Robots to the Rescue

Formerly the subject of science fiction, robots have evolved to become a specialized branch of engineering and technology. These machines are found in a myriad of applications, from space exploration to domestic help. As robots free mankind from danger and drudgery, they are making the improbable possible.

As the Deepwater Horizon tragedy unfolded, millions sat transfixed at video monitors and television screens viewing live feeds streamed from remotely operated vehicles (ROVs) at the ocean floor. Beyond human capabilities—in water depths below the range of inhabitable submarines—these robotic heroes performed incredibly intricate tasks.

Robotics, however, encompasses much more than remote oceanic operations. In modern society, robots fill a variety of functions, relieving humans of mundane, repetitive tasks, on the one hand, while performing dangerous duties that are beyond human capabilities on the other. Industrial robots are used in a wide range of roles, primarily in factories. Service robots perform in hospital operating rooms, on battlefields, in outer space and in homes, as well as in the oil field. This article offers a short history of the field of robotics and presents a few of its diverse applications.

Menacing Machines

In early 1800s England, the Industrial Revolution created profound changes that reshaped the manufacturing landscape. A by-product of these changes in manufacturing methods was the displacement of traditional manual laborers. In the textile industry this was especially pronounced as automated looms replaced large numbers of unskilled workers.

Unfortunately, these workers had few job alternatives and in desperation a group of them banded together and attacked their perceived enemy, the mechanized loom. The movement took its name from Ned Ludd who, although not a part of this uprising, reportedly had smashed knitting frames in a fit of passion 30 years earlier. The actions of the Luddites were short lived—quickly quelled by military intervention—but a deep-seated animosity between man and machine was established. The concept of robots and robotics developed against the backdrop of this adversarial relationship.

The word robot first appeared in a 1921 work of fiction, R.U.R. (Rossum’s Universal Robots), by Czechoslovakian playwright Karel Čapek. Derived from the Slavic word “robota,” which means servitude, and “robotas,” which means compulsory labor or drudgery, the term robot carried the connotation of a hard-working laborer. Čapek’s robots were relegated to menial tasks, releasing humanity from drudgery and boredom. However, in the end the robots rebelled and turned on their human oppressors. From this inauspicious beginning, a genre of literature was born in which robots were cast most often as an enemy rather than a helper, perhaps reflecting earlier Luddite fears.
About 20 years later, one of the early masters of science-fiction writing, Isaac Asimov, introduced the concept of robot ethics with his Three Laws of Robotics. This is generally recognized as the first use of the term robotics, which is now an accepted branch of science and engineering. In Asimov’s novels, sentient anthropomorphic robots were almost human but lacked emotion. They are far different from modern society’s robot machines, which, although still lacking emotion, have moved from the pages of science fiction into factories, farms, oil fields, homes and a host of other environments.

Fiction to Fact(ory)

There is no consensus on what constitutes a robot. Most definitions include the idea that it is a machine guided by automatic controls and that it often replaces human effort. With this concept in mind, a likely candidate for first robot was born—as many inventions are—of necessity, although it is difficult to confer the title of first when definitions are a bit nebulous and there are competing interests for the title.

In the early 1940s, during the Manhattan Project, it was impossible to directly handle the radioactive materials being studied. Scientists developed a telemanipulator that allowed an operator to perform rudimentary tasks remotely and in relative safety. Although the device may lay claim to being first, because it was part of the top-secret project to develop the first atomic bomb, it was unavailable and unknown to the general public.

Today, the role of telerobotics in the nuclear industry is well established—every part of the fuel life cycle is managed by robotic machines. This includes transport, storage, fueling, rod retrieval, and, eventually, decommissioning. Nuclear power plants maintain robots for a second line of defense; they are designed to dismantle and remove first-line robots should they become stuck in the reactor.

The first generally recognized commercial robotic device was an invention of George Devol and Joseph Engelberger. In 1956, they offered Unimate—defined by the Robot Institute of America as an industrial manipulator—for sale. Unimate was an electronically controlled hydraulic arm that performed preprogrammed tasks and

1. Asimov’s Three Laws of Robotics are as follows: A robot may not injure a human being, or, through inaction, allow a human being to come to harm. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

was first sold to General Motors and General Electric (left). Industrial manipulators and automated guided vehicles are the two most common robot technologies that have evolved for industrial use. In 2000, materials handling and manipulators used for welding occupied three-quarters of the applications of industrial robots in the US.

