View Point

# Robotics – Landscape and Emerging Areas

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## Abstract

Robotics is a vast field involving a multitude of software and hardware technologies and has diverse applications across areas such as manufacturing, logistics, healthcare and defense. Apart from these established domains, there are several exciting areas that are fast emerging such as autonomous vehicles, swarm robotics and cloud robotics. The future of robotics appears undoubtedly promising and in this context businesses need to take a hard look at where robotics can be useful to them. In this context, this paper explores the technology landscape, challenges, existing applications and emerging areas in the field of robotics. The intended target audience is technology driven firms and analysts who are interested in exploring the current state of robotics along with its applications and future outlook.

## Introduction

Robots have for long captured human imagination. People in the past believed that a day will come when all physical work will be performed by robots and all people will have to do is eat, drink, sleep and entertain themselves. Popular culture has entertained us with stories of robots taking over the earth with us mortal souls being reduced to slavery. Fortunately robots today have not come that far, but have certainly established their rightful place on the factory floor along with providing diverse services such as vacuum cleaning, medical interventions, bomb disposal and of course lots of entertainment. Robotics is the vast field of technology that covers anything and everything to do with robots. Wikipedia provides an elaborate definition:

> *"Robotics is the branch of technology that deals with the design, construction, operation, structural disposition, manufacture and application of robots."*[1]

The term 'robot' is used in a very broad sense today and it is difficult to provide a water-tight definition. In general it may be said that any **programmable** or **remote-controlled machine** that achieves a **complex task** qualifies as a robot. However, this definition too has its exceptions – in this case by the inclusion of virtual intelligent robot agents, which commonly are referred to as 'bots'. As such we hear of internet bots, chatterbots, video game bots and the like. At this point, we will regard virtual agents to be beyond the scope of this work and go with robotic machines as our primary focus.

In this paper, we provide a broad overview of the technology and domain landscape of robots, along with an outlook of potential industrial applications and opportunities. The target audience includes those new to the field along with decision makers looking for opportunities to leverage robotics for enhancing their business.

## Robot classification

As we are investigating robotics from a commercial perspective, let's start with an overview of a common industry classification of robots (there are many other ways of classifying them). The International Federation of Robotics (IFR), a global consortium of robotics suppliers and associations, categorizes robots into Industrial robots and Service robots. Industrial robots are used in manufacturing and food processing, while service robots are used to provide services to humans or equipment. An Industrial robot, also known as "Manipulating Industrial Robot" is formally defined in ISO 8373:1994:

> *"An automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications."*[2]

Industrial robots are typically configured as robotic arms and are used for assembling, testing, painting, welding and packaging. On the other hand, service robots come in various shapes and sizes and are utilized for functions as diverse as material handling (industrial Automated Guided Vehicles, AGV), healthcare, exploration, inspection, military, and personal service. Table 1 provides a bird's eye comparison between these types. Another useful classification system divides robots into stationary and mobile categories, with the latter further categorized as land, sea, aerial and space robots.

| | Industrial Robot | Service Robot |
|---|---|---|
| Purpose | Manufacturing operations | Facilitating and servicing operations |
| Autonomy | Low (Activities are pre-programmed in detail) | High (Activities are often situation based) |
| Mobility | Typically stationary and installed on the factory floor | Can be stationary or mobile (land, sea, aerial and space) |
| Nature of tasks | Highly repetitive | Often dynamic depending on situation |
| Situational awareness (Machine perception) | Low | Higher than industrial robots. May have an inbuilt array of sensors, cameras |
| Need for artificial intelligence | Low (as most tasks are repetitive) | Needed when environment is dynamic. May require machine learning |
| Human-robot interaction | Usually no direct interaction with humans | May involve direct human interaction |
| Domains | Manufacturing, food processing etc. | Healthcare, logistics, military, entertainment, household etc. |
| Applications | Assembling, testing, painting, welding, packaging etc. | Vacuum cleaning, lawn mowing, robotic wheelchairs, surgery, exploration, material transportation etc. |

Table 1: Comparison of Industrial and Service Robots (Source: Infosys research)

Industrial robots are commonly classified based on their mechanical configuration such as gantry, SCARA (Selectively Compliant Articulated Robotic Arm) and articulated; each configuration optimized to serve a different industrial function. Service robots are classified in multiple ways. The industry prefers dividing them into Professional service and Personal service robots. Professional service robots are high-end robots designed for highly specialized functions such as exploration, medical interventions, military applications etc.; whereas Personal service robots (also called consumer robots) are employed for domestic help, personal assistance and entertainment.

