sensor networks to rapidly and accurately detect, classify, and track threats and events of interest in the battlefield. The effort also includes new technology to make changes in complex software systems predictably to ensure the safety and reliability of critical military systems.

(U) The Gigabyte Applications project was initiated to develop technology to enable robust operation of DoD's mission-critical systems and platforms that are inherently geographically dispersed and are dependent on extremely high data flows. Capabilities for end-applications to tie in with other applications as well as with signals from multiple hardware sources and with human users were developed with technologies that allow ultra high-throughput, sustained low-latency data delivery and processing. Funding for this effort ended in FY 2001.

(U) **Program Change Summary:** (*In Millions*)	**FY2001**	**FY 2002**	**FY 2003**
FY02 Amended President's Budget	52.407	75.561	62.000
Current Budget	47.876	65.561	60.000

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(U) **Change Summary Explanation:**

FY 2001 Decrease reflects the SBIR reprogramming and minor program realignments.

FY 2002 Decrease reflects congressional program reduction.

FY 2003 Decrease reflects reprioritization of Agency requirements.

(U) **Other Program Funding Summary Cost:**

- Not Applicable.

(U) **Schedule Profile:**

- Not Applicable.

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COST (In Millions)	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Networked Embedded Systems Design AE-01	8.850	18.191	22.000	25.443	24.746	27.676	24.658	Continuing	Continuing

(U) Mission Description:

(U) This project will extend DoD's ability to build complex embedded software systems, which are the primary source of superiority in modern weapons platforms. Embedded software monitors and controls the physical environment, and lends intelligent behavior to platforms. The design and implementation of embedded software systems require an in-depth approach to information systems. Embedded systems will manage the vast quantities of physical information that can be accessed by sensors and actuators in direct contact with the real world. To enable the design of these tightly integrated physical and information systems, network and software infrastructures must be extended to interact with a wide diversity of physical world devices and environments. Designs will accommodate vast increases in the numbers of nodes with real-time data requirements, and must support operating regimes in which network-based nodes must host services on behalf of embedded clients. Research on embedded software creation must radically extend the technology to enable the modular composition of software systems subject to physical constraints.

(U) The Model-Based Integration of Embedded Systems (MoBIES) component will facilitate tools to design and test complex computer-based systems such as avionics, weapons, and communications systems. It will simplify the design of complex embedded systems by focusing on the pre-production environment rather than after-the-fact integration. The approach is to customize the design tools used by applications engineers so that controller design and systems integration can be more fully automated and the errors thereby reduced. The technology will formalize system modeling and programming tools in a common mathematical form. This analysis will allow integrated design of hardware and software from the earliest stages in system development, leading to interoperable tools, automatic systems integration, and simplified test and evaluation. The MoBIES program will allow such custom-designed toolsets to be easily tailored to specific applications, resulting in more efficient, verifiable, scalable, and re-usable programs for complex weapon and vehicle systems applications. Its objectives are to increase by 100% the size of the embedded software programs that existing tools can reliably produce, and decrease by 80% the design time necessary to create application-specific tools.

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(U) The Adaptive and Reflective Middleware Systems (ARMS) program will focus on mission-critical distributed embedded systems where different levels of service are possible and desirable under different conditions and costs; the levels of service in one dimension may need to be coordinated with and/or traded off against the levels of service in other dimensions to achieve the intended overall result. Autonomous system behavior requires the middleware components and frameworks to adapt robustly to quantifiable changes in environmental conditions. In ARMS, middleware will be responsible for coordinating the exchange of information efficiently, predictably, scalably, dependably and securely between remote entities by using advanced Quality of Service capabilities of the underlying network and endsystems.

(U) <u>Program Accomplishments and Plans:</u>

(U) <u>FY 2001 Accomplishments:</u>

- Model-Based Integration of Embedded Software. ($ 8.850 Million)
  – Developed modeling tools that can manage overlapping modeling views.
  – Investigated methods for the mathematical modeling and composition of model-based software generators.
  – Developed customizable design frameworks for embedded software.
  – Demonstrated the rapid synthesis of embedded systems using customizable frameworks and model-based code generators.
  – Developed meta-modeling techniques for integrating different commercial off-the-shelf analysis tools into a single tool environment.

