RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)								DATE June 2001		
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 2000	FY2001	FY2002	FY2003	FY2004	FY2005	FY2006	FY2007	Cost To Complete	Total Cost
Total Program Element (PE) Cost	30.000	52.407	75.561	62.000	65.700	50.000	60.000	60.000	Continuing	Continuing
Deeply Networking Systems AE-01	5.405	12.214	20.656	25.000	30.000	32.000	42.000	42.000	Continuing	Continuing
Software for Autonomous Systems AE-02	16.873	14.171	27.205	25.000	21.983	18.000	18.000	18.000	Continuing	Continuing
Software for Embedded Systems AE-03	7.722	17.803	27.700	12.000	13.717	0.000	0.000	0.000	0.000	N/A
Gigabyte Applications AE-04	0.000	8.219	0.000	0.000	0.000	0.000	0.000	0.000	0.000	N/A

(U) Mission Description:

(U) The goal of the Embedded Software and Pervasive Computing program is to greatly extend the reach and effectiveness of networked computation. It is funded in the applied research budget activity because it is pursuing network and software research to facilitate the "deep networking" of computers, such as those embedded within DoD platforms and weapons. It will also conduct research to greatly increase the autonomy of those systems, so as to promote the human role from that of operator to supervisor.

(U) The Deeply Networked Systems 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 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.

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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

(U) The Software for Autonomous Systems project develops software to enable predictable, safe, and cooperative operation of a 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 software agents (knowbots) that can range over cyberspace performing information services, including the capability to negotiate for and assign selected resources. Further, some autonomous systems should be able to learn and adapt to change and uncertainty while improving with experience.

(U) The Software for Embedded Systems project develops a new class of software to deal with the processing of physical world information by networked 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. For example, cheap, smart micro-sensors can be deployed quickly in large quantities in the battlefield to perform new monitoring and control functions; and a host of sensors can be attached to warfighters and assets to autonomously monitor safety and health information, and equipment condition. Funding will end in FY 2004.

(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 will be developed with technologies that allow ultra high-throughput, sustained low-latency data delivery and processing. Funding ends in FY 2001.

(U) **Program Change Summary:** (*In Millions*)	**FY2000**	**FY 2001**	**FY 2002**
Previous President's Budget	30.000	69.282	105.196
Current Budget	30.000	52.407	75.561

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(U) Change Summary Explanation:

FY 2001 Decrease reflects congressional program reduction, Section 8086 reduction and government-wide rescission.

FY 2002 Decrease reflects rephasing of programs following the FY 2001 congressional program reduction and reprioritization of Agency requirements. Specifically, robotic software activities have been reduced and the Gigabyte Applications project has been terminated.

(U) Other Program Funding Summary Cost:

- Not Applicable.

(U) Schedule Profile:

- Not Applicable.

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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, Project AE-01					
COST (In Millions)	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Deeply Networking Systems AE-01	5.405	12.214	20.656	25.000	30.000	32.000	42.000	42.000	Continuing	Continuing

(U) Mission Description:

(U) Extending DoD's ability to monitor and control the physical environment 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 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 networking of embedded and autonomous devices creates additional requirements for: embedded technologies that can achieve drastic reductions in costs while being compatible with a wide range of network and computation media; flexible mechanisms for naming, addressing, configuring and administering communication and computation resources; and system design technology which shifts the emphasis from static verification and validation to dynamic behavior guarantees. These challenges are addressed in the Networked Embedded Systems component of this project.

(U) Close coupling of information processing with physical processes demands new technology for the integrated modeling of software and physical systems. These models will enable designers to capture complex cross cutting physical constraints that the embedded software must satisfy. The Model-Based Integration of Embedded Software component of this project will use integrated models to analyze and verify the aggregate behavior of software and physical processes, and to automatically customize and integrate system components.

(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; and autonomous system behavior requires the middleware components and frameworks to be capable of reflection to adapt robustly to quantifiable changes in environmental

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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) Program Accomplishments and Plans:

(U) FY 2000 Accomplishments:

- Networked Embedded Systems. ($ 5.405 Million)
  - Investigated new modeling methods capturing physical constraints in embedded systems such as avionics and vetronics.
  - Developed customizable modeling tools that can be rapidly adjusted to different modeling views and application domains.
  - Investigated new generation technology with capability to configure, customize and synthesize software directly from models.

