IEEE/NSF Workshop on Cloud Manufacturing and Automation

Aug 17, 2013, Madison, Wisconsin
Hosted by the IEEE Int'l Conf. on Automation Science and Engineering
Program with slides: http://telerobot.cs.tamu.edu/CMA/CMA-program.htm

Summary

Emerging industrial trends such as the Industrial Internet (General Electric), Industry 4.0 (Siemens and other German corporations), and the Internet of Things (RFID Consortium) have vastly increased the amount of data collected by devices, parts, machines, tools etc. Related trends such as Cloud Computing, Big Data, Machine Learning, Crowdsourcing, and Open-Source Software have potential to address the resulting bottlenecks in computation and memory in the next generation of distributed automation systems in manufacturing, healthcare, transportation, agriculture and many other applications (see http://goldberg.berkeley.edu/cloud-robotics/ for recent activities). These developments suggest many new research problems, such as architecture, security, performance/speed tradeoffs, standards, uncertainty, reliability, planning and scheduling. This one-day IEEE/NSF workshop brought together 30 scholars and experts from industry to explore the opportunities, challenges and open problems. Some participants' travel within the US was supported in part by the US National Science Foundation.

Opportunities

The Cloud has potential to improve system performance in at least five ways:

1. Big Data: indexing a global library of images, maps, and object data,
2. Cloud Computing: parallel grid computing on demand for statistical analysis, learning, and motion planning,
3. Open-Source / Open-Access: humans sharing robot code, data, algorithms, and hardware designs,
4. Collective Robot Learning: robots sharing trajectories, control policies, and outcomes that can be analyzed with statistical machine learning methods, and
5. Crowdsourcing and call centers: offline and on-demand human guidance for evaluation, learning, and error recovery.

Benefits in Manufacturing and Automation

The Cloud could increase productivity, quality, efficiency, flexibility, and versatility of almost all automation systems. Below is a list of potential benefits:

- Allow manufacturing and automation as services over the cloud
  - Facilitate small shops bidding on jobs and also let shops rent out idle equipment
  - Reduce design and prototype time

    - Better connection to consumers and suppliers
- Extremely flexible manufacturing
    - Adaptive and reconfigurable manufacturing line for multiple products
    - Fast response to market change
    - Connection to database at both micro (i.e. production line status) and macro (social activities, news, weather, stock market, currency exchange, etc.) levels to allow proactive response to changes.
    - Autonomous material recognition, handling and transportation
    - Fault diagnosis and robustness to failure to reduce down time
- Crowdsourcing
    - Crowd assisted data analysis
    - Provide knowledge for automation system to learn
    - Collaborative design and verification
    - Better access to a variety of intellectual resource for complex problems
- Personalized and customized products
    - Commodity vs branding, online user reviews and feedback systems enable small businesses to quickly establish themselves.
    - Enabling new technologies such as 3D printing and mobile phones
    - In medical markets, fashion items (e.g. shoes, eyeglasses)
- Production capacity / resources sharing
    - Higher utilization of the equipment
    - Reduction of capital investment
    - Easier management
- Optimized complexity
    - Better managing increased globalization and complexity
    - Reduced impact on quality due to complex manufacturing network

Challenges and Open Problems

According to our workshop discussion, we would recommend NSF and research funding agencies worldwide to invest on the following strategic areas to further foster the development of this new exciting frontier. The discussion on cloud computing certainly bring us a new perspective on the supporting technologies that are urgently needed to maximize its potential. The following partial list can serve as a starting point.

- Information technology infrastructure
    - intelligent Information integration,
    - aggregation and analysis,
    - models and prediction,
    - distribution,
    - security;
- Cloud supported manufacturing-related technologies for flexible and versatile manufacturing
    - sensing,

    - planning,
    - grasping,
    - actuation, and transportation;
- New inter-connects
    - service model,
    - architecture,
    - protocol,
    - standard;
- Foundations
    - big data, timing, and scalability,
    - load balancing between on-board computation and cloud,
    - scalable parallelization,
    - latency,
    - reliability and robustness to failure,
    - performance analysis;
- Human-cloud Interaction,
    - algorithms and interface to facilitate crowdsourcing,
    - decision-support,
    - telepresence for remote factory and technical support;

Acknowledgment

We sincerely thank National Science Foundation for the tremendous support. Without it, this workshop would not be possible. Special thanks are given to our speakers (see the attached program) and anonymous participants. Your enthusiastic participation had made this workshop great fun to organize. We also thank CASE 2013 organizers for doing a great job in logistics.

