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Three Researchable Areas

First Ohio ICE RFPs

First, let me thank Michael Branicky, Ken Hall, and Dan Simon for their help in developing our research areas and our first RFPs. I am proposing that we adopt the following as our research areas and then we will present four possible RFPs for your consideration.

Michael Branicky first proposed the following three areas:

1. Sensors
2. Distributed systems and autonomous agents
3. Advanced motion control

After a lot of thought and discussions, I feel that these represent the best first cut at what should be our focus.

This then leads to possible RFPs which Dan Simon was most helpful in developing. I propose we consider releasing the following RFPs (these can be found in an expanded version in Attachments B, C, D, and E):

1. Sensors
    a. ***Advanced Sensor Technology*** This is an opportunity to compete for a grant to develop new wireless and network-capable sensors. The sensor technology that is developed could include one or more of the following features.
        - functionality in harsh environments (dirt, temperature, humidity, vibration, etc.)
        - low power requirements
        - embedded algorithms for diagnostics and prognostics
        - small size
        - noninvasive
        - manufacturable in high volumes at low cost
        - high sensitivity (e.g., micro-g acceleration sensors)
        - high bandwidth (fast response time)
        - ability to communicate without wires

2. Distributed systems and autonomous agents
    a. ***Distributed Control Systems*** This is an opportunity to compete for a grant to develop new algorithms and technologies for distributed control. This includes the capability of autonomous control agents to cooperate with one another in a self-aware manner so as to increase robustness, security, and fault-tolerance. The autonomous control agents will be embedded systems that may include several of the following features.
        - functionality in harsh environments (dirt, temperature, humidity, vibration, etc.)
        - low power requirements
        - algorithms for diagnostics and prognostics (of themselves, and also of the controlled objects)
        - small size
        - manufacturable in high volumes at low cost
        - high bandwidth (fast response time)
        - ability to communicate without wires
    b. ***Performance and Stability Verification System for Distributed Autonomous Agents*** This is an opportunity to compete for a grant to develop methodologies and systems to verify the performance and stability of distributed, autonomous sensor, actuator and control agents. This verification system should be capable of determining the statistical dimensions of performance and stability over a range of operating conditions, as well as the deterministic performance and stability boundary for a given set of operating requirements. The proposed research should, at a minimum, result in a description of infrastructure requirements for the autonomous agents, as well as for the interconnections between the agents, in order to enable this performance and stability verification system.

3. Advanced motion control

    a. ***Advanced Motion Control*** This is an opportunity to compete for a grant to develop new algorithms and technologies for motion control. This includes the development of control systems for (possibly nano-scale) electromechanical applications. The motion control applications may have conflicting performance requirements, such as minimum time and low jerk. This grant could include one or more of the following components.
        - new path planning algorithms (in the presence of constraints)
            - splines (algebraic or other)

    - artificial intelligence
- new path tracking algorithms (in the presence of constraints)
    - nonlinear control
    - artificial intelligence
- estimation algorithms to reduce the number or accuracy of sensors that are required for feedback
- new electromechanical system configurations

Attachment A

More detailed explanation of the three research areas from Michael Branicky and others from Case.

(1) SENSORS:

(a) Wireless and network-capable micro-sensors, esp. for harsh environments and low-power applications.

(b) Multi-element sensor arrays for in-situ monitoring of critical equipment. Includes sensor design, characterization, testing, and the development of application specific algorithms for diagnostics, prognostics and life-extending control.

Application Areas:
* semiconductor manufacturing (Rockwell)
* engine control (Zin)
* in-situ monitoring (for humans, animals, and industrial apps.)

(2) DISTRIBUTED SYSTEMS AND AUTONOMOUS AGENTS

(a) Monitoring
(b) Diagnostics
(c) Security
(d) Control

Design, testing and performance verification of distributed control architectures that explicitly accounts for: the distributed nature of sensors, actuators and plant elements and network/communication constraints on sensor/control performance.

Development activities: integrated monitoring, diagnostics and prognostics and the design and implementation of distributed control methodologies including secure communications, protocols and sensing/control architectures, decomposition/aggregation methodologies, and autonomous agent-based systems.

