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The Economic Impact of Technology Infrastructure for Advanced Robotics

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Key Findings

- Closing critical gaps in advanced robotics technology infrastructure would conservatively save manufactures $40.4 billion annually.
- Barriers to innovation increase the cost of advanced robotics R&D, weaken private investment incentives, and magnify the role of public institutions.
- Overcoming critical technical barriers may require investments in public-private manufacturing consortia.
- Small and medium-sized enterprises, key beneficiaries of advanced robotics technology, face significant barriers to adoption.

Introduction

Advanced robotics and automation are potential game-changing technologies for strengthening the U.S. manufacturing sector, particularly for small and medium-sized enterprises in the manufacturing sector. Next-generation advanced robots will be mobile, free to move about their environments and able to safely collaborate with humans. This represents a stark contrast with current-generation industrial robots that operate in highly controlled environments and are frequently isolated from workers out of safety concerns. A recent study,[1] commissioned by the National Institute of Standards and Technology (NIST) finds that "barriers to innovation lead to a shortage of critical technology infrastructure and inhibit the development and adoption of robotics technology." Technology infrastructure[2] is the broad base of public and quasi-public technologies and technical knowledge that support the research, development, production and diffusion activities of national laboratories, universities and firms.

The analysis is based on in-depth interviews with more than 80 advanced robotics experts from leading robotic systems and component developers, systems integrators and end users in a variety of industries as well as stakeholders from universities, research centers and industry associations. The unique contribution of the study is the focus on barriers to the development and adoption of advanced robotic technology. The study finds that gaps in critical technology infrastructure, which include standards, measurement technology and other platform technologies, act as a barrier to innovation. Meeting these needs would enable the development of advanced robotic capabilities that "would stimulate industry investment in robotics technology and lead to the realization of an estimated $40.4 billion in net economic savings of U.S. manufacturers." This represents a 5.3% reduction in the cost of goods sold. Meeting the identified needs "will make U.S. manufacturers

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Table 1: Technology Infrastructure Gaps and Potential Benefits

Industry Needs	Examples of Infratechnology to Help Meet Needs	Potential Benefits and Impacts
Safe human-robot interaction (HRI) Universal standards for developers of robotics technologies and the application of these technologies in manufacturing settings with robots working in close proximity to people (see more below on sensing/perception for unstructured environments, relevant for intuitive HRI)	• Test protocols, objective scientific and engineering data, reference databases, and other technical inputs into standards for safe HRI (power/force-limiting, speed/separation monitoring, hand-guided operation, safety-rated monitored stop)	• More flexible, smaller-footprint production lines • New and creative use cases of robots working in close proximity and in collaboration with people • Lower integration costs • Improved safety • Reduced market risk for developers • Reduced liability for end users • Adoption of collaborative robots
Sensing and perception for unstructured (or less-structured) environments Improved perception (and the ability to plan and re-plan the robot's actions based on what it "sees" and "knows") gives a robot greater autonomy, lessening its demand that its work environment meet stringent tolerances	• Sensor registration and calibration • Performance characterization (benchmarks, testbeds, and technical inputs to standards to characterize the performance of systems, subsystems, and components) • Sensing/perception engines/architectures • Proof-of-concept robotics applications of knowledge representation and reasoning	• Lower integration costs associated with accommodating tolerances • Flexible navigation of unstructured or less-structured environments • More flexible plant layouts • Improved safety • Optimized robot motions • Data streams to calibrate simulation models
Objective, low-cost performance characterization Making it easier for robotics users to know what they are buying and for developers and suppliers to show what their systems do	• Common performance metrics, objective data, testbeds, test methods, and benchmarks to characterize the performance attributes of advanced systems, subsystems, and components	• Reduced uncertainty • Improved understanding of new technologies • Increased adoption of robotics by SMEs
Interoperability and modularity Plug-and-play for system components, enabled by standards for physical and electronic interfaces and software interfaces or translators	• Objective technical inputs into the standard-setting process: scientific and engineering data, benchmarks, testbeds, objective third-party testing of candidate technologies and configurations	• Plug-and-play functionality • Reduced integration costs (physical and software interfaces) • Modular development of systems • Increased adaptability of robotic systems • Scalable, reconfigurable, and reusable robotic systems • Reduced retooling costs • Increased adoption in industries with small production runs
Intuitive interfaces Enabling rapid programming and training without specialized skills	• Protocols to simplify the programming, training, and rapid re-tasking of robots • Standard programming language for industrial robotics	• Simplified programming • Reduced setup time and setup costs • Decrease need for specialized training to commission a robotics
Modeling and simulation Virtual factory floor allowing modeling and simulation, calibrated based on real-time data feed from robots, machine tools, sensors, and control systems on the floor	• Robust, open, real-time operating system on the factory floor • Reference models, modeling frameworks to fully integrate robots into models of the manufacturing environment and enable robust simulation/prediction	• Control of processes from central dashboard • Improved prediction • Adjustments can be optimized • Reduced delay and work stoppage • Software reconfigurable factory floor • Reduced retooling costs • Improved "as-built" documentation • Using robot teaching to refine simulation models