Early on, the trend in industrial applications of robotics was in mass production, a concept that would have pleased Henry Ford, who is credited with developing the assembly-line method of automobile production. His four principles of mass production—interchangeable parts, continuous flow, waste reduction and the division of labor—are well suited for robots. Division of labor allows an assembly-line worker to focus on doing one task very well rather than having to perform multiple tasks, possibly less effectively. Based on Ford’s legacy, it should come as no surprise that the worldwide automotive industry employs more robots than all other industries combined.

The successful introduction of industrial robots in automotive manufacturing was soon replicated in other industries. Just as robots were being widely introduced into the workplace, manufacturers began demanding broad customization for products. This need for customization, in contrast to assembly-line uniformity, has been perceived by experts in the robotics industry as a setback for the acceptance of robots in some industries. The difficulty in retooling and reprogramming added unwanted inefficiencies. In the past decade, however, there has been a resurgence of robots in the manufacturing sector, especially in Asia, with Japan leading in the pursuit of robotization. Today, there are more than one million industrial robots in operation worldwide (left).4

However, the factory is by no means the only place for robots. Unmanned space exploration offers an ideal venue for the use of robotics. In the early days of space exploration, the assumption was that space flight would have to be manned to complete tasks necessary to make the journey. This has not proved to be the case. The only foray to the surface of a planet other than our own, Mars, has been by robot rovers: Sojourner in 1997 followed by Spirit and Opportunity in 2004 (next page). The robotic unmanned Voyager 1 and Voyager 2 spacecraft hold the distinction of being the only human-made devices to depart our solar system.

These space travelers, although not autonomous, were designed to sense their environment and perform tasks based on their findings. Distance and time between issuing and receiving

\[\text{\textcopyright \ Joseph Engelberger.}\]

Industrial robot growth. The worldwide economic climate curtailed new installations of industrial robots in 2009; however, the estimated stock of operational industrial robots topped one million units that year (top). From 2006 to 2009, Japan led all countries in the pursuit of industrial robotization (bottom). (Adapted from the International Federation of Robotics, reference 4.)
Three-dimensional stereographic imaging also remote manipulators, particularly surgical robots. A resurgence in the developing field of telepresence has experienced out by the physical robot. commands are then translated and carried operator controls a graphic image of the robot monitor is an alternative to virtual reality. The a robot’s actions using images on a computer often incorporates virtual reality, an immersive brainstorm expects or is able to process. Telepresence master-slave relationship of remote operations often produces cognitive fatigue for the human manipulator. This is primarily a result of information updates being much slower than the human brain expects or is able to process. Telepresence often incorporates virtual reality, an immersive medium, to reduce cognitive fatigue. Simulating a robot’s actions using images on a computer monitor is an alternative to virtual reality. The operator controls a graphic image of the robot and commands are then translated and carried out by the physical robot.

Haptics, from the Greek word for touch, is the study of sensory feedback that has experienced resurgence in the developing field of telepresence. Remote manipulators, particularly surgical robots. Three-dimensional stereographic imaging also offers a means of improving the human-machine interface. This technology is used extensively in the nuclear-power industry where only robots can work in and near the reactor. When these plants were first developed, guiding robots using images from conventional television or computer monitors was difficult because these technologies provided no depth perception. People with vision in one eye were more adept at overcoming this deficiency, and it was common practice to employ those with monocular vision to operate the robots. The use of 3D imaging has overcome this limitation.

Whether it is through 3D visualization or sensory feedback, it is beneficial for the operator to have real- or near real-time control of the equipment. Semiautonomous control, also referred to as supervisory control, is another means of connecting man to machine with higher levels of robot complexity. There are two basic types: shared control and control trading. In shared control, the telesoperator instructs the robot to perform a task or performs the task using direct control. An example of semiautonomous control is using a robotic arm in space. The operator instructs the arm to move to a specific position then takes control for tasks requiring manual dexterity.

