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Contents

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ABSTRACT

Recently, the robotics industry celebrated its 60-year anniversary. We have used robots for more than six decades to empower people to do things that are typically dirty, dull and/or dangerous. The industry has progressed significantly over the period from basic mechanical assist systems to fully autonomous cars, environmental monitoring and exploration of outer space. We have seen tremendous adoption of IT technology in our daily lives for a diverse set of support tasks. Through use of robots we are starting to see a new revolution, as we not only will have IT support from tablets, phones, computers but also systems that can physically interact with the world and assist with daily tasks, work, and leisure activities. The present document is a summary of the main societal opportunities identified, the associated challenges to deliver desired solutions and a presentation of efforts to be undertaken to ensure that US will continue to be a leader in robotics both in terms of research innovation, adoption of the latest technology, and adoption of appropriate policy frameworks that ensure that the technology is utilized in a responsible fashion.

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1

Executive Summary

1.1 Introduction

Recently the robotics industry celebrated its 60-year anniversary. We have used robots for more than six decades to empower people to do things that are typically dirty, dull and/or dangerous. The industry has progressed significantly over the period from basic mechanical assist systems to fully autonomous cars, environmental monitoring and exploration of outer space. We have seen tremendous adoption of IT technology in our daily lives for a diverse set of support tasks. Through use of robots we are starting to see a new revolution, as we not only will have IT support from tablets, phones, computers but also systems that can physically interact with the world and assist with daily tasks, work, and leisure activities.

The “old” robot systems were largely mechanical support systems. Through the gradual availability of inexpensive computing, user interfaces, and sensors it is possible to build robot systems that were difficult to imagine before. The confluence of technologies is enabling a revolution in use and adoption of robot technologies for all aspects of daily life.

Thirteen years ago, the process to formulate a roadmap was initiated at the Robotics Science and Systems (RSS) conference in Atlanta. Through support from the Computing Community Consortium (CCC) a roadmap was produced by a group of 120 people from industry and academia. The roadmap was presented to the congressional caucus and government agencies by May 2009. This in turn resulted in the creation of the National Robotics Initiative (NRI), which has been an interagency effort led by the National Science Foundation. The NRI was launched 2011 and had its ten-year anniversary. The roadmap has been updated 2013 and 2016 prior to this update.

Over the last few years we have seen tremendous progress on robot technology across manufacturing, healthcare applications, autonomous cars and unmanned aerial vehicles, but also major progress on core technologies such as sensors, communication systems, displays and basic computing. All this combined motivates an update of the roadmap. With the support of the Computing Community Consortium three workshops took place 11-12 September 2019 in Chicago, IL, 17-18 October 2019 in Los Angeles, CA and 15-16 November 2019 in Lowell, MA. The input from the workshops was coordinated and synthesized at a workshop in San Diego, CA February 2020. In total the workshops involved 79 people from industry, academia, and research institutes. The 2016 roadmap was reviewed, and progress was assessed as a basis for formulation of updates to the roadmap.

The present document is a summary of the main societal opportunities identified, the associated challenges to deliver desired solutions and a presentation of efforts to be undertaken to ensure that US will continue to be a leader in robotics both in terms of research innovation, adoption of the latest technology, and adoption of appropriate policy frameworks that ensure that the technology is utilized in a responsible fashion.

1.2 COVID-19

Over the last few months we have seen some major changes to society. The COVID-19 (Center for Disease Control and Prevention (CDC), 2020), or the more accurate name for the infection Sars-CoV-2, has changed many things. It has already infected more than 27 million people with 6+ million of them in the US alone (by September 2020) (Worldometer, 2020).

The outbreak of the pandemic has had a number of effects. First of all, the healthcare system has been challenged. People have also been quarantined at home for extended periods of time. A large number of people have been laid off in USA (and globally). In addition, people have almost stopped traveling. An obvious question is how robotics and automation can assist in such a scenario.