(U) <u>FY 2002 Plans:</u>

- Model-Based Integration of Embedded Software. ($13.191 Million)
  – Develop methods to integrate different models of computational processes for different applications.
  – Develop methods for efficient run-time checking for models of computation.
  – Demonstrate ability to propagate different physical constraints among modeling views.
  – Demonstrate ability to coordinate different design aspects across modeling perspectives.
  – Develop hybrid (continuous and discrete) modeling and analysis techniques for embedded systems.
  – Develop generic components for model-based software generators.

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- Develop and demonstrate techniques for the mathematical modeling and formal verification of software generators.
- Develop formal models for synchronous embedded software frameworks.
- Demonstrate end-to-end tool integration in avionics and vehicle electronics experimental platforms.

• Adaptive Reflexive Middleware Systems. ($5.000 Million)
- Develop adaptive protocols, algorithms, patterns, and tools for distributed resource management.
- Develop meta-programming policies and mechanisms to customize quality of service enabled middleware services and applications.

(U) **<u>FY 2003 Plans:</u>**

• Model-Based Integration of Embedded Software. ($17.000 Million)
- Demonstrate ability to dynamically combine distributed components with different models of computation.
- Develop tools for automatically checking safety and reliability properties of automatically generated software.
- Develop techniques for customizing real-time operating systems according to application domains.
- Investigate methods for the mathematical modeling and composition of model-based software generators.
- Develop customizable frameworks for the design of embedded software.
- Demonstrate the rapid synthesis of embedded systems using customizable frameworks and model-based generators.
- Develop techniques for integrating different commercial off-the-shelf analysis tools into a single tool environment.
- Develop and demonstrate the use of multiple view modeling techniques for military avionics and combat vehicular electronics applications.

• Adaptive Reflexive Middleware Systems. ($5.000 Million)
- Develop formalized design expertise (pattern languages) for generating Quality of Service-enabled middleware frameworks and application components.
- Develop reflective techniques for synthesizing optimized real-time and embedded middleware.

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(U) **Other Program Funding Summary Cost:**

- Not Applicable.

(U) **Schedule Profile:**

- Not Applicable.

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COST *(In Millions)*	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Software for Autonomous Systems AE-02	13.757	23.896	26.000	10.926	9.906	9.884	9.863	Continuing	Continuing

(U) Mission Description:

(U) This project develops revolutionary control technology to enable predictable, safe, and cooperative operation of free ranging, autonomous systems. DoD needs revolutionary new capabilities for increasing autonomy of weapon systems. Increased autonomy will enable combined manned and unmanned warfare, and the extensive use of robotics technologies empowers future warfighters to accomplish their missions more effectively with less risk of casualties, preserving the U.S. military's most important resource. The project builds on major advancement in computing and software during the past decade, which makes the practical application of complex nonlinear, hierarchical control techniques feasible.

(U) The Common Software for Autonomous Robotics component of this project will develop software technologies for large groups of extremely small and highly resource constrained micro-robots, enabling the coordinated action of many robots to achieve a collective goal while allowing the operator to task and query the ensemble of robots as a group, rather than as individuals. This component addresses four critical areas: (1) coordinated behaviors, including both explicit control strategies that decompose tasks and propagate instructions to individual elements, and implicit control strategies analogous to potential fields; (2) inter-robot communications, including networking protocols that minimize energy consumption and novel alternative communications strategies such as insect-like "pheromone" communications; (3) computational architectures ranging from fully distributing the processing among the micro-robots themselves to off-loading the processing to a separate "proxy" processing resource; and (4) human-robot interfaces, including both explicit (symbolically grounded) and novel implicit (non-symbolic) user interface technologies. The payoff will be distributed "swarm" systems of robots that effectively exploit the scalability of large numbers to robustly perform important military tasks such as area surveillance and mine clearing.

