Workshop on Opportunities in Robotics, Automation, and Computer Science

Sponsored by CCC, NSF, OSTP and the Robotics VO

Introduction

Over the last few years, we have seen tremendous growth in use of robots in the manufacturing and material handling sectors. The latest industry statistics report shows a 40% growth in use of robot systems[1]. At the same time we have also seen tremendous economic growth and increased new employment in the same sectors. Companies such as Apple, Lenovo, Flextronics and HP have re-shored major manufacturing facilities through the use of advanced automation in combination with a skilled workforce.

The Federal government has made significant investments in robotics through the National Robotics Initiative (NRI)[2]. One of the important themes in the NRI is *co-robots*, robots that can work in close cooperation with humans to perform tasks more effectively and safely. Co-robots have seen applications in diverse applications including those in the manufacturing, agriculture, healthcare, service and space sectors. Co-robots are particularly important in manufacturing enterprises where lot sizes may be too small to justify full automation and product life-times can be short. Humans must function alongside robots to enable fast deployment, especially since the environment may only be partially structured.

With this as a backdrop, on October 21, 2013, NSF, CCC, OSTP and the Robotics-VO organized a meeting at the White House Conference Center in Washington, DC. The objective of the meeting was to discuss current opportunities for US manufacturing related to robotics, automation and computer science. A second objective was to try to define use-cases for use of advanced technology to promote growth in the general area of manufacturing. The meeting had participation from a broad set of industry representatives, academic researchers and government representatives to ensure a balanced dialog about the challenges and opportunities. This document is a summary of the main discussion points from the workshop.

The workshop consisted of a few plenary presentations on application scenarios from industry, and several parallel group discussions that explored application scenarios, challenges and opportunities and associated R&D needs. The following sections provide a summary of the main points discussed during the workshop. A summary section at the end synthesizes a number of challenges and considerations for future R&D.

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[1] IFR World Robotics 2012, IFR/VDMA Statistics Department, October 2013
[2] http://www.nsf.gov/nri

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Application Scenarios

As part of the workshop four major application scenarios were identified

1. Large volume manufacturing
2. Small volume high value manufacturing
3. One-off manufacturing
4. Supply chain and material handling

The four applications all have differing requirements.

The large volume manufacturing is, for example, seen in automotive and in electronics manufacturing. The product lines typically change on a regular basis and revisions may happen as frequently as every 6-12 months. Broadly speaking, there are two distinct scenarios: (i) mass manufacturing of a single product such as a smart phone over a short time scale; and (ii) manufacturing of a product family where potentially every product can be customized. An example product in this latter category is cars. Today's cars are sold with a variety of different options and it is not unusual to have more than one million variations for the same model. To utilize automation for such products it is necessary to have a high degree of modularity in the design to manage and operate such product lines. The large scale manufacturing lines for electronics typically have a life time of less than a year and it is consequently important to be able to specify, design and implement production systems very quickly.

Small-volume/high-value manufacturing is exemplified by the aerospace sector, where product volume is much smaller, typically in less than 100 units per month. The value of each unit is high and there are significant quality requirements. Through utilization of automation, it is possible to achieve consistent quality, increased speed and easy configuration across unit variations. The key drivers are: 1) quality, 2) in-process inspection, 3) increased volume and 4) reduction of cost. The increase in performance for robot systems gradually allows for replacement of hard automation such as CNC machines, which has the potential to significantly reduce infrastructure investments and provide high flexibility in per unit processing and/or manufacturing multiple significantly different items on the same line.

One-off manufacturing is typical in a large variety of small and medium sized companies. Special purpose items such as spare parts or one-off engineered products are often manufactured with limited use of automation. The process may involve use of multiple CNC machines but the handling of the part and all assembly is typically performed using manual labor. The cost of programming for these applications is typically too demanding. There is a lack of adequate tools for the rapid design, programming and deployment across an existing suite of manufacturing tools. An example of how this problem is addressed is the AMP Digital

Manufacturing Effort and the recent EU project – Factory in A Day[3]. The main requirements here are related to multi-tasking, efficient programming for a particular product, and integration with the design process to ensure effective translation from design to production.