Control trading operates under the assumption that the robotic machine is capable of completing tasks that, once initiated, require no operator intervention. An operator can control multiple robots as long as they don’t encounter unforeseen circumstances. Uncertainty and unexpected situations have increased the need for some level of AI, which is the most advanced level of robotics.

There are several levels of robot AI, the oldest method being the hierarchical paradigm originating in the 1960s, based on a sense-plan-act sequence (left). Early AI-enabled robots typically operated using this method. The robot’s sensors validate a predefined world, a specific task is planned given its understanding of that world, and then the robot acts accordingly. The major disadvantage of this method is the planning stage in which, after the robot has defined its world, any unanticipated event may create a major disruption. This method deals poorly with uncertainty, and there is no feedback system to validate successful completion of a task.

Acknowledging the shortcomings of this approach, roboticists looked to biological sciences for direction. The reactive paradigm emerged in the 1980s and minimized the planning stage of the previous methodology. This system coupled sense and act sequences in an overarching concept of behavior; programmers determine the desired behavior and can combine behaviors based on what the robot senses. This is more representative of biological thought processes. For example, in a fight-or-flight situation, animals using lower-order thinking rarely plot an escape route; they react. Actions and reactions are quicker than thoughtful planning. However, this reaction may be detrimental if the perceived escape route leads to a trap.

The problem with the reactive methodology is that robots shared a human characteristic; paraphrasing George Santayana: If they could not learn from their mistakes, they were condemned to repeat them. In the 1990s, roboticists built machines with powerful but increasingly less expensive processors. This increased power allowed programming theory to evolve and develop the hybrid deliberative/reactive paradigm. In this methodology, a reactive robot learns from past experiences and chooses a response that best accomplishes a task, learning, it is hoped, from previous attempts.

A number of architectures have been developed using the hybrid methodology, all in an effort to create autonomous thinking machines. As computer processing power and speed continue to increase, and software complexity evolves, the science fiction writer’s vision of anthropomorphic robots may become reality. For now, however, robots generally fill a very different role: the three Ds of robotics. With a few notable exceptions, they perform tasks that are dirty, dull or dangerous. Difficult is a fourth D often proposed by roboticists.

**Field and Factory**

Like other service robots, oilfield robots perform all three: dirty, dull and dangerous tasks. These activities include automated directional drilling and closed-loop continuous drilling. In addition, service robots such as ROVs have made drilling operations in deepwater environments possible.

As oil companies began exploring in deeper waters, the water-depth limit for drilling was defined by the maximum depth of human intervention. With specialized diving equipment, that...
limit was about 300 m [1,000 ft]. Manned submarines were a possible option but they could only operate to about 600 m [2,000 ft]. Below these depths, ROVs are the only option for intervention. For this reason, all floating rigs currently in operation have at least one ROV. Even for wells being drilled in water depths where human interaction is possible, ROVs have replaced humans as the primary means of underwater intervention.

ROVs are classified as remotely controlled manipulators and belong to the professional service robot branch of robotics (previous page, bottom). They can perform a multitude of tasks, as long as these tasks have been engineered prior to the initiation of the job. Unlike human operators, who can respond to changing conditions, ROVs have difficulty completing even simple tasks when operations diverge from the plan. Experimentation is a difficult option. Thus, for ROVs, operator planning is the most critical stage of job execution, and reaction is a function of the ROV operator’s ability to understand and respond to the situation.

Other robotics applications in the oil and gas industry may replace processes that require reactions that exceed human capability. For example, a recently introduced technique automates an approach used for drilling lateral wells with rotary steerable assemblies. The SLIDER automated surface rotation control system uses a robotic drilling approach (right). Based on a torque-rocking technique, this technology offers a layer of automation that greatly enhances ROP, improves safety and increases the life of downhole equipment. ROP improvements of 294% have been achieved with the technique.8

In torque rocking, which has been used for many years, predetermined torque values are applied using a topdrive drilling system. This surface-applied torque is dissipated in the drillstring before it reaches the bottomhole assembly. The objective is to minimize drag while simultaneously keeping the toolface of the bottomhole assembly unchanged.

