**EL Project:** Intelligent Planning and Modeling for Autonomous Systems

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**Summary:**

This project will develop the measurement science and standards to enable advancements in planning by robots in scenarios relevant to manufacturing, starting with kitting and aiming towards assembly. Plans enable a robot to change its actions to deal with uncertainty in its environment and to rapidly switch to new tasks. Plans are based on models of the current environment, predictions about the future, and *a priori* knowledge of causal relationships between current actions and results. The breadth and usability of knowledge in these models is one of the main factors that constrains the flexibility and performance of manufacturing planning systems. Currently, there is no accepted standardized way to represent this knowledge, to reason with this knowledge, or to measure the performance of these systems.

**Approvals:**

**Objective:**

To develop the measurement science and standards for planning and modeling by robots so that they are able to be more quickly re-tasked and are more flexible and adaptive by the end of FY2014.

**What is the new technical idea?**

This project will develop standard data abstractions for maintaining and sharing knowledge of the world and how to plan actions in it. Performance measurement techniques and artifacts will be developed to enable manufacturers to use these systems and abstractions in a cost-effective manner. The lack of an abstraction has led current manufacturing robots to have little or no understanding of the world around them and no capability to dynamically change their actions if the environment changes. This restricts them to operate in highly constrained environments and makes it difficult to change from one task to another. The primary challenges that may be solved by a unified knowledge abstraction are:

* Lack of agility that would allow robots to be quickly and easily re-tasked. With current teach pendant programming of robots, it may take an order of magnitude longer to program and configure the system than the task would take to complete by hand.
* Lack of adaptability that would allow robots to cope with part and environmental variations. Many subcomponents have component-by-component or lot-by-lot variations. Today’s high-precision robotic systems are not able to adapt automatically to such variations.
* Lack of flexibility in planning and perception systems that would allow them to cope with unexpected events or failures. A standard framework for representing knowledge would enable interoperation of planning and perception thus promoting knowledge reuse and flexible operation.
* Lack of performance measures to determine a system’s ability to be flexible, adaptable, and agile. Here a better understanding of what enables agility and how to measure it are needed.
* Lack of a standard framework for representing knowledge necessary to allow flexibility in robotic systems.

Initially, an open-source simulation engine will be used to simulate plan execution in content rich worlds that include semantic labels and virtual sensors capable of detecting and reporting the entirety of the environment. Repeatable scenarios will allow for the comparison of planning systems that are capable of exploiting this rich content. Later, work in the project will migrate to real robotic hardware.

**What is the research plan?**

While knowledge abstractions are needed across manufacturing, a decision was made to start addressing the problem by focusing on assembly, and in particular on the construction of kits. The work will focus on three key areas:

**Knowledge Representation**: Develop standard representations for world knowledge and plan knowledge, and the related performance evaluation criteria. We will design a comprehensive model that is able to represent knowledge for the general class of manufacturing problems in the area of rapid re-tasking for general assembly tasks. We will work in cooperation with the IEEE Standards Working Group on Knowledge Representation for Robotics and Automation to create a standard for knowledge representation and will provide a test implementation of the proposed standard to validate its usability. We will also derive methods of defining the performance requirements for the knowledge and will develop performance methods and metrics.

**Planning**: Develop techniques to compare planning algorithms that utilize the representations developed above to address next generation robotics for the class of manufacturing problems in the area of adaptable and reconfigurable assembly. Under this task, we will examine input/output standards and performance measures for planning systems.

**Simulation**: Develop a simulated manufacturing test method that is capable of demonstrating rapid re-tasking and evaluation using our performance measures. This test method will validate the utility of our interfaces and performance measures. In order to populate the semantic world representation, the existing simulation system (called USARSim) will be augmented and expanded to include new virtual sensing and representation capabilities. The simulation system will provide representations that are not yet possible to obtain from the real sensing systems. It therefore provides a high-fidelity but more advanced testbed for developing performance requirements and validating test methods.

