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INTELLIGENT ROBOTICS CAN BOOST AMERICA'S ECONOMIC GROWTH

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Abstract

A case is made for strategic investment in intelligent robotics as a part of the solution to the problem of improved global competitiveness for U.S. manufacturing, a critical industrial sector. Similar cases are made for strategic investments in intelligent robotics for field applications, construction, and service industries such as health care. The scope of the country's problems and needs is beyond the capability of the private sector alone, government alone, or academia alone to solve independently of the others. National cooperative programs in intelligent robotics are needed with the private sector supplying leadership direction and aerospace and nonaerospace industries conducting the development. Some necessary elements of such programs are outlined.

The National Aeronautics and Space Administration (NASA) and the Lyndon B. Johnson Space Center (JSC) can be key players in such national cooperative programs in intelligent robotics for several reasons: (1) human space exploration missions require supervised intelligent robotics as enabling tools and, hence, must develop supervised intelligent robotic systems; (2) intelligent robotic technology is being developed for space applications at JSC (but has a strong crosscutting or generic flavor) that is advancing the state of the art and is producing both skilled personnel and adaptable developmental infrastructure such as integrated testbeds; and (3) a NASA JSC Technology Investment Program in Robotics has been proposed based on commercial partnerships and collaborations for precompetitive, dual-use developments.

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1. Introduction

Intelligent robotics can boost America's economic growth by enabling productivity improvements that raise the standard of living for everyone and by enabling the U.S. to build products at world cost and quality.[1] But the boost can occur only if intelligent robotics technology is developed as a mature commercial capability and is used to solve productivity problems in critical sectors of the economy (e.g., advanced manufacturing, construction, field applications, and service industries such as health care). Both the development of intelligent robotic systems and their early application in these strategic sectors require strategic investment. The government, and NASA in particular, should contribute to the strategic investment by buying down the risk for commercial technology. The government can accomplish this by developing needed intelligent robotic systems for government applications and then sharing the technology with the commercial sector in ways that allow profitable products. These precommercial, dual-use investments and developments are in line with President Clinton's technology policy.[2]

Intelligent robotics is the use of robotic systems in solving problems in tasks and environments where the robot's ability to acquire and apply knowledge and skills to achieve stated goals in the face of variations, difficulties, and complexities imposed by a dynamic environment having significant unpredictability is crucial to success. This means the robots can recognize and respond to their environments at the pace of their environments and to spoken human supervision in order to perform a variety of mobility and manipulation tasks. This does not require a broad-based general intelligence or common sense by the robot.

These robots are capable of significant autonomous reaction to unpredictable events, yet they are subject to optional human supervision during operation in a natural way such as by voice. We refer to this capability in the supervised robot as "adjustable autonomy."

I believe that the most important path to fundamental change in the U.S. economy is a long-term focus on actions that will provide strategic investment in our nation's future. I believe that investments in intelligent robotics-related innovations of the precommercial, dual-use variety will lead to products that are ready to be commercialized and introduced into the marketplace, which, in turn, can provide a valuable solution to at least a part of our continuing economic crises.

A lack of foresight in this area could inhibit American competitiveness in today's and tomorrow's global economy.

Intelligent robotic systems mean that less structuring of the robot environment is required to obtain robotic task performance, which, in turn, means lower costs. For those applications where structuring the environment is generally not possible, intelligent robotics offers the flexibility to enable robotic tasks otherwise not possible. Packaging mobility with manipulation as intelligent robotics allows frequently means fewer manipulators than otherwise, further lowering costs.

The benefits of innovation transcend the new technologies themselves. Because new technology allows more cost-effective investment in infrastructure and commercial competitiveness, the U.S. will be more competitive globally. This, in turn, will produce more jobs, improve the economy, and reduce the trade and budget deficits.

The scope of the country's problems and needs is far beyond the capability of the private sector alone, government alone, or academia alone. Cooperation by all interested parties is essential to maximize the benefits from innovation! National cooperative programs are needed with leadership direction from the private sector.

To support this approach, an example of a cooperative program currently ongoing is the University Space Automation and Robotics Consortium (USARC) consisting of the University of Texas at Austin, Texas A&M University, Rice University, the University of Texas at Arlington, MITRE Corporation, and NASA JSC.