Service robots are also classified into Indoor robots and Field robots. Indoor robots operate in fairly predictable environments and have applications like medical, laboratory, entertainment and domestic help. On the other hand, Field robots operate in much more dynamic and unstructured environments. Applications include mining, military, agriculture, construction, demolition and logistics.

## Robotics technology

Robots are expected to have autonomy with some degree of intelligence for decision making, adaptability to changing environment, capacity to be reconfigured, usually via software for new tasks and ability to co-operate and co-work with humans as well as other machines [3]. Figure 1 provides a list of the major components of a robot in a hierarchical tree model. The primary modules are marked in orange, the sub-components and systems marked in green have been grouped under the primary modules based on their functionality. The modules marked in red are software and embedded systems, which are responsible for management and control of a robot.

The control system consists of intelligent agents and various systems, through which these agents interact, control the robot's mechanical systems as well as receive information from users and other auxiliary systems. The energy source, storage, distribution and management together form the power system. Sensors are the group of devices used for understanding the environment and receiving feedback regarding the robots actions by converting physical quantity into signals that can provide valuable data required for decision making. Mechanical system consists of motors, actuators and the physical structure based on the purpose for which the robot has been built.

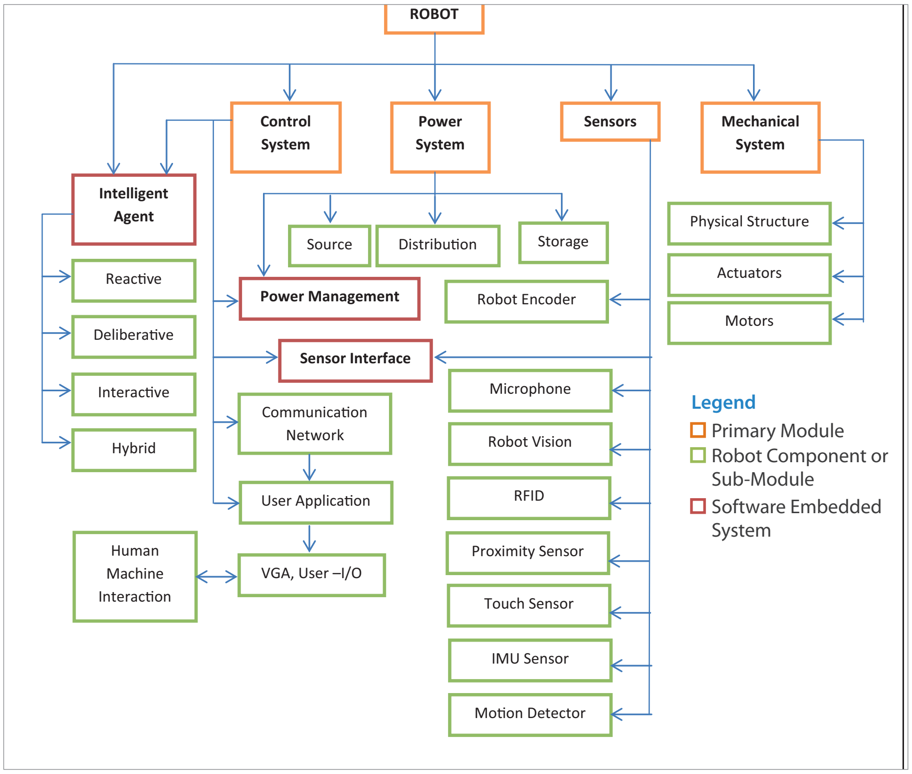


**Figure1 – Robot component tree (Source: Infosys research)**

## Robotics Hardware and Software Vendors

Robot hardware manufacturers are mostly engaged in design and development of robots as branded products, system integration specialists, engineering of special components and standard supplier of components like sensors, motors, batteries, actuators, etc. Small companies run the entire gamut of businesses, while large companies are limited to manufacturing industrial robots, reselling, defence contracting, and producing computer hardware and electronics.