(U) The Software Enabled Control component leverages growth in computing and software technologies to improve the capabilities of control systems for advanced manned and unmanned aircraft. The challenges are to mathematically model complex changes in flight conditions and vehicle status, to design fast digital control systems to automate aggressive maneuvers, to automatically detect and recover from faults or damage, and to provide a common computing platform and programmer's interface for real-time implementations of these methods on a variety of vehicles. Advanced control system development will exploit recent successes in hybrid systems research, which combines continuous-time systems with randomly occurring discrete events. Hybrid systems can then adapt to sudden changes such as aerodynamic disturbances, threat conditions, damage

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or failure, or limits in the flight envelope. The software to implement these controls must manage these events and guarantee stable operation throughout the execution of the mission. The Software Enabled Control component will provide fast, reliable automation and failure recovery for flight control systems in manned and unmanned aircraft both fixed- and rotary-winged.

(U) The Automated Light Transport Aircraft (ALTA) Control Systems component will provide the integrated vehicle management and control system technology to enable small VTOL (vertical takeoff and landing) air vehicles to serve as "personal" delivery vehicles in logistics and combat support operations.

(U) The Agent Based Negotiation component developed technologies for the autonomous operation of large collections of agents negotiating real-time resource allocation issues, such as those encountered in logistics and countermeasures.

(U) Program Accomplishments and Plans:

(U) FY 2001 Accomplishments:

- Common Software for Autonomous Robotics. ($4.114 Million)
  - Performed experimental evaluation of networking protocols for distributed robot controls that are more energy efficient than conventional implementations.
  - Performed prototype demonstration and experimental evaluation of software for distributed robotics capable of coordinating the operation of 10+ robotic devices in a collective task.

- Software Enabled Control. ($8.736 Million)
  - Completed prototype implementation of multi-mode control architectures and frameworks.
  - Developed a predictive active model framework to anticipate changing conditions.
  - Developed parametric predictive and adaptive control frameworks.
  - Completed multi-level, multi-modal advanced design tools.
  - Demonstrated real-time adaptive control through Open Control Platform (OCP).
  - Integrated OCP on laboratory vehicle.

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- Agent Based Negotiation. ($ 0.907 Million)
  – Completed prototype demonstration of autonomous software's ability to utilize negotiation in logistics scenario.

(U) **<u>FY 2002 Plans:</u>**

- Common Software for Autonomous Robotics. ($6.814 Million)
  – Demonstrate energy-saving protocols with at least 70 percent savings over conventional protocol implementations.
  – Integrate developmental network protocols into selected distributed robotic platforms and evaluate in the indoor application domain.
  – Integrate natural, implicit communications modes and user interface into selected distributed robotic platforms
  – Investigate cooperative approaches to achieving critical situational awareness in the indoor application domain.
  – Assess coordination and fusion of multiple sensing modalities with computational processing to achieve real time operation.

- Software Enabled Control. ($17.082 Million)
  – Develop Open Control Platform (OCP) services for control coordination of unmanned avionics (e.g., mode switching; event generation; discrete blocking, enabling, forcing).
  – Configure OCP prototype for three-level hybrid (discrete + continuous) control.
  – Integrate hybrid Fault Detection Identification Reconfiguration framework on OCP.
  – Integrate asynchronous hybrid control on OCP for multi-system coordination.
  – Release beta prototype framework for multi-system hybrid control coordination platforms.
  – Integrate predictive active services, control parameterization, hybrid stability, and transition management framework on OCP.
  – Develop system concept for high-confidence authority management for hybrid control.
  – Develop theoretical framework for robust hybrid control.
  – Conduct simulation experiments for two-level control; conduct flight experiment.
  – Plan integrated flight experiment on fighter aircraft and unmanned vehicles.
  – Develop baseline sensor and actuator resource services for unmanned aerial platforms.

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(U) FY 2003 Plans:

- Common Software for Autonomous Robotics. ($4.000 Million)
  - Conduct field experiments using selected distributed robot platforms.
  - Demonstrate realistic mission scenarios using representative platforms in a simulated mission context.
  - Develop coordinating techniques between cooperating platforms to support accelerated mobility and reconnaissance.
  - Develop shared representations to support collaborative communication between humans and robotic systems.