**Recent Results:**

Outputs:

1. A workshop at the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) established our relationship with IEEE Robotics and Automation Systems Standards Committee Ontologies for Robotics and Automation Study Group (now a working group) and updated the group on our work in representations.
2. Created and circulated a planning document in the USARSim community that outlines an implementation strategy for developing the ability to include high-level semantic knowledge in the simulation. Making high-level semantic knowledge available allows for the simulation of yet-to-be-developed sensor processing systems that are capable of reliably reporting an object’s type and pose. The simulated sensor outputs may be intentionally corrupted with noise to resemble expected sensor processing output.
3. Developed the integrated system outlined above that allows virtual sensing of high-level semantic knowledge to be extracted from the simulation and delivered it to the USARSim community for comment.
4. Developed a simulation-based planning system using leading techniques from the domain independent planning community for creating static plans for adaptable and reconfigurable assembly. Due to the standard planning representation that we have adopted, several different planning approaches can be compared and evaluated. In order to allow other members of the IEEE Standards Working Group to easily experiment with our data abstraction, we created a tool set that allows planning and sensor processing systems to easily query and utilize the information stored in the world model.

Papers Published:

1. S. Balakirsky, and Z. Kootbally, USARSim/ROS: A Combined Framework for Robotic Control and Simulation. Proceedings of the ASME 2012 International Symposium On Flexible Automation (ISFA 2012). St Louis, MO, USA.
2. S. Balakirsky, Z. Kootbally, T. Kramer, R. Madhavan, C. Schlenoff, and M. Shneier (2012, March). Functional Requirements of a Model for Kitting Plans. Proceedings of the Performance Metrics for Intelligent Systems (PerMIS’12) Workshop. College Park, MD, USA.
3. Craig Schlenoff, Edson Prestes, Raj Madhavan, Paulo Goncalves, Howard Li, Stephen Balakirsky, Thomas Kramer and Emilio Miguelanez. "An IEEE Standard Ontology for Robotics and Automation" in "Bridges between the Methodological and Practical Work of the Robotics and Cognitive Systems Communities - From Sensors to Concepts" to be published in the Springer-Verlag series “Intelligent Systems Reference Library”.
4. C. Schlenoff, S. Foufou, S. Balakirsky. Performance Evaluation of Robotic Knowledge Representations (PERK). 2012. Performance Metrics for Intelligent Systems (PerMIS’12) Workshop. College Park, MD, USA.
5. MODEX IR

Papers Submitted for publication:

1. S. Balakirsky, Z. Kootbally, C. Schlenoff, T. Kramer, and S. Gupta.

An Industrial Robotic Knowledge Representation for Kit Building Applications. Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2012). Vilamoura, Algarve (Portugal).

1. Craig Schlenoff, Edson Prestes, Raj Madhavan, Paulo Goncalves, Howard Li, Stephen Balakirsky, Thomas Kramer and Emilio Miguela´n˜ez. "An IEEE Standard Ontology for Robotics and Automation" Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2012). Vilamoura, Algarve (Portugal).
2. Schlenoff, C., Foufou, S., Balakirsky, S. (2012). An Approach to Ontology-Based Intention Recognition Using State Representations. submitted to 4th International Conference on Knowledge Engineering and Ontology Development (KEOD 2012). Barcelona, Spain.
3. Schlenoff, C., Pietromartie, A., Foufou, S., Balakirsky, S (2012). Ontology-Based State Representation for Robot Intention Recognition in Ubiquitous Environments. Submitted to UBICOMP 2012 Workshop on "Smart Gadgets Meet Ubiquitous and Social Robots on the Web (UbiRobs)". Pittsburgh, PA.

Outcomes:

1. Project Authorization Request (PAR) accepted by IEEE Robotics and Automation Systems Standards Committee, resulting in the formation of the Ontologies for Robotics and Automation Working Group.
2. Held an industry workshop where representatives from the kitting, packaging, and palletizing industries came together to discuss common problems in component placement. As a result of this workshop, a NIST IR was produced, a mailing list that allows interested parties to stay in touch was created, and an industrial working group to advise the project was formed. This occurred at the MODEX show on 6-12 Feb in Atlanta, GA.
3. A draft representation for semantic world knowledge that is capable of supporting a priori and static knowledge gathered from sensors and databases was delivered to the IEEE Standards Working Group. This knowledge supports next generation robotics for manufacturing problems in the area of component placement.