On the other hand, the software industry is highly fragmented with few common standards or platforms. In most projects where the robot is designed for specialised application the software is custom built for optimum performance also they require secure and fail-safe operating systems. However with recent trends of hardware standardization and development, mass produced robots are being used for multiple applications. The robotics industry is adopting common standard connection protocols, shared libraries and modularity.

Let us look at some software used in Robotics. Solid Works from Dassault Systèmes is used for designing of robot and its components. Microsoft Robotics Studio has developer tools and frameworks for partners and developers to build applications. *MATLAB* from Math Works provides a high computation processing and simulation environment and comes with a robotics toolkit for *MATLAB*. Robot Operating System (ROS) provides hardware abstraction and low-level device control; this initially started as a research project at Stanford AI Laboratory and presently it is supported by Google and Willow Garage as an Open Source platform. Google's *ROSJAVA*, the Java implementation of ROS enables to connect to cloud and other devices. Some other frameworks and libraries specially designed for robotics applications are OpenCV, dLife, ScottsBots, Coupled-Layer Architecture for Robotic Autonomy (CLARAty), Mobile and Autonomous Robotics Integration Environment (MARIE), etc.

## Technical Challenges

Robots have been in existence since the 1960's. However, rapid development like the IT sector has not been possible in robotics because the technology demands are far more challenging. Also there are safety concerns as robots need to function alongside humans without posing any danger. A lot of research and development is still required in the field of manipulation and mobility, machine perception to understand 3D environments including touch, taste, sound, sight, smells etc. Human-robot interaction is quite primitive and often involves the need for users to learn how to program or remotely control the robot. There is a need to support more natural means of two way interaction such as speech and gestures. Effective communication and real time processing of vast amount of information is also a big challenge as robots need to interact among themselves and other auxiliary systems to operate in a dynamic environment. Moreover, as the environments in which robots operate get more complex and unstructured, there is a need for them to have learning and problem solving abilities in the form of artificial intelligence. Some of the challenges are being addressed today by emerging robotics technologies, which will ultimately make the dream of making robots ubiquitous a reality.

## Emerging Robotics Technologies

In robotics, success depends on bringing together a variety of technologies. Currently, we are moving from robots performing repetitive pre-programmed tasks generally used in industries to new types of mobile and intelligent robots. The key technologies driving innovation are:

**Tele-robotics:** Innovation in wireless and worldwide network technologies has made it possible to control robots from any place on Earth. The Deep Space Network, which is a worldwide network of large antennas and communication facilities, has enabled Deep Space Operations Center located at Jet Propulsion Laboratory to control and gather data from Mars Exploration Rovers. Remote controlled robots are now capable of defusing bombs and clearing minefields. Surgical robot through tele-surgical devices is helping doctors carry out critical operations in different parts of the world from one location there by allowing more number of patients to receive better healthcare.

**Cloud robotics:** Cloud can enable smaller, cheaper and smarter robots. The infrastructure exists and is rapidly evolving in terms of performance [5].Fast and reliable wireless network with sufficient bandwidth is enabling physical separation of hardware and software. This makes it possible to offload complex processing activities like image processing, motion analysis, 3D reconstruction of the environment, task planning and scheduling to the cloud where applications running on clusters communicate with robots to carry out high level processes. Tasks, thus gets uploaded to cheaper and easier to maintain hardware which allows invisible upgrades and also makes it possible to build lighter robots with long battery life. The data collected by a robot when stored on the cloud can be used by other robots or application and vice-versa. This helps the robot to make better decisions as it has better knowledge of the environment and more learning models for reference. The cloud provides the infrastructure for on demand usage which can help avoid regular skills upgrades for the robots. Any robot once connected to the cloud can easily request for an unknown skill and upgrade itself based on necessity.