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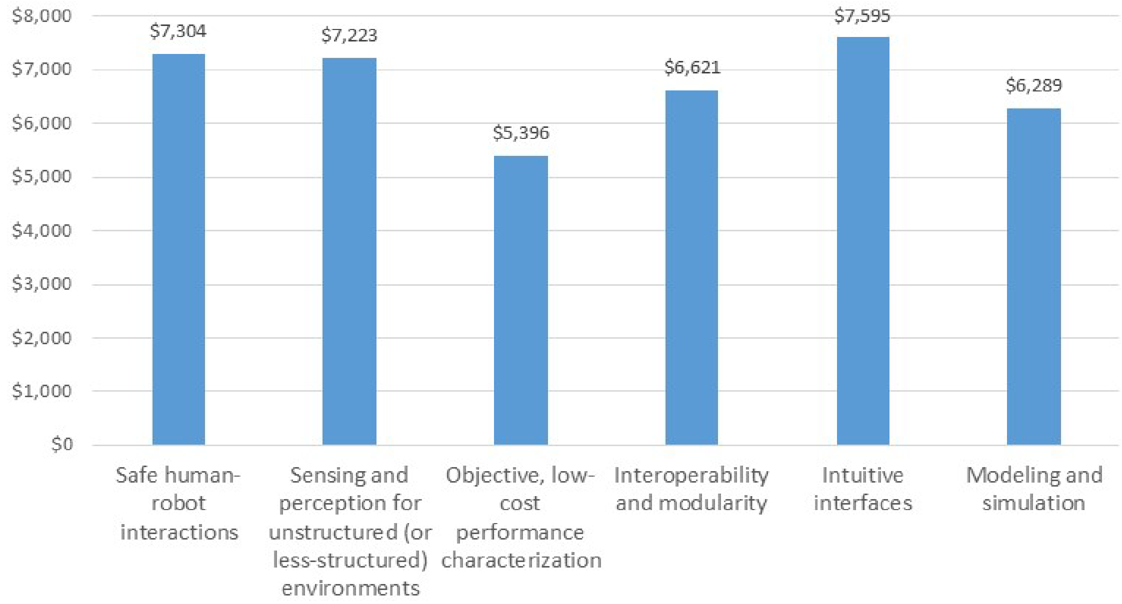
Figure 1: Total Annual Impact, Apportioned by Technology Need (Millions of 2013 US$)



more efficient and more flexible, making the U.S. manufacturing sector better positioned to compete internationally."

The analysis first identified six broad areas of technical need and the qualitative benefits of meeting these needs. Then the analysis estimated manufacturing cost savings of providing industry with the new technical capabilities. The identified needs and quantitative benefits of meeting those needs are summarize in Table 1 and Figure 1 respectively. The identified needs include safe human robot interaction, technologies for sensing and perception in unstructured environments, object performance characterization for advanced robotics, interoperability for advanced robotic components, intuitive user interfaces, and modeling and simulation for advanced robotics. The analysis is based on primary data collected from small manufacturing establishments as well as Fortune 500 companies**.**

Key Findings

First, the analysis indicates that the benefits to meeting the identified technology infrastructure needs are large. Overall, enhanced technology infrastructure for robotics and automation would result in an estimated $40.4 billion in annual cost savings for the U.S. manufacturing sector. The report finds that these estimates are lower-bound impact estimates because difficult-to-quantify benefits such as R&D efficiencies, accelerated product development, impacts on competitiveness and the creation of entirely new advanced robotics markets such as personal robots are not included in the impact estimates. It is however important to note that the report found significant variation across industries with respect to estimated impacts.