However, all this is of major interest only because intelligent robotics is within our reach as a commercial technology, although perhaps not yet within our grasp. Major intelligent robotics capabilities exist in many places in industry (e.g., Transitions Research Corporation, Teleos, Sarcos, Robotics Research Harvesting, and Intellagent Systems), in not-for-profit companies (e.g., MITRE Corporation, SRI International, and Southwest Research), in academia (e.g., Carnegie Mellon University, Massachusetts Institute of Technology, Stanford University, University of Michigan, Rensselaer Polytechnic Institute, University of Pennsylvania, and USARC), and in government (e.g., NASA, National Institute of Standards and Technology, and Department of Energy). Many intelligent robotics efforts have been reported.[3] These organizations and activities could form the basis of cooperative national programs that could pay off in the near term.

2. Investment for U.S. Manufacturing

"Both American industry and government under-invest in manufacturing. In contrast to their foreign competitors, U.S. firms neglect process-related R&D within their overall R&D portfolio. And the federal government allocated only two percent of its $70 billion R&D budget to manufacturing R&D in FY92."[2]

Strategic investment in and use of intelligent robotics in manufacturing offer partial solutions to many cost and quality problems, if the robotic systems are properly targeted and designed. Product manufacturers and their people must identify problem areas and ways to integrate intelligent robotics into their manufacturing processes. Flexible approaches by robot manufacturers are necessary to offer solutions to problems rather than robots per se. These problem identification and proposed solution activities both require strategic investments that government should help with in order to buy down the initial risk. Leading technology needs are in sensors and information extraction techniques from sensor data to support the task needs.

One of the needed developments is to reduce the cost of production of the intelligent robots themselves through generic software architectures (standardized and modular) and modular hardware approaches.

The benefits to product manufacturing of such strategic investment are as follows:

- Having the ability to build products at world cost and quality
- Improving productivity
- Reducing time to market for manufactured products

- Reducing costs
- Improving quality
- Improving our global competitiveness
- Having the ability to preserve and create jobs in manufacturing
- Creating jobs in intelligent robotics for manufacturers and integrators including training and support
- Improving the economy and boosting economic growth
- Increasing profits
- Increasing tax revenue
- Reducing the trade deficit
- Reducing the budget deficit
- Raising the standard of living for everyone

A cost-benefit analysis for intelligent robotics in manufacturing should be conducted if this will help make the case more compelling for all parties.

Also, manufacturing is a strategic industry related to defense and national security in non-threatening ways, so that its vitality is not simply a pure economic issue.[4]

3. Investment for Applications in Other Sectors

Cases for strategic investment in intelligent robotics for applications in other sectors have just as compelling a basis of rationale and benefits as manufacturing, whether in construction, mining, agriculture, undersea applications, health care, nuclear power, or other service applications such as grocery warehouse uses.

In construction, both the national architectural and engineering firms and the civil engineering community want more productive methods such as those offered by intelligent robotics.[5,6] Our physical infrastructure is deteriorating at an exceedingly dangerous rate.[7] This includes our highways and bridges, mass transit, aviation facilities, water transportation, wastewater treatment, drinking water distribution systems, and a host of other public works and public facilities. This is the physical framework that supports and sustains virtually all domestic economic activity; it is essential to maintaining international competitiveness as well. Intelligent robotics applications could reduce the cost of replacing or upgrading much of this infrastructure.[6] NASA, likewise, needs space construction intelligent robotics.

Intelligent robotics is required in mining in order to enable the U.S. to remain globally competitive cost-wise in coal production, and to improve mine safety for miners.[8] Clearly energy and its cost are fundamental to industrial competitiveness in the global economy. The deeper coal veins, in general, do not have large cross-sectional areas at the coal interface, and robotics that can sense the vein edges from the surrounding rock are needed. Transportation to the surface is another task where robotics could aid productivity. Again, NASA needs mining intelligent robotics for large-scale planetary resource use.

In controlled environment agriculture, which is a several billion dollar per year business in the U.S., intelligent robotics is needed to keep prices competitive.[9] Market forces are compelling greenhouse operations, which are labor intensive, to automate. A major motivation is for U.S. producers to improve productivity in international competition.[10] Similarly, NASA needs intelligent robotics in advanced life support systems where higher order plants (crops) will be used in food production, water purification, carbon dioxide uptake, and oxygen release as part of the bioregenerative recycling systems that need little, if any, resupply.[11]

A large number of other sectors and applications of intelligent robotics is evident, from undersea applications to nuclear power and a number of service industry uses.[12] Low-cost health care is another critical factor in global competitiveness as a major labor-related cost, and intelligent robotics can reduce costs while increasing quality. Despite the varied capabilities of current field and service robots, there are many additional tasks awaiting future field and service robots. Some robots will be cleaning up toxic and radioactive waste and monitoring water pollution. Other robots will provide mobility aids for the handicapped and infirm and bring new forms of education and entertainment. The time required to add these capabilities is measured not in years but in person years of research and development.