Supply chain management and material handling have seen tremendous progress over the last few years. The key drivers are effective utilization of space, increased delivery rates, and better ergonomics. Warehouses and distribution centers have a space utilization that is typically less than 50%. I.e., less than 50% of the available volume is used for storage. New systems such as the Amazon KIVA[4] allow for significant improvements in utilization of space. A warehouse/distribution center is typically composed of areas devoted to in-processing, storage and shipping. In-processing covers de-palletizing, selection of locations for storage. The storage can be optimized through use of automated storage and retrieval systems, which typically are compact areas with highly automated handling of material. Shipping could involve fetching material, palletizing, and wrapping. For groceries it is typical that a person will spend 80% of their time walking between pick locations, which is ineffective. Utilization of automation to reduce the need for space and to perform faster palletizing / truck loading/un-loading are considered major challenges. For loading and unloading of trucks the main requirement is speed. A person can typically unload 1000 units / hour and load 500 unit / hour. Such rates require careful consideration of gripping technology, dynamics and perception to be robust. The main requirements here relate to the speed of processing and optimization of utilization of a fleet of static and mobile platforms with respect to speed and space utilization.

Challenges / Obstacles to Progress

Automating the Automation:
One of the most pressing issues identified in the workshop was related to the cost of deploying and managing a production line. According to the IFR World Robotics 2009 the cost of deploying an automation system can be split into 20-25% for the robot, 20-30% auxiliary hardware and 45-60% systems integration. This fraction appears to have not changed significantly over the last four years. The cost of systems integration is significant and there is very limited reuse of software from one application to the next. In addition, the time required to deploy a line can be significant. This is one of the motivations behind the earlier mentioned EU project on Factory in a Day. An earlier project considered – Lot-size One Manufacturing – and the need for flexible design tools that allow for fast deployment. A theme identified as the need for new methods to enable one to “Automate the Automation. ” The question has many facets and challenge range from modular architectures and software reuse to more effective design tools for complex systems. Automated methods for configuration management, code-generation, verification and simulation have been widely used in systems and software engineering, but they have so far seen little adoption in the robotics and automation domain.

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[3] http://www.factory-in-a-day.eu
[4] http://www.kiva.com

High performance:
Traditionally high accuracy has been achieved through use of stiff mechanical structures. The two main solutions have been massive mechanical structures with an inherent stiffness for each link or use of parallel kinematic structures as seen in the recent wave of "delta" mechanisms. However, there is a need for low-cost, lower inertia systems to enable higher safety and speed, using sensing, perception and feedback control to ensure the required accuracy. Today most of the accuracy is achieved through electro-mechanical and structural design rather than through integrated systems design. A few systems have started to emerge such as the Electro-Impact system for precision processing, but at a very significant cost. The desire is to have the same performance but in much lower cost systems. How can accuracies better than 0.1mm be achieved in robots that cost less than $25k? In electronics assembly there is a desire to have manipulation systems that cost less than $4k and they might only have 4 degrees of freedom, as the orientation of parts typically is horizontal. There is thus a need for lower-cost robot mechanisms that utilize feedback control and advanced sensing such as part recognition to achieve high performance.

In-process inspection:
Gradually perception is being integrated into robot systems, as seen at the recent International Conference for Vision Guided Robotics[5] (2013), but the integration is tedious, time-consuming and requires significant engineering. There is a lack of standardized perception modules that would allow for faster deployment without customization to individual applications. Today it is common to separate processing and inspection. With the more widespread use of sensor technology for control of the process it is natural to consider how the same technology can be utilized to also perform inspection and to integrate processing an inspection to increase speed. Recent advances in sensory technology, processing and delivery of such methods in standardized packages is very interesting to end-customers. The availability of standard Robot Operating Systems (ROS) modules that can be used for inspection is considered essential to accelerate progress in this area. Inspection in most cases is metric measurement of dimensions of a sub-part or full object or identification of the objects as part of material handling.

End effector technology:
For R&D there is a very limited availability of high quality flexible end effectors. For deployment in the factory domain it is not unusual that the cost of the end-effector is the same as the cost of the robot. Most end-effectors are specially-designed grippers. There is no doubt that design of modular or standardized grippers would significantly improve the economics of deployment. In addition, new advanced on compact sensors point to a desire to further integrate tactile, haptic and force-torque sensors into the grippers to provide a higher degree of dexterity in a final system. However, integrated mechatronic end effectors can have a much lower price/performance ratio. New advances in materials point to potential changes in paradigm such as the electro-static adhesion examples that have been reported.

[5] http://www.visiononline.org/events/event.cfm?id=181

Co-robot safety:
Co-robots present a significant challenge in terms of safety because robots and humans have to share a common workspace. How can it be ensured that there are no accidents in such a setup? The recent ISO 10218.6 was established to provide rules for employment and limits the amount of energy and force that a robot can exert on a human. In most industrial applications the cost of the safety part of the setup is significant. It raises the question – what is the best model for robot safety and how can it be achieved in a cost effective manner? Is a specification merely in terms of force and power an adequate model. Humans collaborate and have a model of mutual respect and trust which is a two-sided model, both are responsible for the overall safety. In the present setup for co-robots the responsibility is entirely on the robot and the safety only covers contact situations. Is it possible to define a balanced model for safety, which goes beyond direct contact? And could such a model be implemented at a reasonable cost.