Manual control of the technique used in deviated and short lateral sections has been realized, but as well profiles have become more complex, the technique has been less successful. It is virtually impossible to efficiently perform the manual torque-rocking technique when drilling extended laterals or complex wellbore geometries because of the large volume of information from input sources that must be integrated and processed. The SLIDER system automates the application of torque and reacts to both uphole and downhole conditions. Not only is the reactive torque measured downhole and incorporated into the timing and amount of applied torque, the system can detect dangerous conditions—such as bit stalling, pipe back off and sticking—and take immediate corrective action.7 The original version used robotic controls to turn knobs, move levers and push buttons. The most recent version uses an electronic interface to control existing rig equipment, precisely regulating voltage and current at the drive control panel.

Four example wells, representing a broad spectrum of types and complexity, were studied and the benefits monetized based on extended

5. For more detailed information on AI robotics: Murphy, reference 2.
6. Murphy, reference 2.
9. Reactive torque is defined practically as the length of pipe measured from the bit toward the surface that fully dissipates the torque produced while drilling in sliding mode. It is measured by correlating the pressure differential value in rotary mode with that during sliding mode.

^ Robotic control for the torque-rocking technique. The original robotic SLIDER system, shown here attached to a drilling console (bottom), used servo-motors to control the power swivel while drilling. Today, the interface (not shown) electronically controls torque while monitoring topside and downhole conditions. In one example, the SLIDER system provided improved drilling results, compared with manual control (top). In 45 minutes, the bit stalled nine times as indicated by pressure spikes (red curve) under manual control (tan shading) and the orientation of the toolface was very unstable (black curve). Under automated control (green shading), only one stall occurred and the toolface was much more stable.
Remote surgical-assistant robots. SARs, such as the da Vinci system shown here, bring robots to the operating room. The surgeon (left) sits at a computer console and remotely manipulates robotic arms. The patient (center) is operated on with assistance from support staff. The surgeon’s hand movements are sensed and translated electronically to micromovements on the operating platform. The ability to magnify and inspect areas of concern gives greater control than is possible with traditional surgical methods. Remote observation (right) provides additional visual access for training or consultation. (Image courtesy of Intuitive Surgical, Inc., copyright 2010.)

At Your Service
The SLIDER system is an example of a service robot, but there is no internationally accepted definition for this classification. The International Federation of Robotics has adopted the following preliminary definition: A service robot operates semi- or fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations. There are two subcategories of service robots: professional service robots (examples include the SLIDER system, bomb disposal and surgical robots) and personal service robots (examples are vacuum-cleaner, lawnmower and disability-assistant robots).
Surgical assistant robots (SARs) are a specialized branch of professional service robots. They allow doctors to perform remotely controlled, minimally invasive procedures through small incisions. In some cases, traditional invasive surgeries have been reduced to outpatient procedures. Because of the decreased physical trauma, pain and recovery times are greatly minimized.

The first documented robot-assisted procedure, a neurosurgical biopsy, was performed in 1985 using the Puma 560 system. Soon after, researchers at the National Aeronautics and Space Administration (NASA), in conjunction with the Stanford Research Institute in Palo Alto, California, USA, developed a dexterous telemanipulator for surgery; its goal was to give the surgeon, located elsewhere, the sense of operating directly on a patient. NASA’s interest was in providing surgical options in remote operations, especially in outer space.

Recognizing the potential for these developments, the US military funded research for bringing a surgeon to wounded soldiers through telepresence. In such a scenario, a soldier is taken to a mobile unit and operated on remotely. As of today, the system has not been used on actual field casualties, but successful remote operations were carried out on animals. This demonstrated the tremendous potential for remote robotic surgical procedures.

Engineers and surgeons who worked on the earlier projects developed a commercial SAR. With the AESOP endoscope positioner, a surgeon used voice commands to manipulate a robotic arm containing an endoscopic camera. Built and sold by Computer Motion Inc., this was the first robotic system approved by the US Food and Drug Administration (FDA). After extensive modification and redesign, these early developments evolved into the da Vinci master-slave surgical robot marketed by Intuitive Surgical, Inc.