Program and Slides

[08:30-09:00] *An Introduction to Cloud Automation*, Ken Goldberg (UC Berkeley)

[09:00-09:30] *A report of the first cloud robotics workshop*, Richard Voyles (NSF)

Session 1: [Session Chair: Ken Goldberg]

[09:30-09:50] *The Industrial Internet*, Austars Schnore (GE)

[09:50-10:10] *The Humans in the Cloud: Towards Shared Autonomy over the Internet*, Matei Ciocarlie (Willow Garage)

[10:10-10:30] *Internet of Things*, MengChu Zhou (New Jersey Institute of Technology)

[10:30-10:50] *Progress in Algorithmic Motion Planning Related to Cloud Robotics, Automation and Manufacturing*, Kostas Bekris (Rutgers University)

[10:50-11:35] Panel and Discussion

Session 2: [Session Chair: Dezhen Song]

[13:00-13:20] *Robotics as a Service (RaaS): A Service Model for Robotics and Automation Software*, Ben Kehoe and Arjun Singh (UC Berkeley)

[13:20-13:40] *A Practitioner's Experience of the use of Cloud Computing in Control*, Sekou Remy (Clemson)

[13:40-14:00] *Cloud Manufacturing in Healthcare: A Gamma Knife Center Experience*, Emin Kececi (UVA)

[14:00-14:20] *Cyberinfrastructure enabling personalized production*, Dawn Tilbury (U Michigan)

[14:20-15:05] Panel and Discussion

Session 3: [Session Chair: Dawn Tilbury]

[15:15-15:35] *View planning for object recognition*, Gabriel Oliveira (UMN)

[15:35-15:55] *Flexible Manufacturing Line with Multiple Robotic Cells*, Heping Chen (Texas State U., formerly at ABB)

[15:55-16:15] *Cloud Mediated Nature Observation*, Dezhen Song (Texas A&M)

[16:15-17:00] Panel and Discussion

Speaker Notes (Partial)

Introduction to Cloud Automation

Ken Goldberg, UC Berkeley

What if robots and automation systems were not limited by onboard computation, memory, or software? Advances in wireless networking and rapidly expanding Internet resources can reduce these limitations. In 2010, James Kuffner at Google introduced the term "Cloud Robotics" to describe a new approach to robotics that takes advantage of the Internet as a resource for massively parallel computation and real time sharing of vast data resources. The Google autonomous driving project exemplifies this approach: the system indexes maps and images that are collected and updated by satellite, Streetview, and crowdsourcing from the network to facilitate accurate localization. Another example is Kiva Systems' approach to warehouse automation and logistics using large numbers of mobile platforms to move pallets using a local network to coordinate platforms and update tracking data. Related concepts include the "Internet of Things", General Electric's vision of the "Industrial Internet", and Siemens' concept of "Industry 4.0".

Cloud Robotics and Automation recognizes the wide availability of networking, incorporates elements of open-source, open-access, and crowdsourcing to greatly extend earlier concepts of "Networked Robots". Cloud Robotics and Automation has potential to improve performance in at least five ways: 1) Big Data: indexing a global library of images, maps, and object data, 2) Cloud Computing: parallel grid computing on demand for statistical analysis, learning, and motion planning, 3) Open-Source / Open-Access: humans sharing robot code, data, algorithms, and hardware designs, 4) Collective Robot Learning: robots sharing trajectories, control policies, and outcomes that can be analyzed with statistical machine learning methods and 5) Crowdsourcing and call centers: offline and on-demand human guidance for evaluation, learning, and error recovery.

Cloud Robotics Research at UC Berkeley is supported by the National Science Foundation, Google Inc, and Cisco Inc.

For updated links and papers, please see http://goldberg.berkeley.edu/cloud-robotics/

The Industrial Internet

Aussie Schnore, GE Global Research

In introducing the term "Industrial Internet" GE is acknowledging the need for infrastructure to fuel a new wave of innovation extending the waves of change created by the Industrial and Internet revolutions. This new wave is driven by the constructive intersection of new technologies and new business models emerging from such innovations as the Internet of Things, Intelligent Machines, Big Data and Analytics across a wide set of industrial domains. The future of Industrial Internet is not assured as there are challenges to be overcome in areas such as Performance, Cyber-Security, Maintenance and Interoperability which are accentuated at scale and could turn customers away from the technology as well as deeply undercut potential profits. Key to addressing these challenges is a community approach that reaches across industrial/vendor/business boundaries and strives to leverage highly automated standards based approaches to assure that the journey into the Industrial Internet era can be comfortably taken.

The payback for this journey will be realized in a multitude of areas many of which are outside of the core of GE's business focus and so GE can only speculate on the effect in those areas. Much of what is going to be gained is necessarily in the future and as a result again is very speculative. What GE can do to support this payback story is to look at early indicator projects that leverage those emerging innovations mentioned above. The examples GE has used are from a broad range of industries and customers such as Healthcare, Energy Distribution and Renewables which impact a large portion of the population of the planet. Some of these early indicator projects have already changed or created new markets, excited/motivated customers by exposing new gains to be had and pulled the corner back on what will be possible in the future if the necessary infrastructure is available. As the effort to grow and accelerate the development of the necessary infrastructure of the Industrial Internet gains momentum you can expect the number of these examples across many other businesses will grow and potentially outpace GE. This is as it should be as the Industrial Internet is an idea that will only see its full potential if it is available across the planet.