- Software Enabled Control. ($18.000 Million)
  - Integrate coordinated hybrid system services into Open Control Platform (OCP) middleware, useable across several military avionics platforms.
  - Integrate multi-system hybrid prediction and transition control into OCP.
  - Integrate active state model data services into OCP.
  - Integrate software customization and sensor/actuator resource services into OCP.
  - Lab demonstration of coordinated flight with coupled system dynamics.
  - Demonstrate integrated controller with active state modeler and fault reconfiguration strategies.

- Automated Light Transport Aircraft (ALTA) Control Systems. ($4.000 Million)
  - Develop digital flight control systems for “personal” Vertical Take-Off and Landing vehicles.
  - Automate cockpit control to perform high-speed, low altitude nape-of-earth maneuvers with minimal piloting.
  - Synthesize integrated situation awareness displays from passive sensing and telemetry in order to reduce vehicle signature.
  - Transform robust control principles into safe, certified avionics systems.

(U) Other Program Funding Summary Cost:

- Not Applicable.

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(U) Schedule Profile:

- Not Applicable.

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COST *(In Millions)*	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Software for Embedded Systems AE-03	17.288	23.474	12.000	14.597	13.868	9.884	9.863	Continuing	Continuing

(U) Mission Description:

(U) This project develops a new class of software to deal with mobile, distributed sensor networks and the processing of physical world information by embedded devices. The convergence of processing power, vanishing size and decreasing cost of today's microprocessors has created new devices and micro-sensors that enable a new wave of DoD applications. The effort includes new algorithms and software that enable distributed micro-sensor networks to rapidly and accurately detect, classify, and track threats and events of interest in the battlefield. The effort also includes new technology to make changes in complex software systems predictably to ensure the safety and reliability of critical military systems.

(U) The Large Scale Networks of Sensors component is comprised of the Sensor Information Technology (SensIT) program which develops new algorithms and software that enable distributed micro-sensor networks to rapidly and accurately detect, classify, and track threats and events of interest in the battlefield, including reconnaissance, surveillance, and tactical applications. New technology challenges include robust, reliable, low-latency networking methods than can scale and provide rapid ad hoc networking of fixed and mobile devices. Another challenge is to develop energy efficient algorithms for in-network collaborative processing required to convert multi-modal sensor data to useful information. Additionally, remote querying and accessing data and information collected by the sensor network, by multiple users, should be simple, with easy to use interfaces. The program develops new ad hoc networking strategies based on diffusion methods that achieve application-specific connectivity, as traditional internet protocols are not effective for large sensor networks. A distributed micro-database approach is being developed for collecting and storing data, as well as to support dynamic querying and tasking of sensors through a simple language that enables users to access geo-referenced events, hiding unnecessary detail. Finally, the algorithms and software are being integrated, with iterative design refinement and technology demonstration through field-experiments jointly conducted with the military.

(U) The Dynamic Assembly for Systems' Adaptability, Dependability and Assurance (DASADA) Program goal is "self healing" systems. Technology is being developed to automatically insert measurement probes and gauges into running (software) systems -- allowing them to judge their health and status. Complementary technology will allow the systems to automatically reconfigure themselves to "fix" problems. Major technical challenges include developing technology to: 1) Precisely determine and usefully specify the allowable variation in components and their composition; and, 2) Measure that components fit together as systems change, within functional and non-functional tolerances permitted by

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dynamically evolving system requirements. The DASADA Program will enable developers and implementers to make changes in complex software systems predictably to ensure the safety and reliability of critical military systems.

(U) <u>Program Accomplishments and Plans:</u>

(U) <u>FY 2001 Accomplishments:</u>

- Large Scale Networks of Sensors. ($12.590 Million)
  - Implemented experimental prototype supporting automated aggregation and distribution of sensor-derived information involving at least 50 nodes and 100 sensors.
  - Evaluated methods for efficient interoperation of fixed and mobile sensors.
  - Demonstrated multi-node sensor network software and benefits of collaborative signal processing for military operations such as ground moving target detection.
  - Developed prototype for declarative interfaces for tasking and querying of multi-taskable sensor networks.
  - Testing and demonstration at Twenty-nine Palms, U.S. Marine Corps, included applications for detector/tracker cueing an imager; mobile query from an Unmanned Air Vehicle seismic tracking.

