Technologies Guiding the Future of Robotics in Manufacturing

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Abstract

Industrial robots, both stationary and mobile, have been used in manufacturing applications for decades and are most often employed based on requirements for dedicated and repetitive manufacturing operations. Industrial robot capabilities have continued to advance in areas such as payload, accuracy and speed. Looking to the near-future, the use of robots must also transition to operate in dynamic environments for high-mix low-volume production. A variety of affordable technologies are emerging and blending to bridge the gap between the traditional use of industrial robotics and the future where robots react to consumer-driven customized product demands. This paper is intended to be informational in nature and will present applied technology development to overcome some of the historical limitations in the use of automation for complex industrial tasks. Additionally, this paper will describe internal and industry sponsored research efforts that are giving robots greater intelligence, more flexibility and greater ability to work collaboratively with humans.

1. Introduction

One of the earliest robotic manipulators was developed in the late 1950s and deployed on a General Motors automotive assembly line in 1961. The robot, called Unimate, handled hot, die-cast parts that were potentially dangerous to workers. Although robots like Unimate did not fulfill the human-like depictions of mid-20th Century science-fiction robots, they were steadily adopted by manufacturers for jobs such as spot welding or painting automobile bodies [1].

Industrial robot capabilities have continued to advance in areas such as payload, accuracy and speed. Today's robotic arms can pick up complete truck bodies or emplace minute electronic components, and they can package goods much faster than a human. Despite all these advancements, however, robots are still predominantly utilized for repetitive tasks of the factory floor. One might assume that with effective investment and innovation in the market, a diverse set of applications would be developed extensively beyond welding, material handling, and coating. But, if anything, we see the opposite as shown in Figure 1. There has been relatively weak growth in new applications like assembly of consumer goods, construction and agriculture.

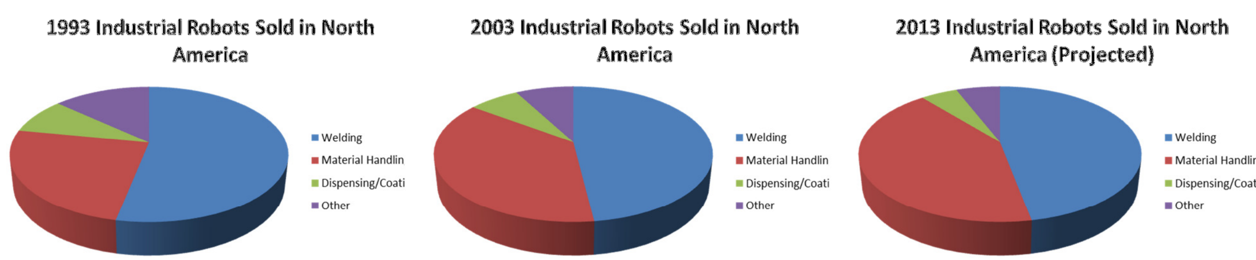

Figure 1. The mix of applications for industrial robots has not changed much in 20 years, and is dominated by high volume welding, material handling and dispensing. 1993 data is from International Federation of Robotics (IFR) statistics [2]. The 2003 and 2013 data is from Robotic Industries Association (RIA) statistics [3].

Unlike the futuristic expectations of the 1950s, people still have limited exposure to robots in their daily lives, and even the robots in manufacturing environments typically are relegated to simple, repetitive and highly structured tasks. Why is this? Shouldn't there be a market for a robot that is able to fold our laundry or perform our mundane daily work tasks?

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This paper presents recently emerging technologies that overcome some of the historical limitations in the use of automation for complex industrial tasks. Through internal and industry-funded research highlighted below, SwRI researchers and collaborators are giving robots greater intelligence, more flexibility and greater ability to work collaboratively with humans in industrial environments.

2. Perception and Planning

Traditionally, industrial robots have been deployed in jobs that require little decision-making. They typically perform the same task repetitively and have little ability to adapt to new situations. Providing robots with more human-like flexibility to adapt to dynamic or uncertain environments is a classic problem for robotics researchers. Many cognitive models exist to describe this problem, but they all share common elements of perceiving the environment and using this data, combined with prior knowledge, to plan an action.