Application Areas:
* smart manufacturing
* engine and motor control
* power distribution

(3) ADVANCED MOTION CONTROLS:

(a) Smart Rotating Machinery
(b) Advanced Motor Control (e.g., minimum jerk control)

Design of advanced, high performance control systems for electro-mechanical applications (e.g. motor control, motion control, smart rotating machinery) as well as the development of new electro-mechanical system configurations to replace existing hydraulic and pneumatic systems (e.g. in avionic and ship-board applications). This will require integrated diagnostics and control approaches to achieve the required levels of performance and reliability of existing implementations.

Application areas:
* material handling (Rockwell)
* avionics and shipboard automation (Rockwell)

NOTE:

The sensor-actuator networks proposed by UAkron are directly in line with the "Networked Control Systems" (NCS) work Case proposed for the WCI; in fact, we have been working in that area for the past two years or so and have an NSF grant (Liberatore and Branicky) on NCS. The large portion of our requested WCI funds was to build testbed networks to push this research.
We would be happy to explore a partnership with them.

Attachment B

Advanced Sensor Technology RFP

This is an opportunity to compete for a grant to develop new wireless and network-capable sensors. The sensor technology that is developed could include one or more of the following features.

- functionality in harsh environments (dirt, temperature, humidity, vibration, etc.)
- low power requirements
- embedded algorithms for diagnostics and prognostics
- small size
- noninvasive
- manufacturable in high volumes at low cost
- high sensitivity (e.g., micro-g acceleration sensors)
- high bandwidth (fast response time)
- ability to communicate without wires

New sensor technology development can involve research in several disciplines. This grant could include one or more of the following disciplines.

- electronic technology
- mechanical engineering
- materials science
- biological science
- organic chemistry
- algorithm development
- artificial intelligence
- embedded systems
- wireless communication / networking
- electro-chemical networks
- robust, secure, and fault-tolerant software / firmware

Application areas could include the following.

- semiconductor manufacturing
- nano scale mechanical device manufacturing
- engine control
- health monitoring of biological systems
- fuel cell control
- electrical distribution networks
- organic biological assembly processes

The sensor advances proposed in response to this RFP should be in direct response to specific, documented industrial needs. Sensors of the future should be designed in such a way that they can be networked in a wireless and flexible manner. They should have low power requirements, or be rechargeable without human intervention, so that they can function independently as long as possible. The sensors could be designed to be controlled from central control unit, or they could be designed to cooperate with one another without any central control. In either case, the sensors should transmit sensed data to some central database. The sensors should be able to issue control commands to one another, either on the basis of the self-awareness of the sensor network, or else in response to a command from a central control unit. Likewise, the sensors should be able to receive measurement transmissions from one another, either to increase the self-awareness of the sensor network, or else to pass the transmissions on to a central database or control unit. The sensors should be able to adapt to changing environments, or learn in such a way as to optimize their functionality as their operating environment changes. Low power consumption and low price per unit are key features required of the devices. The sensors may be designed with an adaptability that allows them to extend their life.

A plan for the incorporation of the results of this research into an undergraduate or graduate curriculum will strengthen the proposal.

A successful grant must present a detailed design, simulation results, a prototype (with a performance analysis), a plan for possible future implementation in a real-world application (generated cooperatively with an industrial partner), and a bid of the cost per unit (including development costs, parts, and markup).

At the conclusion of this project, the grantee shall deliver the following items to the grant sponsor.

- A written report giving a detailed description (including schematics, design drawings, and commented source code files) of the new sensor technology
- A public, oral presentation / seminar summarizing the work
- A demonstration of the prototype
- A complete user manual for the new sensor

Attachment C

Distributed Control Systems RFP

This is an opportunity to compete for a grant to develop new algorithms and technologies for distributed control. This includes the capability of autonomous control agents to cooperate with one another in a self-aware manner so as to increase robustness, security, and fault-tolerance. The autonomous control agents will be embedded systems that may include several of the following features.

- functionality in harsh environments (dirt, temperature, humidity, vibration, etc.)
- low power requirements
- algorithms for diagnostics and prognostics (of themselves, and also of the controlled objects)
- small size
- manufacturable in high volumes at low cost
- high bandwidth (fast response time)
- ability to communicate without wires

Distributed control technology is primarily an algorithm development problem, but could also include one or more of the following disciplines.

- electronic technology
- artificial intelligence
- embedded systems
- wireless communication / networking
- robust, secure, and fault-tolerant software / firmware

The distributed control advances proposed in response to this RFP should be in direct response to specific, documented industrial needs. Manufacturing plants, vehicles (land, air, and sea), offices, and many other environments will include distributed sensors, actuators, and controlled elements. The controlled elements must be networked together in such a way that they can be automatically controlled in a robust and fault-tolerant manner. Distributed control algorithms should take the following factors into account.