**Cognitive and learning systems:** The degree of autonomy for taking decisions and the ability to continuously learn from previous or others experience is one of the basic desirable features that distinguishes robot from normal machines. It is humanly not possible to program for every possible scenario that a robot could face in the real world. The only viable option is to make the robot learn on its own like humans. Robots with cognitive capabilities can be flexible enough to adapt to different changes in their surroundings. This involves programming robots how to understand different situations and make their own rules rather than defining the rules based on which a robot is supposed to react. This area is very promising for the software industry as it involves extensive data mining and requires innovative ways of programming to understand the world from a machine's perspective.

**Swarm intelligence:** The analogy is derived from a swarm of insects, involving coordination of a large number of identical robots in order to achieve a common goal. This method helps increase efficiency of work, as work can be properly distributed or assigned to some other robot in real time if one of the robots goes down. Ideally there is no centralized control and decisions are taken locally with certain degree of randomness [6]. The technology is at a very early stage of development to be used for practical robotic applications. Present applications of swarm intelligence are limited to virtual simulations and games but its real potential lies in enabling future robots to independently coordinate with other robots in the absence of a central command in areas like cleaning of oil spill, underground mining and exploration where connection to a central controller through long distance wireless networks is not possible.

**Robotic apps:** With the emergence of tablets and smart-phones as universal devices for communication many applications in the form of apps have emerged. The use of mobile device with robots enables the use of apps that can control, help in time task planning activities along with receiving status reports. MINDdroid an app developed for android phones allows the user to connect to a ROS based robot platform like LEGO's MINDSTORM [4]. Through this app the user can move the robot in desired direction, make the robot speak different languages using external services connected to the app and also run multiple applications simultaneously using the mobile's hardware that might not be possible using robot's hardware. Similar apps when designed for industrial and service robots will enhance their features and provide better user experience.

**Hardware standardization and abstraction:** Hardware is getting standardized and therefore ability to interface and control via software is increasing rapidly leading to innovative applications. There has been an increase in processing power and availability of wide variety of hardware devices. Higher order libraries and operating systems are now available for hardware abstraction. A very good example of this trend is the robot platform NAO [8] a 57-cm tall humanoid robot with 25 degree of freedom this provides an ideal platform for research and development activities. NAO replaced Sony's robot dog Aibo as the robot used in Robocup, an international robotics competition. It can be programmed using its own programming software Aldebaran Choregraphe and also using other software tools like Microsoft Robotics Studio.

## Contemporary applications

Robots are used today to perform tasks that they do better than humans or to do the tasks that humans find dull or dangerous. They can perform repetitive tasks with high speed and the same accuracy every time, thereby increasing the productivity by a large extent. Robots are expendable, making them the closest substitute of humans for dangerous tasks. The classification of robots into Industrial and Service robots is based on their application.

### Industrial robots

Industrial robots have existed in manufacturing factories for decades. They have become an inherent part of assembly lines. Robotic technologies constitute the main elements of factory automation.

**Automobile production:** Robotic arms are more or less used to weld, glue, paint, inspect and assemble mass produced vehicles. Many tasks in industries require dealing with heavy loads. Human presence in such scenarios is extremely dangerous. Heavy manipulators perform these dangerous jobs keeping humans at a safe distance.

**Electronics manufacturing:** SCARA robots mass produce electronic boards by picking, placing and soldering large number of tiny components simultaneously. Within seconds entire electronic board is ready to be packaged into the body of the final product.

**Processing and Packaging:** Industrial robots are synced with conveyer belts handling large number of finished products. The products range from cheap toys to expensive high end electronic appliances. They are segregated, sealed, loaded\unloaded and boxed by the robotic arms with minimal time consumption and almost no damaging. Further robots, have started being used in some food processing industries for items like sausages, chocolates, cheese slices etc.

**Warehouse automation:** Robots found in modern day merchandise warehouses have revolutionized the way large number of physical objects are stored. A group of robot units handle movement of the products. A central coordination system keeps all the individual robot units in sync. The same system ensures maximum traded products stay near the loading area and the least traded products lie deep inside, thereby decreasing the delivery time. These robots don't need lighting and air conditioning hence improve the carbon footprint of the warehouse.

## Service robots

They on the other hand have a wide gamut of applications. They have been involved with some of the most dangerous tasks like space explorations and are finding their way to take over dull and boring tasks like floor cleaning.