Recently, there has been a dramatic shift in the use of 3-D sensing techniques to provide better context for robotic decision-making. Computing power has progressed to make real-time stereo imaging practical, and the console gaming industry has provided a revolutionary 3-D sensing capability with the Microsoft Kinect® sensor. These sensing solutions combine high resolution, color and 3-D views of the robot's workspace, permitting the development of new algorithms to locate and identify objects within that space.

Using novel 3-D data analysis algorithms, SwRI recently developed techniques [4] for object recognition in cluttered scenes. This enables robots to perform material handling tasks without need for dedicated tooling or fixtures (see Figure 2). Such techniques enable robots to pick randomly oriented parts from bins or boxes and then insert them into a subassembly. In addition, sortation of highly varied parts is a common need for applications like mail handling or waste recycling facilities.

The SwRI-developed techniques combine digital models, built using prior knowledge of the parts, and various matching algorithms to identify the parts in the robot's field of view. In some cases, machine-learning algorithms are employed to "teach" the robot what a particular object looks like. Once a hypothesis for an object is generated from the sensor data, a pose estimate is created. This pose information is then provided to the planning algorithms to create robot arm trajectories and grasp strategies.

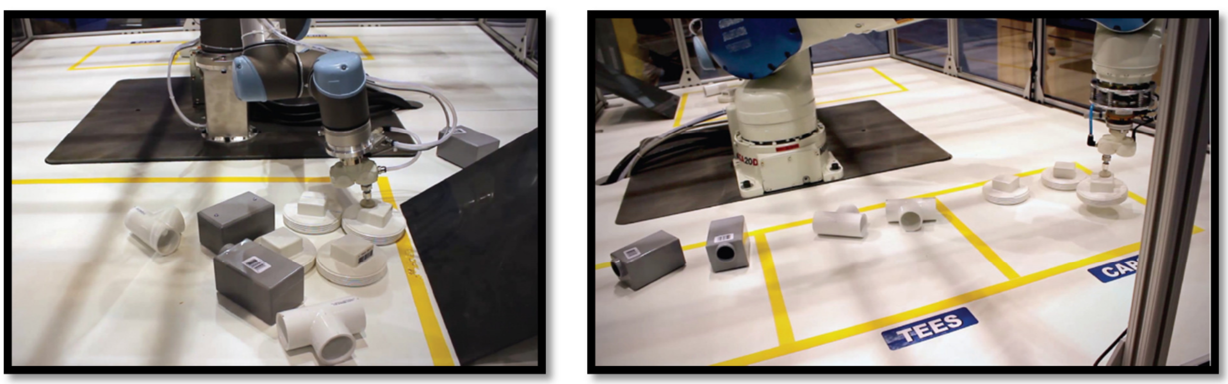

Figure 2. Demonstrated methods that permit robots to pick objects from cluttered piles or bins (left), recognize those objects based on their shape, and sort them (below) [5].

3. Giving Robots Mobility

Most industrial robot installations are permanently bolted in place with cages surrounding them, excluding human interaction with the robot. In such a paradigm, the parts must be brought to the tool (see Figure 3), rather than the tool to the parts. For many industries, such as those that use assembly lines, this is the preferred approach. However, there are situations where it is preferable to bring the tool to the workpiece.

In aerospace manufacturing, for example, it is often easier to move the manufacturing process rather than the part due to the size of most commercial aircraft. SwRI has a long history of developing large robots for use in aerospace coating removal processes, but to date, the robots have been limited to relatively small aircraft such as fighter jets. For larger aircraft, such as commercial airliners, mobile robotic systems are generally expected to be more cost-effective and flexible than the traditional fixed or tracked systems [6][7].

Figure 3. For more than 30 years, SwRI has been developing large robotic systems for aerospace coatings applications such as the robotic depaint system designed to maintain the U.S. Air Force's fleet of F-15 fighter jets. This is an example of bringing the part to the tool [8].