(U) FY 2001 Plans:

- Model-Based Integration of Embedded Software. ($ 12.214 Million)
  - Develop modeling tools that can manage overlapping modeling views.
  - Investigate methods for the mathematical modeling and composition of model-based software generators.
  - Develop customizable frameworks for embedded software.
  - Demonstrate the rapid synthesis of embedded systems using customizable frameworks and model-based generators.
  - Develop meta-modeling techniques for integrating different COTS analysis tools into a single tool environment.

(U) FY 2002 Plans:

- Model-Based Integration of Embedded Software. ($ 13.656 Million)
  - Develop methods to integrate different models of concurrency.
  - Develop methods for efficient run-time checking for models of concurrency.
  - Demonstrate ability of propagating constraints among modeling views.
  - Investigate methods to integrate interdependent modeling views using high-level multiple view modeling languages.

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- Demonstrate ability to compose multiple view models with interdependent modeling views.
- Develop hybrid modeling and analysis techniques for synchronous embedded systems.
- Develop generic components for model-based generators.
- Develop and demonstrate techniques for the mathematical modeling and formal verification of generators.
- Develop formal models for synchronous embedded software frameworks.
- Demonstrate Open Experimental Platform for embedded avionics applications and for vehicular electronics applications.

- Adaptive Reflexive Middleware Systems (ARMS). ($ 7.000 Million)
  - Develop adaptive protocols, algorithms, patterns, and tools for distributed resource management.
  - Develop meta-programming policies and mechanisms to customize QoS-enabled middleware services and applications.

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

- Not Applicable.

(U) **Schedule Profile:**

- Not Applicable.

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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, Project AE-02					
COST *(In Millions)*	FY 2000	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	16.873	14.171	27.205	25.000	21.983	18.000	18.000	18.000	Continuing	Continuing

(U) Mission Description:

(U) This project develops software to enable predictable, safe, and cooperative operation of a 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 software agents (knowbots) that can range over cyberspace performing information services, including the capability to negotiate for and assign selected resources. Further, some autonomous systems should be able to learn and adapt to change and uncertainty while improving with experience.

(U) Autonomous systems will enable revolutionary, asymmetric military capabilities, such as the ability to autonomously convey military payloads (both lethal and non-lethal) to any portion of the battlefield without requiring human operators and the ability to autonomously retrieve, process and deliver information.

(U) The Common Software for Autonomous Robotics component of this project will develop a combination of critical, enabling software technologies that can be reused across a wide range of mobile autonomous robotic systems.

(U) The Software Enabled Control component will leverage increased processor and memory capacity to vastly increase the user's ability to maintain control over mobile devices through the development of novel techniques, such as: predictive mode changes, dynamic control scheduling, composable coordinated control, and dynamic sensor and actuator allocation.

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

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(U) Program Accomplishments and Plans:

(U) FY 2000 Accomplishments:

- Common Software for Autonomous Robotics. ($ 6.734 Million)
  - Developed architectures for the integration of deliberative, reactive and learning behaviors, including knowledge representations.
  - Demonstrated alternative approaches to off-line learning.
  - Demonstrated rapid sensor-motor mapping.
  - Demonstrated "engineered" behaviors.
  - Demonstrated "statistical" control.

- Software Enabled Control. ($ 6.950 Million)
  - Specified architecture for a hybrid control system that synthesizes the control law approach with computationally-enabled mode logic scalable to very large state spaces of 100K+ states.
  - Developed active transition control and joint mode logic/control law designs.
  - Designed services for active model creation, augmentation and query.

- Agent Based Negotiation. ($ 3.189 Million)
  - Developed framework for bottom-up organization of autonomous software.
  - Defined strategy for tasking and consolidation of responses from large numbers (thousands) of software agents with minimal human intervention.

(U) FY 2001 Plans:

- Common Software for Autonomous Robotics. ($ 4.234 Million)
  - Perform experimental evaluation of networking protocols for distributed robot controls that are more energy efficient than conventional implementations.

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- 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. ($ 8.970 Million)
  - Complete alpha-level prototype implementation of multi-mode control architecture and framework.
  - Develop predictive active model framework.
  - Develop parametric predictive and adaptive control frameworks.
  - Complete multi-level, multi-modal advanced design tools.