The da Vinci system is designed to give a surgeon the feeling that he is in direct contact with the patient (previous page, bottom). Three-dimensional visualization and the ability to zoom in on areas of interest provide the surgeon greater control and insight than is possible with traditional surgical techniques. Ongoing research seeks ways to incorporate haptic technology, giving surgeons even greater control of operative procedures. The FDA has approved this system for laparoscopic and thoracic surgery. Trials are underway for endoscopic coronary artery bypass graft surgery.

The benefits of robotic surgery, with devices such as the da Vinci system, include minimal invasion (sometimes referred to as bloodless surgery), minor scarring, reduced infection rates, minimal side effects and same- or next-day hospital discharge. One such procedure is the robotic-assisted laparoscopic prostatectomy. Prerobotic methods required large incisions, which often resulted in postoperative complications and necessitated prolonged recovery periods. Patients frequently experienced excessive blood loss during surgery and had an increased risk of postoperative infection. Prolonged hospital stays and considerable pain followed by high incidence of bladder and sexual dysfunction meant surgery was often a last recourse. Because of the robotic surgery option, this may no longer be the case.

Into the Battlefield and back Home

The need for remote surgical operations in battlefields led to the development of the first commercial SARs, but this is not the only military application of service robots. In 1990, iRobot Corporation envisioned making practical robots a reality. The founders first produced the Genghis robot for space exploration (above). A series of service robots ensued, including the iRobot PackBot series, which was used to search the

wreckage at the World Trade Center in New York City in 2001. The following year, a PackBot robot was first deployed for military use. Military conflicts in Afghanistan and Iraq marked the first time robotic systems played a meaningful role in combat operations. Robots remotely performed activities such as cave and bunker reconnaissance, chemical and radiological substance detection and explosive ordnance disposal (left). Detecting and disarming improvised explosive devices (IEDs) are among their primary roles.

During the early days of a United Nations–sponsored project using robots to clear land mines in Afghanistan, social implications similar to those experienced during the Industrial Revolution surfaced. A contingent of local workers was employed to clear land mines, and their robotic counterparts were seen as a threat to their livelihoods. But, with training, they discovered that their jobs could be accomplished in a far safer manner. Rather than being displaced, they learned that robots enabled them to accomplish more with less risk.

In 2002, the same year that the PackBot robot saw its first military action, iRobot Corporation released its first personal service robot for general home use—the iRobot Roomba vacuuming robot (left). It uses sensors to navigate around obstructions, and its software, similar to that developed for land-mine sweeping, ensures full coverage in an efficient manner.

For control, the Roomba floor-vacuuming robot uses logic similar to the reactive paradigm. The unit calculates an optimal path to clean an entire floor using iRobot Aware 2 robot intelligence software (sense step). It then activates one of several modes of operation to clean the floor (act step). These modes include wall following (tracing the perimeter of the room and navigating around furniture and obstacles), room crossing (crisscrossing to ensure full coverage) and spiraling (cleaning a concentrated area).

A dirt-detection sensor alerts the unit that more-intensive cleaning is needed and it automatically adjusts to those conditions. When the unit has completed its task, or the battery drains below a predetermined level, it automatically returns to and docks in its recharging station.

The World Robotics Survey conducted by the United Nations estimated that 3.54 million robot units were in operation at the end of 2006. Since then the numbers have increased rapidly, with a projection that a total of more than 8.3 million units will be in operation by the end of 2010 (above). These personal service robots, although smart and helpful, have not progressed to a fully autonomous state and human intervention is often required. With the rapid development of autonomous technologies, it seems reasonable to assume that domestic robots with greater autonomy will eventually become commonplace.

Personal service robots include robotic pets, lawn care, home surveillance and home automation, but one area with tremendous growth potential is in rehabilitation and handicap assistance. In the US alone, it is estimated that 3 million people have some form of disability that necessitates the use of a wheelchair. Many rely exclusively on a wheelchair as their primary means of mobility. Worldwide, the number of wheelchair users may exceed 67 million.