**Healthcare:** Intelligent robotic prosthetics loaded with biosensors and feedback devices have improved the lives of lot many unfortunate souls providing them with intuitive control of arm and leg prostheses (e.g. Otto Bock [19]). Robotic wheel chairs are readily available and affordable to the masses. Healthcare robots are involved with medical interventions (e.g. surgical robot Da Vinci [20]), rehabilitation treatment, preventive therapies and diagnosis. Active robotic systems assist surgeons to perform complex minimal access procedures even on the body parts where they do not have enough direct visual information about the target area. Patient physical training therapy is assisted by robots (e.g. LOCOMAT [21]) to provide adaptive treatment for restoring motor coordination.

**Defence:** In recent times, defence sector have very well put into use the capabilities of robots. Military drones have found their place in sea, aerial and terrestrial warfare. Unmanned Aerial Vehicles (UAVs) and Unmanned Underwater Vehicles (UUVs) are mainly used for surveillance, search and rescue but also have the capability of attacking when required (e.g. UAV Predator). UUVs have been part of submarine rescue missions. Terrestrial robots (UGVs – Unmanned Ground Vehicles) include mine sweepers, supply carriers and attack vehicles equipped with various weaponry.

**Personal service:** Personal service robots are the commercially available robots that have the ability to perform day to day domestic tasks. Some robots are involved with cleaning tasks like lawn mowing, vacuum cleaning (e.g. Roomba), swimming pool cleaning and floor washing [22]. Tele-presence robots are available commercially that include a webcam and a display on a moving robot so as to add a touch of mobility to the video call [23].

**Toys and entertainment:** Robots have also found a strong place in toys and entertainment industry. Since late 1990, popularity of cheap, mass produced simple robots with limited interactive abilities have grown up. Millions of these toys have been produced. New trends have come up in recent years in this space like modular toys, simple gesture recognition and basic augmented reality. Small commercial quad-rotor drones (e.g. AR drones [7]) are used by hobbyists as well as for aerial videography since they are remote controlled and has a camera.

**Exploration:** Professional service robots have played a major role in explorations, inspection and action in hazardous environments. They have already been used for extra planetary explorations (e.g. the Lunar and Mars rovers), for deep sea scientific research and oceanography, for oil and mineral exploration and for volcanic explorations. Robots are also used for inspection and maintenance in radiation prone environment.

**Inspection and Maintenance:** Robots have played an important role in maintaining the nuclear reactors in their regular state as well as during and after calamities [14]. They have been used to control the undersea oil well leakages [17]. Huge mining robots can break, shovel, load, haul and dump rocks [15]. Robots are used to inspect, clean and\or repair oil and gas pipelines and tanks with or without stopping their normal usage [18].

**Search and rescue:** Small robot units with tracked wheels are used to inspect the debris due to calamities like earthquakes to find human survivors. Bomb squads have been using semi-autonomous robots for inspection and/or detonation of IEDs and bombs.

**Logistics robots:** Robots have been providing logistic services in various sectors like industrial, domestic, security and space. Industrial Automated Guided Vehicles (AGVs) follow markers and use lasers to move. They are prevalent on the floors of large facilities moving raw materials and semi-finished parts from one section to another with the least required human intervention. They can identify inbound deliveries based on barcodes and tags and can also label the outbound products with data like date, batch numbers, etc. Satellites are launched in space via manned and unmanned rockets. Huge robotic arms are a major part of space shuttles. They assist in launching the satellites and telescopes into their orbits, capturing them back as well as in their repairs, in the hostile environment of outer space.

Robots, be industrial or service have myriad applications. The applications and outcomes of industrial robots are mostly linear. They do repetitive work and the outcome is cheaper, better, mass produced goods. Service robots on the other hand work in dynamic environment and have a high impact business outcome. By and large, modern world robots touch our lives directly or indirectly to a great extent. Robots have a multitude of possibilities for their applications, which are progressively increasing with advances in technology.