Progress in Algorithmic Motion Planning Related to Cloud Robotics, Automation and Manufacturing

Kostas Bekris, Rutgers University

Recent progress in motion planning and multi-robot planning together with developments in cloud robotics has the potential of significantly benefiting manufacturing and automation applications.

In particular, the conditions under which popular sampling-based motion planners converge to optimal solutions have only recently been defined. Such algorithms can be used for manipulating objects using robotic arms in industrial settings. Nevertheless, asymptotically optimal planners result in quite large and dense roadmaps, which introduce computational challenges especially when they are to be queried and communicated over a network or updated dynamically in the context of cloud robotics. Recent progress has resulted in the definition of sparser representations that can still provide near-optimality properties motivated by tools in graph theory. These graphical representations are appropriate for cloud robotics tasks as they can be queried and communicated much faster.

The area of multi-robot path planning relates to warehouse automation challenges, such as setups similar to KIVA systems, and involves combinatorial challenges related to discrete search. Recently, there has been progress in the development of more efficient complete and optimal planners that can deal with problems involving tens of agents for multi-agent path-finding on graphs with a variety of methods that range from more efficient heuristic search algorithms to techniques utilizing linear programming solvers. At the same time, there is also progress in the development of suboptimal but still complete planners that can deal with problems that involve up to thousands of agents by taking advantage of a line of work in algorithmic theory. These discrete solutions can also form the basis of solving efficiently multi-robot motion planning problems in continuous representations, where the computation of the solution takes place in a cloud computing facility.

The Humans in the Cloud: Towards Shared Autonomy over the Internet

Matei Ciocarlie, Willow Garage Inc.

Our vision is that of a robot operating in an unstructured environment requesting (and receiving) assistance from a remote operator whenever the environments presents challenges beyond autonomous algorithms. The Internet can connect many such robots and operators, but a number of challenges must first be overcome. These challenges include:

- controlling of a complex, high-dimensional system through a low-dimensional interface
- using a limited bandwidth connection with high latency while still providing the operator(s) the needed level of environmental awareness
- enabling robot operation by non-experts.

The talk presented new methods and technologies from our group aimed in these directions, including shared autonomy for mobile manipulation in complex environments, efficient transmission of depth images over the Internet, and a portable framework for developing interactive robot applications using a browser-based frontend.

Cyberinfrastructure enabling personalized production

Dawn Tilbury (U Michigan)

As mentioned by several other speakers, cloud computing technologies have the potential to revolutionize manufacturing. This presentation explored the opportunities for personalized production. In the future, consumers will be more engaged not just in selecting the products they wish to buy but also in designing them. Each personal design (perhaps based off of a family of modular designs) then needs to be manufactured, while keeping quality control, delivery time, cost, and safety of the products at the forefront.

Crowdsourcing has been demonstrated for automotive design through Local Motors, but manufacturing of these new cars was by hand. To meet increasing demand while keeping quality high and final costs low, mass-production techniques must be used. Cyberinfrastructure can enable personalization within a large-scale factory, but standards and interfaces need to be developed to facilitate this level of differentiation.

Cyberinfrastructure can also enable the interconnection of multiple factories, with smaller job-shops seamlessly integrated into large-factory supply chains, and vice versa. Proprietary considerations must be addressed, as not all suppliers would like to advertise their capabilities or availability. The ownership of a personalized or crowdsourced design must also be defined. If these challenges can be overcome, future products may arrive in the market sooner, with increased personalization, as well as lower cost.

Cloud-Mediated Nature Observation

Dezhen Song, Texas A&M University

Scientific study of animals in situ requires vigilant observation of detailed animal behavior over weeks or months. When animals live in remote and/or inhospitable locations, observation can be an arduous, expensive, dangerous, and lonely experience for scientists. Emerging advances in cloud computing, social networking, robotic cameras and distributed sensors make feasible a new class of observatories that can allow groups of scientists, via the internet, to remotely observe, record, and index detailed animal activity where cloud computing serve as a media to enable a variety of interactions ranging from cloud-assisted teleoperation to distributed bio-diversity recognition algorithms.

One challenge is to develop a mathematical framework for cloud mediated nature observation which includes (1) collaboration between humans of different backgrounds, skill sets, and authority/permission levels, (2) collaboration between humans and automated agents whose behavior arises from sensor inputs and/or computation, and (3) automatic detection and recognition of species, activities, and interactions.

In this talk, I will summarize our eight-year development of algorithms, systems, lessons learned, and results of field experiments (see http://telerobot.cs.tamu.edu for more information).

.