4. Cooperative Programs in Intelligent Robotics

In this section we describe some necessary elements of cooperative national programs in intelligent robotics. This section is based to a significant extent on Carlisle.[13]

First, we must communicate a sense of urgency about the critical importance of manufacturing technology to our country's executives, financial community, and government. Our cost of labor will not likely compete with Singapore or Mexico. But Japan, whose cost of labor is equal to ours, has shown that it is possible to build products at world cost and quality through the use of automation technology. Our government and our boards of directors are asking the question, "What is the manufacturing strategy that will keep us competitive in the world market and will retain jobs?"

Second, we need a manufacturing and automation technology education infrastructure. President Clinton has proposed establishing 170 technology extension centers where local businesses can learn about new technology on state-of-the-art machinery.[2] The Robotics Industries Association (RIA) is developing an encyclopedia of robot applications that, combined with equipment at these technology centers, could greatly accelerate the adoption of robot technology by U.S. industry. Another education-related activity involves communication of information about intelligent robotics and concurrent engineering. JSC is involved in the National Information Infrastructure Testbed (NIIT), which is an industry-led consortium to initiate the "information superhighway," where the government role is primarily to conduct needed research and development and determine the policy environment and legal situation. But another key government role in NIIT that concerns us at JSC is providing technology information, both about intelligent robotics and about concurrent engineering, over the Internet. NIIT members include AT&T, Sprint, Hewlett-Packard, Digital Equipment Corporation, SynOptic Communications, Sun Microsystems, Ellery Systems, Novell, U.S. West Communications, New England T&T, Sandia National Laboratories, University of New Hampshire, Oregon State University, University of California, and Ohio State University. The JSC activity involves providing access to information on intelligent robotics via the Internet and using the Internet as a distributed computing environment for access to a suite of interoperable engineering software applications that support a structured process for concurrent engineering.[14]

Third, the cost and availability of capital for productive investment must be addressed. Japan is providing more than 20 times the amount of federally guaranteed loans to small business than the U.S. is providing – $80 billion per year in Japan versus $3.6 billion in 1989 in the U.S. Also, Japan provides tax credits and zero percent interest loans up to $0.25 million for mechatronics equipment. Banks in the U.S. are still extremely hesitant to make loans to small and midsize businesses due to regulatory pressure as a result of the savings and loan collapse. We need to improve and encourage productive private investment through changed banking regulations and tax policies.

Finally, we must encourage applied research and development on robotic systems for field, construction, factory, service, and space applications. There has been almost no U.S. research funding for industrial applications where we need it most to help us compete in quality and cost in the global market. Nor has there been funding for construction applications where rebuilding our infrastructure is a needed major strategic investment. We need to direct funds toward developing practical applications of robotic systems as integrated solutions to industrial productivity problems. We need to develop system testbeds such as JSC has developed where developers can integrate sensing, control, and mechanical technologies with the objective of testing robotic solutions to actual industrial applications.

5. Johnson Space Center Role

NASA and JSC can be key players in national cooperative programs in intelligent robotics for several reasons: (1) human space exploration missions require supervised intelligent robotics as enabling tools and, hence, must develop or have developed supervised intelligent robotic systems;[15] (2) intelligent robotic technology is being developed for space applications at JSC (but has a strong crosscutting or generic flavor) that is advancing the state of the art and is producing both skilled personnel and adaptable developmental infrastructure such as low-cost simulation environments for software testing and integrated testbeds for complete prototype testing;[16,17] and (3) a NASA JSC Technology Investment Program in Robotics has been proposed based on commercial partnerships and collaborations for precompetitive, dual-use developments.[18] The JSC Technology Investment Program suggests efforts on generic intelligent robotics software architectures, modular manipulation and mobility designs, integrated sensing and perception, dexterous grasping and manipulation, and prototyping and rapid development environments, all as part of an approach for end-user customizing of intelligent robotic systems. The JSC Technology Investment Program also suggests problem-solving approaches to applications in several sectors. JSC also has a Small Business Innovative Research (SBIR) program for intelligent robotics, which is underutilized and has no commercial cost sharing requirement.[19] It is limited in scope to about $0.6 million and 2 years in Phase II efforts.