- communication constraints (although networks continue to get faster)
- microcontroller / DSP throughput constraints (although embedded computing devices continue to get faster)
- fault diagnosis / prognosis
- system robustness in the presence of local failures
- controller algorithm / software updates without interrupting control operation

Application areas could include the following.

- semiconductor manufacturing
- automotive system control
- fuel cell control
- nano scale mechanical device manufacturing
- organic biological assembly processes
- large scale power distribution (e.g., a utility power grid)

- medium scale power distribution (e.g., within a manufacturing plant)
- small scale power distribution (e.g., within a spacecraft)

Distributed control could be accomplished from a central control unit, but this results in a single point of failure. A control architecture that does not involve a central control unit might be more tolerant to single point failures. For instance, neural networks are often touted for their fault tolerance due to the distributed nature of their memory and processing. This RFP is not looking for a neural network solution, but that type of robustness and fault tolerance in a distributed control architecture is clearly desirable. Scalability is also an important consideration to ensure the future practicality of any architectures that are developed. The distributed control architecture should be scalable to tens of thousands of nodes.

With a distributed control system it may be difficult to prove that the solution will satisfy a given problem. Theoretical research that guarantees a solution to some well-defined class of distributed control problems would be an important contribution in the area of distributed control. In case the performance of the distributed controller cannot be guaranteed theoretically, advances in verification and validation technologies could increase the user's *a priori* confidence in the performance of the controller without resorting to exhaustive testing.

Distributed control systems should be designed in such a way that they can be networked in a wireless and flexible manner. They should have low power requirements, or be rechargeable without human intervention, so that they can function independently as long as possible. The individual nodes should transmit status readings to some central database. The nodes should be able to issue control commands to one another, either on the basis of the self-awareness of the control network, or else on behalf of a central control unit. Likewise, the nodes should be able to receive transmissions from one another, either to increase the self-awareness of the control network, or else to pass the transmissions on to a central database or control unit. The nodes should be able to adapt to changing environments, or learn in such a way as to optimize their functionality as their operating environment changes. Low power consumption and low price per unit are key features required of the individual control nodes. The nodes may be designed with an adaptability that allows them to extend their useful life.

A plan for the incorporation of the results of this research into an undergraduate or graduate curriculum will strengthen the proposal.

A successful grant must present a detailed design, simulation results (with a performance analysis), and a plan for possible future implementation in a real-world application (generated cooperatively with an industrial partner). Delivery of a prototype is desirable but not required.

At the conclusion of this project, the grantee shall deliver the following items to the grant sponsor.

- A written report giving a detailed description (including schematics, design drawings, and commented source code files) of the new distributed control technology
- A public, oral presentation / seminar summarizing the work
- A demonstration of the simulation or prototype
- A complete user manual for the simulation software / prototype

Attachment D

Performance and Stability Verification System for Distributed Autonomous Agents RFP

This is an opportunity to compete for a grant to develop methodologies and systems to verify the performance and stability of distributed, autonomous sensor, actuator and control agents. This verification system should be capable of determining the statistical dimensions of performance and stability over a range of operating conditions, as well as the deterministic performance and stability boundary for a given set of operating requirements. The proposed research should, at a minimum, result in a description of infrastructure requirements for the autonomous agents, as well as for the interconnections between the agents, in order to enable this performance and stability verification system.

This verification system should be capable of discovering the connections and interactions of a distributed system of autonomous agents, along with the performance and stability of the connected agents, without a priori knowledge of those connections and interactions. It should be capable of mapping and displaying for humans the physical as well as functional interconnections of the distributed autonomous agents. It should also be capable of displaying, for each individual agent and interconnection, the relative contribution to the lumped performance and stability of the total distributed system.

The verification system should display the performance and stability model and information for each individual agent and interconnect in the total system. The verification system should, given a defined set of operating requirements, also be capable of providing a sorted list of agents and interconnections relative to their contribution to total performance and stability. It should also allow the examination and calculation of the lumped parameters for any user defined subsystem. The verification system should enable proposed modifications to the distributed autonomous agent system and simulation of the resulting performance and stability.