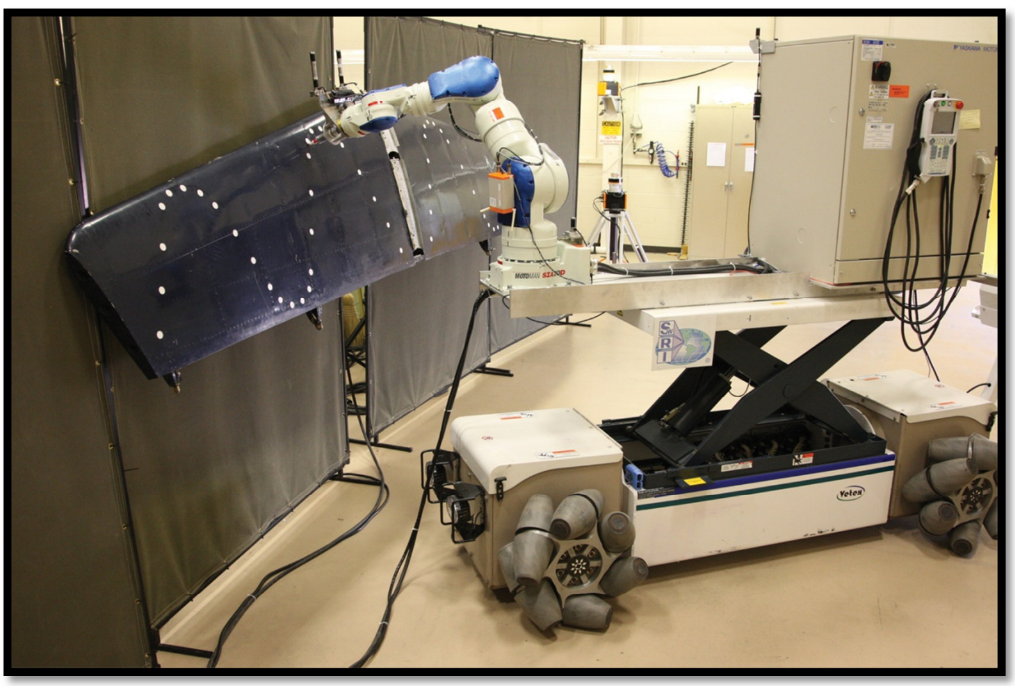

Figure 4. Current research has demonstrated that for some applications, a mobile solution can be less costly and more flexible [9].

SwRI demonstrated the ability to integrate a commercially available off-the-shelf (COTS) robotic manipulator onto a COTS mobile base (see Figure 4) to increase the effective workspace of the robot by a factor of 10 or more. This system, called MR ROAM (Metrology Referenced Roving Accurate Manipulator) uses a high-accuracy metrology system to locate the mobile system to sub-millimeter accuracy in work volumes of more than 500 square meters. Data indicates the positional accuracy is less than one-half inch and repeatability is one-quarter inch according to ISO Standard 9283. The system maintained a standard deviation of less than one-quarter inch in all coordinate directions.

Current research is focused on developing low-cost metrology solutions using consumer-grade cameras to provide high performance localization of the automation across an entire factory.

The SwRI team developed specialized control strategies to permit coordinated motion of the mobile base with the manipulator, thereby providing the capabilities of a much larger robot. In addition to larger scales, MR ROAM technologies can be more flexible because the mobile base does not require significant facility modifications for tracks or dedicated work cells.

4. HUMAN FACTORS IN ROBOT INTERACTION

Robot mobility and the manipulation of objects in unstructured environments are two capabilities that set the stage for robotic systems to operate openly in the "human" environments found in most factories. However, such a future vision is only possible if it can be done safely. There is significant activity in the robotics community and at SwRI to address these issues. Recently, the Robotics Industries Association (RIA), which is responsible for robotics safety standards in the U.S., ratified an updated ANSI/RIA R15.06-2012 standard [10]. For the first time, this standard outlines situations where people may work collaboratively with industrial robots.