Second, in addition to measurement and standards needs, this study identifies a number of critical technology platforms such as sensing and perception technologies, technologies for improved robot mobility and navigation, machine vision, methods for object identification, and tactile sensing and perception. The study finds that ensuring that such industry needs are met may require investments in public-private manufacturing consortia.

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The study also identifies distinct barriers to innovation, caused by market failures[3], beyond the public good nature of technology infrastructure. These barriers increase the cost of advanced manufacturing R&D, weaken private investment incentives and magnify the role of public institutions in meeting these scientific and technical needs. The infrastructure gaps alongside critical uncertainties and network effects ensure that current advanced robotics research, development and deployment is excessively costly and accessible to a limited set of companies. The stakeholder interviews identify critical uncertainties that increase transactions and adoption costs and diminish the incentive of all parties - across entire supply chains - to invest in robotics R&D. For example, a lack of critical standards “makes it difficult for end users to compare product offerings and choose the best solution to meet their needs.” Across the array of industry needs identified, “end users find it costly to convey their needs to developers, and developers similarly find it costly to communicate to the end users what their systems can and cannot do and to prove that their systems will perform as advertised.” In this environment it is difficult if not impossible to reap the rewards of investment.

Further, the study provides evidence that proprietary standards[4] fail to address these underlying barriers to innovation. The analysis demonstrates that when measurement and test methods, interoperability standards, scientific and engineering databases are treated as proprietary intellectual assets, firms can use these to create market distortions by conveying market power through branding and reputation The analysis also warns that “companies that develop industrial robots may have incentives to limit interoperability due to customer lock-in.” Further, “lock-in and market power are problems of proprietary standards. Public standards eliminate this barrier to innovation.” “[I]nterviewees emphasized NIST as a credible, objective, unbiased third party” important to overcoming these uncertainties. By filling this “honest broker” role, public institutions are vital to overcoming such barriers to innovation. These findings highlight the importance of public research institutions in meeting the identified technical needs. The current gaps in technology infrastructure increase the costs and weaken private investment incentives in advanced manufacturing research, development and deployment. Privately developed standards may be further distorting the market.

Finally, although the study finds that small and medium-sized manufacturers “are more likely to use collaborative robots than traditional industrial robots and represent a largely untapped customer base,” they also face significant barrier to adoption of advanced robotic technology. Low levels of interoperability, a lack of low-cost tools for measuring safety, a lack of objective performance measures and high and uncertain integration costs all “act as a barrier to adoption for many SMEs.”

References

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[5] Tassey G (2015) The Economic Nature of Knowledge Embodied in Standards for Technology-Based Industries. *Routledge Handbook of the Economics of Knowledge*, eds Antonelli C, Link A (Routledge, New York), pp. 189-207.

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[1] See Link, et al. [3].

[2] Technology infrastructure includes infratechnologies and technology platforms. Infratechnologies are technical tools, such as measurement and test methods, reference materials, scientific and engineering databases, process models, and the technical basis for physical and functional interfaces between individual components of both cyber and physical systems technologies. Technology platforms are precompetitive proofs of concept that demonstrate the potential commercial viability of multiple new or improved products, processes, or services. Technology infrastructure shares many common feature with tangible infrastructure. Namely, it is difficult and even undesirable to exclude potential users implementing the technology and usage of the technology infrastructure by a particular organization does not does not preclude others from benefiting to much the same extent. See Anderson [1], Link and Scott [2] and Tassey [4] for a richer discussion of the public good nature of technology infrastructure.

[3] A market failure is a situation where free markets do not allocate resources efficiently. In particular, the study finds evidence that network externalities, uncertainty and economies of scope all impact research in technology infrastructure for advanced robotics. The result is that markets invest too few resources in R&D.

[4] Proprietary standards can include both product and non-product standards such as measurement and test methods, interoperability standards, scientific and engineering databases and artifacts such as reference materials (infratechnologies). At times, these non-product standards become the technical basis for standards developed through voluntary consensus standards developing organizations. However, just as market dynamics drive the adoption of de facto product standards so to can market dynamics drive the development and adoption of non-products standards. Tassey [5] notes the negative effects on economic efficiency of market power conveyed through proprietary product and non-product standards.