In the healthcare sector there are quite a few obvious use-cases. i) there is a need to increase the frequency of testing people to get a nuanced view of the degree of infection and the speed of infections (R0). Laboratory robots allow for faster processing of samples and return of answers to people. Laboratory robots can automate the testing and allow for extensive testing. Many healthcare professionals have been exposed to COVID due to their front-line jobs. There is a real need to use automation to acquire samples from patients, but also to enable a doctor at a distance to examine a patient and acquire basic information such as temperature, blood pressure, pulse, etc. Using tele-presence robots, it is possible to increase the social distancing between patients and medical personnel for routine tasks and through this reduce the risk of exposure for professionals. There are numerous use-cases for medical robots beyond the well-known examples in surgery.

Manufacturing has declined significantly during COVID-19, which is partly due to changes in market needs, but also due to the economic recession gaining momentum after the start of the pandemic. Total industrial production is seeing a downturn. We have seen automotive sales go down by as much as 50% (Federal Research Economic Data, 2020). When isolated at home the traffic patterns change dramatically. Retail sales was down by 20+% during September 2020 and food/drink sales were down by 50% in September 2020. At the same time e-commerce continued to have significant growth. Sales of goods in the traditional retail sector was shifting from brick-and-mortar shops to the web.

E-Commerce has seen tremendous growth over the last year. The growth is both in US with major companies such as Amazon and Walmart, but also internationally by companies such as Alibaba, JD and Tmall. Already today Alibaba with Taobao is 50% larger than Amazon and is expected to continue to grow. Amazon has deployed more than 200,000 mobile platforms in their warehouses (the number is more like 300,000 by now) (Tech Crunch, 2020). In addition, we are also seeing major progress on automated object pick-up / handling with companies such as Covariant.AI, Righthand Robotics and Berkshire Grey. As people desire a minimum of contact for items entering their house, we will see higher automation at distribution centers. There is significant interest in the last-mile problem of delivering from the truck to the front door in a domestic setting. The last mile could be solved using a traditional mobile platform as seen by Amazon's Scout (Amazon, 2020) another solution is clearly humanoid robots such as digit by Agility Robotics (Agility Robotics, 2020) or traditional services such as May Mobility (Maymobility Corp, 2020). Leaving the ground for a minute the drone market is considered for last mile deliveries as seen by Amazon Prime Air (Wikipedia, 2020) or the experiments by UPS (Drone Life, 2020).

Cleaning is another important topic. This includes cleaning and disinfection beyond the hospital and the home. iRobot has seen a major uptick in sales of vacuum cleaners and floor scrubbers during the pandemic and shares are up 65% year to date. Additional cleaning is important to many households. A flood of UV-C disinfection robots has also been announced. Using UV-C lighting it is possible to achieve a high degree of disinfection with more than 99.9% of the virus eliminated when more than 10 micro watt / cm^2 is radiated onto a surface. In many cases, a high-power source is used to allow even indirect illumination to kill the virus. There are already more than 100 companies worldwide pursuing this market. Keenon has developed a robot that uses both UV-C lighting and a vaporizer to disinfect an area. The vapor will get to areas that may not be directly exposed by the UV-C light and provide redundant security. These two robots are merely examples of the vast number of new robots entering this market. The first place to see deployment of these UV-C robots were hospitals and care facilities. High-traffic use-cases such as airports have also seen deployments. One would expect other use-cases to include hotels, malls, cruise ships, and eventually they may enter your house as supercharged home cleaning robots. This is a new robotics segment that was unrealistic just a few months ago.

COVID has exposed a number of opportunities for robotics from cleaning/disinfection over e-commerce to manufacturing and transportation. Robots are primarily designed to empower people to do things better, in some cases in terms of accuracy in other cases as power or sensory extensions, and access. In the aftermath of the 2009 recession adoption of robotics grew significantly. In a post-COVID world we will see new behavior patterns for social interaction, cleaning, collaboration and delivery. There are thus many new opportunities for utilization of robot technology to enhance many of everyday life.