- Agent Based Negotiation. ($ 0.967 Million)
  - Complete prototype demonstration of autonomous software's ability to utilize negotiation in logistics scenario.

(U) FY 2002 Plans:

- Common Software for Autonomous Robotics. ($ 7.914 Million)
  - Demonstrate energy-saving protocols with at least 70 percent savings over conventional protocol implementations.
  - Integrate developmental network protocols into selected Distributed Robots platforms.
  - Evaluate developmental network protocols using the representative robot platforms in representative mission scenarios.
  - Integrate natural, implicit communications modes into selected Distributed Robots platforms.
  - Evaluate implicit communications modes using selected Distributed Robots platforms in representative mission scenarios.
  - Evaluate "world-embedded" user interfaces.
  - Investigate cooperative approaches to achieving critical situational awareness in tactical environments.
  - Assess coordination and fusion of multiple sensing modalities with computational processing to achieve real time operation.

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- Software Enabled Control. ($ 19.291 Million)
  - Develop Open Control Platform (OCP) services for control coordination for unmanned avionics (e.g., atomic mode switch; event generation; discrete blocking, enabling, forcing).
  - Configure OCP prototype for three-level hybrid (discrete + continuous) control.
  - Integrate hybrid Fault Detection Identification Reconfiguration (FDIR) 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 concept and instrumentation technology for flight qualification of single-system multi-modal control.
  - Develop system concept for high-confidence authority management for hybrid control.
  - Develop theoretical framework for robust hybrid control.
  - Integrate OCP on lab vehicle.
  - Conduct simulation experiments for two-level control; conduct flight experiment.
  - Develop baseline sensor and actuator resource services for unmanned aerial platforms.

(U) Other Program Funding Summary Cost:

- Not Applicable.

(U) Schedule Profile:

- Not Applicable.

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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, Project AE-03					
COST *(In Millions)*	FY 2000	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	7.722	17.803	27.700	12.000	13.717	0.000	0.000	0.000	0.000	N/A

(U) Mission Description:

(U) This project develops a new class of software to deal with the processing of physical world information by networked 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. For example, cheap, smart micro-sensors can be deployed quickly in large quantities in the battlefield to perform new monitoring and control functions; and a host of sensors can be attached to warfighters and assets to autonomously monitor safety and health information, and equipment condition.

(U) Harnessing the full potential of micro-sensors and embedded devices requires addressing new information technology challenges. Networking these untethered devices creates new requirements on hardware and software, including rapid self-assembly, timely acquisition, processing and exchange of sensor data, and energy efficient operation. Accurate identification of events and collection of information require new ways of cooperation among these devices to process physical world signals, and to integrate information in the network. Additionally, remote querying and accessing data collected by the sensor net should be simple, with easy to use interfaces.

(U) This project will build on Software and Networking R&D activities, extending and specializing them to geographically distributed micro-sensor networks. A major challenge is the development of software technologies that spans a variety of sensor nets, on ground and water, on buildings and bodies. Another challenge is to design reliable networked embedded systems retaining only supervisory control, while automating traditional "in-the-loop" tasks. The sensor tasking, data collection, integration and analysis must be fully automated to enable operation within time constraints far shorter than could be achieved by human operators.

(U) Complex software systems must be able to reconfigure and evolve themselves dynamically, while operating. This project will develop the dynamic gauges or measures of composability necessary to enable software components from any source to support assured applications under the Dynamic Assembly for Systems Adaptability, Dependability and Assurance (DASADA) program. Outputs from this program will ensure that the critical properties of complex, heterogeneous software systems are maintained during and after composition, adaptation and deployment.

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(U) Program Accomplishments and Plans:

(U) FY 2000 Accomplishments:

- Large Scale Networks of Sensors. ($ 7.722 Million)
  - Identified diffusion-based approaches to networking, and aggregation and distribution of information from large numbers of multi-taskable sensor nodes.
  - Explored low-latency system designs; developed experimental platform and simulation capability.
  - Developed methods for collaborative signal processing and information integration.
  - Investigated use of declarative interfaces for tasking and querying of networked embedded systems; developed experimental prototype based on relational database query technology and lightweight operating environment.