- Dynamic Assembly for Systems Adaptability, Dependability and Assurance (DASADA). ($4.698 Million)
  - Conducted preliminary demonstrations of dynamic software component composability with multiple standard communication (e.g. Distributed Component Object Model, Common Object Request Broker Architecture, Distributed Computing Environment) or structuring (e.g., Extended Markup Language, Resource Description Framework, Document Object Model) infrastructures.

(U) <u>FY 2002 Plans:</u>

- Large Scale Networks of Sensors. ($14.592 Million)
  - Optimize embedded node processing and protocols to minimum latency in sensor networks.
  - Integrate candidate protocols for interoperation between fixed sensor devices and mobile devices, for lab and field evaluation.
  - Implement distributed algorithms for sensor coverage, and easy graphical user interface, to support real-time incremental deployment in battlefield contexts.

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- Implement algorithms for application-specific distributed computing software for collaborative signal processing including detection, classification, and tracking for a range of military applications.
- Implement efficient ways to fuse information at various levels in the network to support collaborative signal processing and to facilitate extraction of timely information from the sensor network.
- Implement technology for dynamic tasking, querying, multi-tasking, and rapid specialization, customization, and reconfiguration of software during operation, through mobile code technology.
- Develop modeling and simulation capability scalable to large sensor networks.
- Develop design principles for deployment of sensor networks in specific DoD contexts, including determination of the right network size, density of nodes, sensor suite, node and link capacity.
- Conduct field demonstrations to show new technology capabilities of embedded distributed micro-sensor software for tracking of mobile targets, and detection and classification of threats in battlefield scenarios. This will include 'Steel Knight' exercise with U.S. Marine Corps, and imaging for target validation.
- Engage Intelligence, Emergency, and National Guard end users in joint experimentation to demonstrate new paradigms for sensing threats.

• Dynamic Assembly for Systems Adaptability, Dependability and Assurance (DASADA). ($8.882 Million)
  - Demonstrate a "toolkit" of software components/gauges to:
  - Determine the suitability of components for insertion / (re)use in a given system.
  - Enable safe run-time composition and deployment.
  - Enable continual monitoring of the system to guide adaptation.
  - Ensure that critical (user defined) properties are maintained during and after composition, adaptation and deployment.
  - Solicit inputs from DoD agencies to conduct experiments based on planning efforts and preliminary demonstrations.
  - Identify most promising technologies for experiment transition.

(U) <u>FY 2003 Plans:</u>

• Dynamic Assembly for Systems Adaptability, Dependability and Assurance (DASADA). ($12.000 Million)
  - Conclude Phase I, technology refinement and integration projects.

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– Fifteen programs are currently evaluating DASADA technology with respect to their needs – two to three of these will be selected to conduct experiments that quantify benefits resulting from use of DASADA technologies. The programs include:
-- Theatre High Altitude Area Defense to provide assured dynamic system adaptability and real time defense planner updates.
-- U.S. Pacific Command's Geoworlds system to provide more rapid installation, deployment, and continual adaptation with guarantees of overall operational effectiveness
-- Space and Naval Warfare Systems Command's Managed Information and Network Exchange Router to provide more predictable results when replacing system components and improved ability to detect when performance is violating constraints.
-- Infosphere Situational Awareness Master Caution Panel to provide monitoring tools that operate in component based (rather than conventional client/server) environments.
-- USAF AWACS 40-45 block upgrade to provide distributed Client/Server systems with real-time error recovery / reconfiguration capabilities that have defied current technology solutions.
-- Aerospace Command, Control, Intelligence, Surveillance, and Reconnaissance Center, Air Operations Center to provide improved capabilities to upgrade software components and integrate commercial off-the-shelf components in a reliable manner.

(U) **Other Program Funding Summary Cost:**

- Not Applicable.

(U) **Schedule Profile :**

- Not Applicable.