This is likely to spur new and enabling research in the area of human tracking (see Figure 5) and behavior monitoring. Effective collaboration between machines and people requires that the machines be able to detect human presence and actions. For the former, one example was a collaborative effort between SwRI and the National Institute of Standards and Technology (NIST) to develop a 3-D sensor-based capability to detect humans and track them in typical manufacturing environments [11]. NIST is using this system to develop measurement methods and standards for incorporating human tracking systems onto machines like automated guided vehicles (AGVs), forklifts and mobile manipulators.

In addition to knowing the location and velocity of a person in a robotic workspace, often one would like to recognize specific actions so the machines can respond appropriately. For example, if a person holds up a tool in a certain posture, the robot might respond by grasping the tool and taking it from the person. Efforts are underway to utilize machine learning methods that enable robots to visually detect such classes of actions. These methods extract a kinematic "skeleton" model of the person from a 3-D image. By tracking this skeleton over time, SwRI's methods are able to classify certain repeated motion sequences as specific actions to which the robot can then react in a more meaningful, or safer, manner [12][13]. A novel feature was developed from raw motion measurements and shown to discriminate well between exercise behaviors. This feature, called a Motron, is constructed from natural cluster centers in data vectors containing position and velocity measurements of the subject. A new clustering algorithm was also developed and shown to be useful for both analysis and for accurately modeling sampled data.

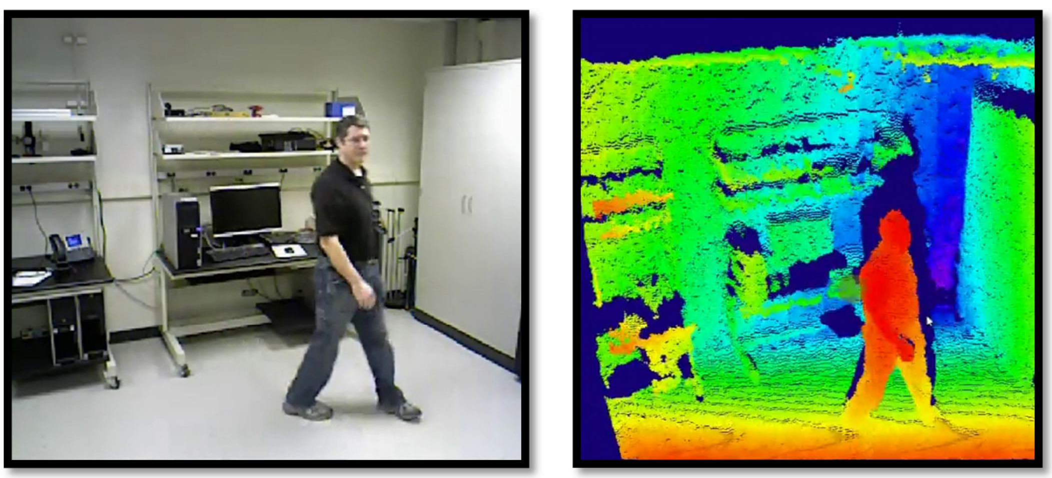

Figure 5. SwRI engineers developed a system to detect and track humans in manufacturing environments, even in the presence of occlusions or variations in the human pose. The system uses color and 3-D images like those shown at right and learns the "signature," or visible characteristics, of individuals in real time so that they can be uniquely tracked through the field of view.

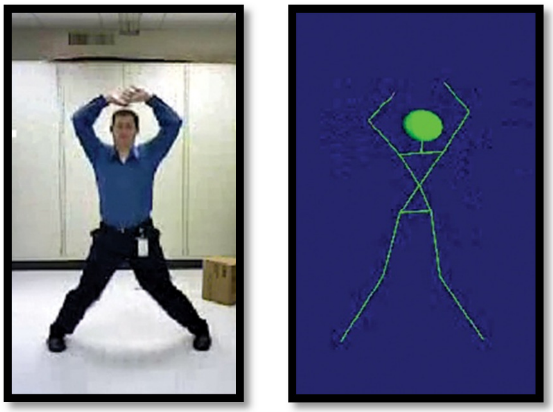

Figure 6. To recognize human actions, the SwRI-developed system tracks gross motions using skeleton models. A machine learning system, which has prior knowledge about different types of actions, can then classify the motion by type.