Modularity / Standardization:
As mentioned earlier the cost of deploying systems is significant. In addition, the time to deployment is also a challenge. Recently there has been a lot of interest in the Robot Operating Systems[6] (ROS) and the industrial version ROS-I, managed by Southwest Research Institute[7] (SWRI). The availability of standardized solutions or modules has the potential to significantly reduce development and deployment time and cost. So far the ROS development has focused on core architecture components and the academic community has developed a rich variety of modules. One such example is the MoveIt suite for planning and control of manipulators[8]. Recently the ROS development has also been supported by the National Robotics Initiative[9], NASA and DARPA as part of the DRC.

Simulation:

Simulation is a key capability that supports both design of a manufacturing process at the process level as well as providing direct support of planning and control during execution. However, there is a substantial gap between low-level physical simulation and high-level process flow simulation. As a result, it is difficult to assess the impact of "low-level" changes on the overall process. This is further complicated when the process involves both human and robotic elements. Creating a unified, vertically - integrated, simulation environment would allow for more effective design and optimization of manufacturing processes. It is equally important, to create simulations that can be updated with data from a process in operation to enhance its predictive capabilities.

[6] http://www.ros.org
[7] http://rosindustrial.org
[8] http://moveit.ros.org
[9] http://www.nsf.gov/nri

Opportunities

Go where humans can't and do a task with superhuman quality

Humans are limited by size, strength, stamina, and biological perception. Robots have none of these limitations. For example, running cables in an aircraft fuselage or applying coatings to an assembly are ergonomically challenging. Cooperative systems could "transport" human skill into these applications, and augmentation of sensing and manipulation capabilities could improve quality, reduce ergonomic injuries, and enable "superhuman" task performance.

General purpose automation for special purpose use:

There are two reasons for the high cost of most manufacturing operations: special purpose capital equipment designed for the specific task at hand, and programming of the system to accomplish a task. Both of these could be mitigated if it were possible to deploy general purpose automation (e.g., a robot arm) to provide application-specific skills in a flexible and reliable fashion. For example, feeders and fixtures are designed to provide steady and reliable flow of parts or material. All of these capabilities could be replaced by general-purpose bin-picking or part sorting combined with programmable fixturing methods.

Flexible material handling:

Many industries depend on handling flexible materials – cables, hoses, wiring, cloth, insulation, etc. Thus far, there is little known about how to structure the problem of flexible material manipulation. Simulation of flexible materials is difficult and dependent on large numbers of parameters. Lack of good models means that control is difficult to design. In most cases, perception is essential in order to manage deviations from a planned manipulation. Flexible materials also typically require additional dexterity, either in the form of specialized manipulators or the use of multiple manipulators (for example, tying a knot requires at least three parallel jaw grippers).

Plug and Play Robots:

Human-intensive manufacturing has developed highly efficient organizations and processes for assembly and packaging. Completely reorganizing these processes to accommodate new forms of automation will meet substantial resistance due to the disruption, risk, and cost involved. Creating robots that could easily "plug in" to a human workstation presents an attractive alternative. However, to do so, new forms of programming, demonstration or instruction must be created, supported by adequate and reliable perception allowing robots to detect and understand human actions and to monitor and operate processes in an assembly line.

Summary

Manufacturing currently comprises about 12% of the US GDP -- about 1.8 trillion USD. Although there is a perception (and some truth) to the fact that manufacturing is leaving the US for low wage countries, there are many manufacturers that are interested in innovating in ways that would grow manufacturing (and jobs!) in the US. There are many efforts, such as the recently announced National Network for Manufacturing Initiative[10] (NMMI), to accelerate this trend. The main goal of this workshop was to articulate areas and approaches to enable the robotics and computing research communities to support these efforts.

The workshop identified three important areas that need immediate attention.

1. "Automate the automation" – streamlining the design of assembly lines and the deployment of robots to reduce the time to start production, independent of the product mix or volume. This in turn points to the need for research and development on model-based design, simulation and analysis for manufacturing automation enabling the optimal setup, design, and implementation of new assembly lines.

2. Abstractions and representations for middleware - currently the "missing middleware" makes it difficult to generalize from successful deployments of components for specific tasks and transfer solutions across different manufacturing equipment and products.

3. Models of collaboration: There was extensive discussion of novel models of collaboration that could give academia more immediate access to relevant problems faced in manufacturing automation and lead to a successful collaborative research and development program.

[10] http://www.manufacturing.gov

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