A key element in the cutting edge intelligent robotics technology work at JSC is an understanding of and solution approach to the key issue of melding artificial intelligence planners with reactive capabilities. Artificial intelligence planners offer goal-achieving planning, but also high-time variance due to searching. Reactive capabilities are needed to deal safely in real time with dynamic, unpredictable environments at the pace of the dynamics[16]. A second key element that JSC brings is an approach to improved robotic reliability as required for space, but also useful in industry. A third key element that JSC brings to cutting edge technology is an understanding of and solution approach to the key issue of robotic safety while maintaining productivity.

Of all of these elements, the most important one is the personnel skilled in the state of the art and knowledgeable about the technology.

6. The Role of Government

The proper role of government in industry, in general, and intelligent robotics, in particular, may be controversial. Government establishes the environment within which business operates such as laws, taxes, and services. Government provides education and training funding and negotiates mutual trade policy such as the North American Free Trade Agreement (NAFTA). Government also spends $70 billion per year on research and development.

The global competitive landscape may be different today than we have assumed in America. Peter Drucker points out: "The emergence of new non-Western trading countries – foremost the Japanese – creates what I would call adversarial trade. ... Competitive trade aims at creating a customer. Adversarial trade aims at dominating an industry. ... The aim in adversarial trade ... is to drive the competitor out of the market altogether rather than to let it survive."[20]

James Fallows argues about the semiconductor industry: "The prevailing American idea requires us to view industrial rises and falls as if they were the weather. We can complain all we want, but in the long run there's nothing much we can do, except put on a sweater when it's cold. Or the American idea makes economic change seem like an earthquake: some people are better prepared for it than others, but no one can constrain the fundamental force. A different idea – that industrial decline is less like a drought than like a disease, which might be treated – would lead to different behavior."[21]

"On its way up and on its way down, the semiconductor industry was driven not just by private companies – although they made every crucial operating decision and came up with every new design – but by a network of government-business interactions."[21]

Fallows quotes the Semiconductor Industry Association: "Government policies have shaped the course of international competition in microelectronics virtually from the inception of the industry, producing outcomes completely different than would have occurred through the operation of the market alone."[21]

Again Fallows states: "For instance, in 1962 NASA announced that it would use integrated circuits – the first simple chips, produced by Texas Instruments, Fairchild Semiconductor, and other suppliers – in the computer systems that would guide Apollo spacecraft to the moon. ... Every history of the semiconductor business regards these contracts as a turning point; they guaranteed a big and relatively long term market, which no private purchaser could have offered at the time ... price went down, and commercial customers began buying more and more chips. ... Government contracts had paid for some of the research that led to patents."[21]

"For aircraft ... even more than with semiconductors, the government provided the initial market. ... Governments may not be able to pick winners, but they seem to be able to make winners."[21]

The precompetitive, dual-use technology investment concept advocated here for intelligent robotics appears to have many successful historical precedents in buying down initial commercial risk and attracting commercial development.[22]

7. Conclusion

We have the intellect and skill in the U.S. to make use of intelligent robots in ways that will boost our economic growth, greatly improve our national ability to compete in the global economy through advanced manufacturing at world cost and quality, create jobs in manufacturing of intelligent robots, improve the quality and reduce the cost of health care, provide needed cost reductions and productivity improvements in construction and mining, and, in fact, preserve manufacturing in the U.S. What we lack, perhaps, is the perception and commitment that this is a strategy we must pursue. Our Congressional track record is less than promising in investing in robotics, but there are signs of hope.[23] We need the commitment of an Andrew Rowan taking "A Message to Garcia," as opposed to "letting someone else do it."[24]

We are at a stage of developing intelligent robotics where a major cooperative development effort would pay off in the near term – less than 5 years, rather than 10 years or more; in fact, the metric should be in person years, not calendar years.

JSC and its Automation and Robotics Division stand ready with intelligent robotics technology, skilled people, low-cost simulation approaches and integrated robotic testbeds, a suggested set of activities for commercial involvement in partnerships, matching funding possibilities, and a small business innovative research program that does not require any cost sharing.

Industry must step forward and lead, but NASA should do its part in supporting development by industry through technology sharing and providing some risk reducing investment funding.

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