5. An Open Software Framework

In 2010, version 1.0 of the Robot Operating System (ROS) [14] was made publically available. ROS is an open-source software framework for developing robotic systems. Since then, it has become a dominant platform for robotics research used by many academic research labs [15], especially for mobile and service robotics. Stewardship of ROS was initially provided by Willow Garage, a private technology startup, but has recently transitioned to the Open Source Robotics Foundation (OSRF).

ROS provides a flexible architecture with advanced capabilities not found in most industrial robot controller solutions. In addition, it has a large community of developers who use it for a wide range of applications. Because of the potential value of integrating the capabilities of ROS more closely with industrial robots, SwRI invested internal research funding to create the foundation of ROS-Industrial (ROS-I) [16][17], an open-source extension of ROS that focuses on the needs of manufacturers and industrial robot users. It includes software packages for things such as low-level drivers for various robots and their ancillary equipment. It also has high-level functionality for capabilities, such as path planning, that are unique to industrial problems.

The ROS-I anticipated technical outcomes, enabled by revolutionizing the way that industrial automation software is developed, deployed and maintained,include:

- **Advanced Industrial Robotics Capabilities:** Making advanced capabilities like collision avoidance, mobile manipulation, 3-D perception-enabled path and grasp planning, and human-robot interaction available to industrial robot users and OEMs.
- **New Applications:** Providing a conduit to transition basic research to real-world industrial applications that were previously intractable or too costly.
- **Interoperability:** Stimulating the development of hardware-agnostic software using standard interfaces. Write software once and use it on many different platforms.
- **Affordability:** Crowd-sourcing code development, making new capabilities readilly accessible and affordable (e.g. Linux).
- **Community:** Engaging a world-wide community of industrial automation users, integrators and researchers through the ROS-I repository, wiki site, and the Consortium.

In its first year the ROS-Industrial project has attracted dozens of developers worldwide and gained support from several major robot vendors. End users are beginning to develop production systems using the software, and the ROS-Industrial consortium has formed to provide a roadmap to continue to foster the project. ROS-Industrial provides an important link between the robotics research community and end users, and SwRI is contributing many of the technologies it has developed back to the project. In doing so, there is a clear path to commercial adoption for these advanced capabilities.