The verification system should be capable of predicting and simulating the performance and stability of the distributed system of autonomous agents in the event of single point failures.

The verification system should also be capable of incorporating legacy nodes and interconnected subsystems.

- Via connections interfaces between the distributed autonomous system and the legacy subsystem
- Using independently supplied performance and stability models for connected nodes
- Using independently supplied distributed parameter models for the legacy network connections

A description of the necessary legacy models structure and information requirements should be part of the verification system development.

The requirements placed upon the autonomous agents, the interconnection system, and the legacy interfaces should take into account relevant technology and economic constraints, under the assumption that many of the autonomous agent and interconnection infrastructure requirements must be met with embedded devices:

- functionality in harsh environments (dirt, temperature, humidity, vibration, etc.)
- low power requirements
- small size
- manufacturable in high volumes at low cost
- high bandwidth (fast response time)
- ability to communicate without wires
- microcontroller / DSP memory constraints (although embedded computing memory continues to grow)
- system robustness in the presence of local failures
- algorithm / software updates without interrupting operation

Application areas could include the following.

- semiconductor manufacturing
- automotive or aerospace system control
- nano scale mechanical device manufacturing
- organic biological assembly processes
- large scale power distribution (e.g., a utility power grid)
- medium scale power distribution (e.g., within a manufacturing plant or shipboard systems)
- small scale power distribution (e.g., within a spacecraft)

A plan for the incorporation of the results of this research into an undergraduate or graduate curriculum will strengthen the proposal.

A successful grant must present a detailed design, simulation results (with a performance analysis), and a plan for possible future implementation in a real-world application (generated cooperatively with an industrial partner). Delivery of a prototype is desirable but not required.

At the conclusion of this project, the grantee shall deliver the following items to the grant sponsor.

- A written report giving a detailed description (including design documents, commented source code files, and a logical justification) of the new performance and stability verification technology, as well as the infrastructure requirements for the autonomous agents and their interconnections in order to enable this technology.
- A public, oral presentation / seminar summarizing the work
- A demonstration of the simulation or prototype
- A complete user manual for the simulation software / prototype

Attachment E

Advanced Motion Control RFP

This is an opportunity to compete for a grant to develop new algorithms and technologies for motion control. This includes the development of control systems for (possibly nano-scale) electromechanical applications. The motion control applications may have conflicting performance requirements, such as minimum time and low jerk. This grant could include one or more of the following components.

- new path planning algorithms (in the presence of constraints)
    - splines (algebraic or other)
    - artificial intelligence
- new path tracking algorithms (in the presence of constraints)
    - nonlinear control
    - artificial intelligence
- estimation algorithms to reduce the number or accuracy of sensors that are required for feedback
- new electromechanical system configurations

The motion control advances proposed in response to this RFP should be in direct response to specific, documented industrial needs. The motion control technology developed under this grant should include integrated diagnostics and prognostics so that required levels of performance and reliability can be satisfied in the presence of faults and disturbances.

Motion control technology is primarily an algorithm development problem, but could also include one or more of the following disciplines.

- electronic technology
- artificial intelligence
- embedded systems
- wireless communication / networking
- robust, secure, and fault-tolerant software / firmware

Motion control algorithms should take the following factors into account.

- microcontroller / DSP throughput constraints (although embedded computing devices continue to get faster)
- fault diagnosis / prognosis
- robustness in the presence of sensor faults

Application areas could include the following.

- material handling
- avionics
- shipboard automation
- nano scale materials manufacturing
- nano machines
- nano robotics

Motion control algorithms must be designed to satisfy multiple, and often conflicting, objectives. These objectives could include the following.

- dynamics (velocity, acceleration, jerk) in nano inertia
- time
- static constraints on the position
- computational constraints
- real-time motion profile / tracking adaptation in case of system faults
- stability

A plan for the incorporation of the results of this research into an undergraduate or graduate curriculum will strengthen the proposal.

A successful grant must present a detailed design, simulation results (with a performance analysis), and a plan for possible future implementation in a real-world application (generated cooperatively with an industrial partner). Delivery of prototype hardware is desirable but not required.

At the conclusion of this project, the grantee shall deliver the following items to the grant sponsor.

- A written report giving a detailed description (including schematics, design drawings, and commented source code files) of the new distributed control technology.
- A public, oral presentation / seminar summarizing the work.
- A demonstration of the simulation or prototype.
- A complete user manual.