1.3 Main Findings

Over the last decade a tremendous growth in utilization of robots has been experienced. Manufacturing has in particular been impacted by the growth in collaborative robots. There is no longer a need for physical barriers between robots and humans on the factory floor. This reduces the cost of deploying robots. In the US the industrial robotics market has grown 10+% every year and the market has so far seen less than 10% penetration. We are thus far away for full automation of our factories. US is today using more robots than it has even done before.

A major growth area over the last decade has been in use of sensor technology to control robots. More digital cameras have been sold the last decade than ever before. When combined with advanced computing and machine learning methods it becomes possible to provide robust and more flexible control of robot systems.

A major limitation in the adoption of robot manipulation systems is lack of access to flexible gripping mechanisms that allow not only pick up but also dexterous manipulation of everyday objects. There is a need for new research on materials, integrated sensors and planning / control methods to allow us to get closer to the dexterity of a young child.

Not only manufacturing but also logistics is seeing major growth. E-commerce is seeing annual growth rates in excess of 40% with new methods such as Amazon Express, Uber Food, ... these new commerce models all drive adoption of technology. Most recently we have seen UPS experiment with use of Unmanned Vehicles for last mile package delivery. For handling of the millions of different everyday objects there is a need of have robust manipulation and grasping technologies but also flexible delivery mechanisms using mobility platforms that may drive as fast as 30 mph inside warehouses. For these applications there is a need for new R&D in multi-robot coordination, robust computer vision for recognition and modeling and system level optimization.

Other professional services such as cleaning in offices and shops is slowly picking up, this is in particular true given the recent COVID-19 pandemic. The layout of stores is still very complex and difficult to handle for robots. Basic navigation methods are in place, but it is a major challenge to build systems that have robust long-term autonomy with no or minimal human intervention. Most of these professional systems still have poor interfaces for use by non-expert operators.

For the home market the big sales item has been vacuum and floor cleaners. Only now are we starting to see the introduction of home companion robots. This includes basic tasks such as delivery services for people with reduced mobility to educational support for children. A major wave of companion robots is about to enter the market. Almost all these systems have a rather limited set of tasks they can perform. If we are to provide adequate support for children to get true education support or for elderly people to live independently in their home there is a need for a leap in performance in terms of situational awareness, robustness and types of services offered.

A new generation of autonomous systems are also emerging for driving, flying, underwater and space usage. For autonomous driving it is important to recognize that human drivers have a performance of 100 million miles driven between fatal accidents. It is far from trivial to design autonomous systems that have a similar performance. For aerial systems the integration into civilian airspace is far from trivial but does offer a large number of opportunities to optimize airfreight, environmental monitoring, etc. For space exploration it is within reach to land on asteroids as they pass by earth or for sample retrieval from far away planets. For many of these tasks the core challenge is the flexible integration with human operators and collaborators.

The emergence of new industrial standards as for example seen with Industry 4.0 and the Industrial Internet facilitates access to cheap and pervasive communication mechanisms that allow for new architectures for distributed computing and intelligent systems. The Internet of Things movement will facilitate the introduction of increased intelligence and sensing into most robot systems and we will see a significant improvement in user experience. The design of these complex systems to be robust, scalable, and interoperable is far from trivial and there is a new for new methods for systems design and implementation from macroscopic to basic behavior.

As we see new systems introduced into our daily lives for domestic and professional use it is essential that we also consider the training of the workforce to ensure efficient utilization of these new technologies. The workforce training has to happen at all levels from K-12 over trade schools to our colleges. Such training cannot only be education at the college level. The training is not only for young people but must include the broader society. It is fundamental that these new technologies must be available to everyone.

Finally, there is a need to consider how we ensure that adequate policy frameworks are in place to allow US to be at the forefront of the design and deployment of these new technologies but it never be at the risk of safety for people in their homes and as part of their daily lives.

1.4 The Roadmap Document

The roadmap document contains sections specific to societal drivers, mapping these drivers to main challenges to progress and the research needed to address these. Sections are also devoted to workforce development and legal, ethical and economic context of utilization of these technologies. Finally, a section discusses the value of access to major shared infrastructure to facilitate empirical research in robotics.

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