**Standards and Codes:**

We are working with the NIST-led IEEE Working Group on Knowledge Representation for Robotics and Automation. As part of this project’s efforts, we are working with industry to produce new standards and performance measures for Knowledge Representation.

**STRS Funding:**

**See attached spread sheet.**

**Project Total: $785K**

**Outside EL Funding:** None

**Project Hazard Assessment:** All NIST Robot Testbed activities will adhere to the risk assessment and safety guidelines as specified in the test bed safety manual. A FLHR will be conducted by 10/01/12 and as necessary when changes are made that might affect workplace safety.

**FY 2013 Milestones:**

**Q1**

* **Output** - Present a white paper that will be shared with our MODEX workshop attendees and the IEEE working group that begins a discussion on flexibility and agility. What does it mean to be flexible? What does it mean to be adaptable? What aspects of the system require flexibility/adaptability to yield the largest payoffs? (**Balakirsky**)
* Augment the data abstraction to include anticipated failure modes of actions and the probabilities associated with them for the kitting application. (**Kramer** & Kootbally)
* Automatically populate the *Planning Language* of our architecture from the *Ontology*. (**Schlenoff** & Kootbally)
* **Output** - Submit a paper detailing our state-based approach to ontology updating. (**Schlenoff**)

**Q2**

* Develop metrics to determine how flexible and agile a kitting system is. These will be based on the definitions from Q1. (**Kramer**)
* Develop test methods that provide a means of testing a kitting system’s flexibility and agility using the definitions produced in Q1 and the metrics produced in Q2. (**Balakirsky** & Kramer)
* Populate specific instances of failure modes for the kitting domain into the ontology and deliver the updated ontology to the IEEE working group. (**Kootbally**)
* **Output** - Develop an interface language for communicating between a high-level planning system and a lower-level planning system. This interface language will be delivered as a report to the IEEE working group for use in the standards activities. (**Kramer**)

**Q3**

* Augment the ontology to support the representation of plan segments. (**Kramer**)
* Demonstrate the use of the interface language delivered to the IEEE working group by augmenting our sample implementation of the kitting planning system to read *Planning Language* files and generate *Robot Language* files that are compliant with the proposed standard. . (**Kootbally** & Pietromartire)
* Develop a visualization/data tool that will allow users to visualize the execution of kitting plans formulated in the interface language and gather statistics on those plans for use in performance evaluation. (**Kramer**)
* **Output** – An initial kitting system demonstrated to IEEE working group that updates the ontology based on state information observations. (**Schlenoff**)
* Develop a representation of detailed state information within the ontology and real-time knowledge base for the kitting application. (**Schlenoff**)

**Q4**

* **Output** - Present a report to the IEEE Working Group detailing our definitions of flexibility, the test methods that may be used to demonstrate flexibility, and a demonstration of how a knowledge representation can aid in assuring system flexibility and agility. (**Balakirsky** & Kootbally**)**
* Augment our kitting planning system to detect action failures, retrieve appropriate responses from the ontology, and execute these contingency plans thus demonstrating the ability to adapt to error conditions. Deliver the system to the IEEE working group. (**Kootbally** & Pietromartire)

**FY 2014 Milestones:**

* Develop a knowledge representation to support robotic kitting, packaging, and palletizing operations in manufacturing and provide the technical basis for standards that enable more rapid deployment and re-tasking of robotic systems in these applications, resulting in more agile and productive assembly and packaging processes.
* Develop the first draft of a new standard on knowledge abstractions for manufacturing in cooperation with the IEEE Working Group.
* Propose our sample planning system, test methods, and performance metrics to the standards committee as performance evaluation tools for the emerging abstraction standard.
* Propose the simulated manufacturing cell to the standards committee as a performance evaluation tool for the emerging abstraction standard.
* Migrate the system to our testbed hardware to provide further validation of our approach on actual robotic hardware.

**Project Outcomes:** New measurement science techniques and standards for knowledge representation, planning, and modeling for kitting, an important task in its own right, will start to address assembly in manufacturing.

**Project Impact:**Industrial adoption of new robot knowledge representation standards will allow for the comparison of robot planning and knowledge generation systems with applications for kitting and assembly in manufacturing. This will ultimately allow for flexible manufacturing robots that can be rapidly re-tasked to perform a variety of functions.