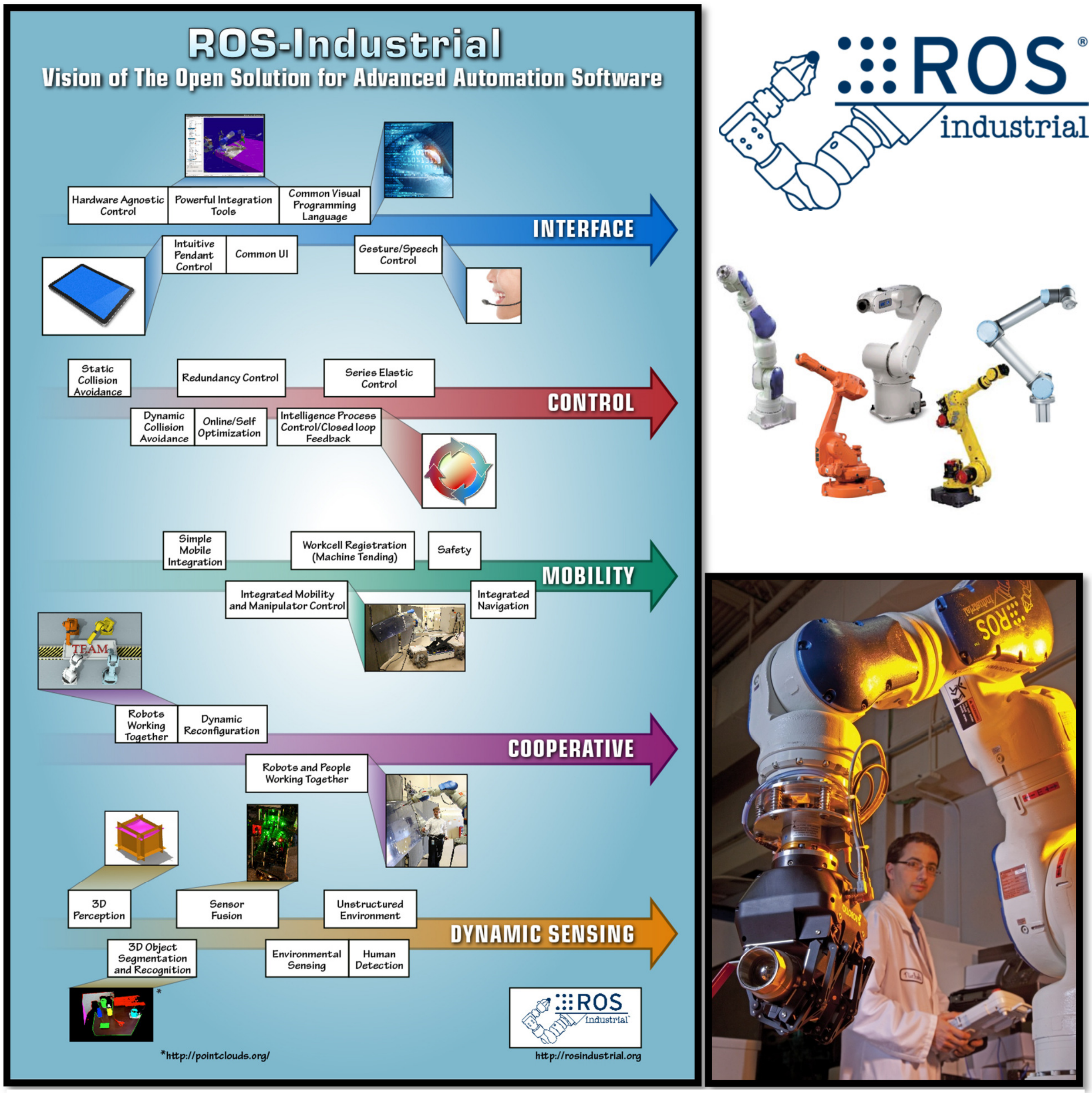

Figure 7. SwRI started the ROS-Industrial open source project to build an international community around the use of the advanced, open-source Robot Operating System (ROS) for industrial applications.

6. FUTURE VISION

The general public's belief is that robots destroy jobs, but the reality is that advancing the capabilities of industrial automation will lead to increased global competition and job creation. Miller and Atkinson present a compelling data-driven case showing how higher productivity leads to more jobs, and specifically address the argument that robots are killing jobs [18]. As manufacturers and policymakers better understand the competitive advantages provided by manufacturing technology investments, we will see accelerated adoption of more flexible and intelligent robotics solutions.

To address manufacturer needs, an important question is how the factories of the future will employ robots? Manufacturers will continue to invest primarily in application-specific solutions that researchers and integrators must extend to generalized solutions for use by many industries. The physical barriers that traditionally separate robot activities from humans will continue to fade as new technologies also address safety concerns, allowing robots to work in concert alongside humans. Interoperability and reuse of enabling software capabilities for advanced applications across robot platforms will become desirable and mainstream. Data-driven and model-based adaptive control strategies will displace the traditional manual path-teaching methods predominantly used today; high-level task-derived programming will replace low-level motion programming.

The combination of technologies for advanced perception, planning, mobility and human interaction within an open software framework is poised to accelerate the adoption of robotics in new manufacturing areas. Industries that traditionally have been difficult to automate are seeing rapid advances, and the ability for workers to interact with machines could improve productivity dramatically. Industries that traditionally have been difficult to automate are seeing rapid advances, and the ability for workers to interact with machines could improve productivity dramatically. Just as the early robotic systems were rapidly adopted for repetitive tasks in automated manufacturing, the next decade will witness a similar revolution in robots used for repetitive tasks where more flexibility and better decision-making are required.

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