## Emerging Areas

**Social Robotics:** Robots designed to work in the real world will require the ability to think and learn from experience to effectively respond to unexpected and unplanned events. The field of social robotics deals with creativity and improvisation that would allow robots to connect with humans at a social level. DATA a robot which is created on NAO platform tells jokes, dances to "Thriller" and paraphrases Shakespeare [9]. These evolutionary robots continuously keep learning from their interactions and can function in unforeseen situations.

**3D object and articulation models:** Certain actions like differentiating between a Coke and a Pepsi bottle and opening it to serve may seem an easy thing to do for humans. But for a robot this simple task will involve a series of complex steps starting with identification of the desired drink using 3D object models which will frequently keep changing based on new bottle and brand designs. And after identification it will require detailed articulation models on how to hold and open the bottle using different kinds of opener. This area has enormous opportunities as in the future when robots start working at our homes, no product company will be able to successfully launch their products without constantly keeping their product's 3D object and articulation models updated to new designs changes along with supporting old designs. In December 2009, RoboEarth project was initiated by researchers from academia and industry to develop a series of demonstrators to prove the concept [10]. The project aims to provide a networked environment through which robots can communicate using common protocols and create database of different models which robots can share.

**Autonomous vehicles:** This technology will bring in a revolution in the automobile sector as vehicles have to be built not only to drive their owners but also cooperate with other vehicles and perhaps help drive one another. Google's experimental driverless car that is capable of reaching a pre-programed destination without human intervention is a good proof of this concept. Currently, a fleet of Toyota Prius and Audi TT models have driven 160,000 miles with limited human input and more than 1,000 miles without driver involvement [11]. The car's decision making system creates an image of the world with all the moving objects and using data from Google Maps and GPS system it keeps track of its location. Most of the data processing is done on Google's cloud servers which controls of the car through wireless network. This technology can help organise the flow of traffic and prevent accidents. Logistics companies will benefit hugely by using this technology as they will be able to operate non-stop in a more optimized manner.

**Robotic Assistance:** Over the next 20 years there will be a 78% increase in population above 65 years in the United States [12]. How can such a large population be sent to old age homes? Nor will everyone be willing to go to old age homes. Everyone wants to live independently in their own house. To make this possible, we have to use technology. And it is not just a software solution because the challenges of aging population are not just informational challenges, they are physical challenges. Service robots in the form of domestic help or robotic exoskeletons can help aged people live with limited external help. Robots will play a significant role in improving customer experience, assisting and capturing feedback from customers at the point of interaction by leveraging adaptive learning techniques like natural interfacing with systems at point of contact like in a Retail Store or Kiosk setup, virtual Concierge and Offering Personalized and/or assisted service.

**Humanoids:** These are robots based on the human body designed to interact and safely work with humans in human habitats. Present humanoids in the market like Honda's ASIMO [13] or Aldebaran Robotics NAO are relatively expensive with limited capabilities for widespread use and are used only for entertainment and research purpose. However, with advancement in technologies these robots will find applications ranging from helping people at home to fighting along with soldiers in the battlefield.

Futuristic robots like micro-bots that are small robots in the millimetre range can be used for various medical, exploration and military applications. But with time as robots become more intelligent and powerful, possibilities exist to enhance human capabilities by integrating robotic systems with the human body there by providing improved communications, enhanced memory, enhancing sense experience and even brain to brain communication in the form of cyborgs.

## Summary

Robotics presents itself today as an indispensible technology in the fields of manufacturing, material handling, defence and exploration among several others. Though robotics has made significant strides where repetitive and remote controlled tasks are involved, it is lacking in areas requiring complex physical manipulation, decision making and human interaction. A positive trend in this area is the emergence of robot autonomy in the form of self-driving vehicles, which will ultimately pave the way for autonomous service robots in general, such as domestic service robots. To reach that stage, robotics faces several technical challenges in terms of improved mobility and manipulation, machine perception, artificial intelligence and operating in complex networked environments. Adoption and advances in cloud robotics may help take care of a few of the software challenges; at the same time relevant hardware innovations may still take a while. As we see today, robots are employed where there is a need to increase efficiency, bring in reliability and operate in hostile environments. It cannot really be said that robotics has directly touched the common man on the street. However, given the current advances and the rate of progress, in the days to come we can expect robots becoming more ubiquitous and assisting us in our day to day lives.

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