(U) FY 2001 Plans:

- Large Scale Networks of Sensors. ($ 12.890 Million)
  - Implement experimental prototype supporting automated aggregation and distribution of sensor derived information involving at least 50 nodes and 100 sensors.
  - Investigate methods for efficient interoperation of fixed and mobile sensors.
  - Demonstrate multi-node sensor network software and benefits of collaborative signal processing for military operations such as fast moving target detection and urban operations.
  - Prototype demonstration using declarative interfaces for tasking and querying of multi-taskable sensor networks.

- Dynamic Assembly for Systems Adaptability, Dependability and Assurance (DASADA). ($ 4.913 Million)
  - Conduct preliminary demonstrations of dynamic software component composability with multiple standard communication (e.g. Distributed Component Object Model (DCOM), Common Object Request Broker Architecture (CORBA), Distributed Computing Environment (DCE)) or Structuring (e.g., Extended Markup Language (XML), Resource Description Framework (RDF), Document Object Model (DOM)) infrastructures.

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(U) FY 2002 Plans:

- Large Scale Networks of Sensors. ($ 16.818 Million)
  - Optimize embedded node processing and protocols to achieve minimum latency in military sensor networks.
  - Develop and implement techniques for obtaining application specific quality of service that accommodates needed mission variations among latency, power, scalability, and reliability.
  - Implement techniques for rapid self-management for ad hoc and dynamic sensor networks.
  - Implement protocols for effective interoperation between fixed sensor devices and mobile devices on robots, vehicles, UAVs, and personnel.
  - Implement distributed algorithms for sensor coverage, and easy graphical user interface, to support real-time incremental deployment in battlefield contexts.
  - 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 techniques for micro-databases for storing, accessing, and processing in a sensor network.
  - Implement technology for dynamic tasking, querying, multi-tasking, and rapid specialization, customization, and reconfiguration of software during operation, through mobile code technology.
  - Complete architecture specification to support integrated software and operation of sensor devices with diverse capabilities: from smart dust or miniature motes to higher functionality devices with multi-modal on-board sensors.
  - Complete modeling and simulation capability scalable to large sensor networks.
  - Develop engineering methods 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.
  - Field demonstrations and joint experiments with DoD agencies including Marines, Army, Air Force and the Navy, to show new operational capabilities of embedded distributed micro-sensor software for accurate and fast tracking of mobile targets, and detection and classification of threats in complex battlefield scenarios including MOUT and urban warfare.
  - Engage Intelligence, Emergency, and National Guard end users in joint experimentation to demonstrate new paradigms for sensing threats.

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- Dynamic Assembly for Systems Adaptability, Dependability and Assurance (DASADA). ($ 10.882 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.
  - Conclude Phase I, technology refinement and integration projects.
  - Identify most promising technologies for experiment transition.

(U) Other Program Funding Summary Cost:

- Not Applicable.

(U) Schedule Profile:

- Not Applicable.

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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, Project AE-04					
COST *(In Millions)*	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Gigabyte Applications AE-04	0.000	8.219	0.000	0.000	0.000	0.000	0.000	0.000	0.000	N/A

(U) Mission Description:

(U) This 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 will be developed with technologies that allow ultra high-throughput, sustained low-latency data delivery and processing. Funding will end in FY 2001.

(U) Program Accomplishments and Plans:

(U) FY 2000 Accomplishments:

- Not Applicable.

(U) FY 2001 Plans:

- Ultra-High Performance Heterogeneous Flow-Based Communications. ($ 4.100 Million)
  - Develop software and physical interfaces that can adapt or be programmed to support diverse link protocols, symbol rates and signaling technologies.
  - Demonstrate gateway technology that can segregate long flows from short flows.

- Gigabit Multi-Link. ($ 4.119 Million)
  - Demonstrate an order of magnitude increase in wireless spectral efficiency for non-mobile end nodes.
  - Demonstrate adaptive multi-link coding technique to enhance immunity to degradations due to mobility or environmental (weather, obstruction) changes.

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(U) FY 2002 Plans:

- Not Applicable.

(U) Other Program Funding Summary Cost:

- Not Applicable.

(U) Schedule Profile:

- Not Applicable.