Engineers are developing orthotic robots that will provide mobility to people who are physically challenged or have lost the use of their legs. The University of California, Berkeley Robotics and Human Engineering Laboratory developed the Berkeley Lower Extremity Exoskeleton (BLEEX), one of several robotic walking frames. Although its design was intended to allow the user to manipulate large loads with minimal exertion, it can also be adapted to assist individuals with impaired mobility. The system attaches to the hips and legs; sensors help wearers lift their legs,
climb and move forward while maintaining stability. Power comes from a wearable pack (below). The current state of robotic motor skills is still poor compared to that of humans and animals. Considerable research is ongoing in this area to improve the human-machine interface to enhance mobility as well as restore it to those who have lost it. In the interim period, robotic wheelchairs that respond to commands and are modified to climb stairs offer promise.

Some quadriplegics, with no use of their hands, use a “sip-'n'-puff” technique to control motorized wheelchairs and operate computers. The user blows into a tube, creating air pressure, which translates to commands that are interpreted by a computer interface. The method has several drawbacks, including slow response, a limited set of commands and the need for frequent cleaning of the tube. Because this technique requires diaphragm control, it may not benefit those who rely on ventilators. Researchers at the Georgia Institute of Technology in Atlanta, USA, recently developed a tongue-drive system (TDS) that has opened a new world of opportunities for individuals with disabilities (next page, top). The tongue-operated assistive technology can operate a computer or direct a wheelchair.

Connected directly to the brain by the hypoglossal nerve rather than by the spinal cord, the tongue is usually unaffected by spinal cord damage. Tongue movements are fast, accurate and require little concentrated effort to control. In addition, the tongue muscle does not fatigue easily. A TDS may potentially substitute for arm and hand movements. Replacements for these functionalities are considered the highest priorities for individuals with severe disabilities.

The TDS is minimally invasive, unobtrusive, noncontact, wireless and wearable. The device uses a rice grain–sized magnet implanted in or applied to the tongue. External sensors detect movement of the magnet and software translates the motion. A number of operations are possible, including the use of a virtual joystick to drive a wheelchair or operate a computer. This novel development demonstrates an effective interface between man and machine that can greatly improve quality of life.

The TDS functions as a master-slave robot, translating movement into commands. The ultimate symbiotic relationship would be to control a robot using a brain-machine interface. Although this may sound like science fiction, in 2009 the research wing of Honda Motors, in conjunction with the Japanese government–affiliated Advanced Telecommunications Research Institute International and Japan-based equipment maker Shimadzu, demonstrated a device that responds to brain activity and requires no body movement. The device measures electrical activity in a person’s brain using electroencephalography and measures blood flow with near-infrared spectroscopy. Honda claims a 90% success rate in using this method to correctly analyze thoughts.

What the Future Holds
At the turn of the previous century, in part due to their fictional portrayal, robots were often viewed as potential enemies of humanity. Today most people are willing to embrace technology in general and robots specifically. Schlumberger Excellence in Educational Development (SEED) is a volunteer-based, nonprofit education program focused on underserved communities where Schlumberger employees live and work. Volunteers, teachers and students incorporate robotics into projects, workshops and day-to-day activities at schools. Using GoGo boards—ineffusive microcontrollers that can be programmed to perform robotic functions—students are creating innovative projects covering a wide range of topics.

At a recent SEED workshop in Tyumen, Russia, students designed and built a robotic turtle that crawled around on a tabletop without falling off (next page, bottom). A sensor, which detected the table edge, directed the turtle to back up and turn away. In Brazil, students and teachers built a model of an automatic irrigation system. Rainwater collected from the roof was stored in a cistern, and when a moisture sensor determined that the ground was dry, the system activated an irrigation pump. At Colegio Alfonso Jaramillo in Bogotá, Colombia, a robotics club has enriched the learning experience of all the
Power of the tongue. This tongue-powered device uses a small magnet and external sensors (left) with a computer interface. This device can provide mobility to individuals with severe physical disabilities and overcomes limitations of traditional assistance methods such as sip ‘n’ puff. It can be programmed to perform a number of operations including control of a robotic wheelchair (right). (Photographs courtesy of Georgia Institute of Technology.)

Roboticists of the future will plot a course for thinking machines that stretches beyond the dangerous, dull and dirty jobs to areas that we can only dream of today. As the students in Russia, Brazil and Colombia have embraced the dynamic world of robotics so, it is hoped, will the rest of the world. —TS