

Cloud Robotics: An Introduction

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Abstract: Early robots were simple mechanical automated machines. Modern robots employ microprocessors and computer technology. They can be programmed and “taught” to perform specific tasks. Cloud robotics is the seamless integration of robotics and cloud computing, which is the process of storing, processing, analyzing, and storing data over the Internet rather than on your hard drive. It is an emerging branch of robotics that uses cloud technologies like cloud storage, cloud computing, and other Internet technologies to offer robotics with the advantages of converged infrastructure and shared services. The paper provides a brief introduction to cloud robotics.

Keywords: Robots, Robotics, Cloud Robotics Machine Learning, Artificial Intelligence

I. INTRODUCTION

Robotics and autonomous systems represent the fourth industrial revolution [1]. An autonomous robot has a basic body structure (the chassis), sensors, a central control system (microprocessor), actuators (motors), a power supply, and software to control its behavior. Many businesses are turning to robotic automation to improve their efficiencies and productivity. It has become easier for them to automate mundane and repetitive tasks.

Robots gained frequent applications in dangerous environments where humans cannot survive, such as defusing bombs, finding survivors in unstable ruins, welding, and exploring mines and shipwrecks. Today, robots perform essential functions in homes, hospitals, industries, military institutions, education, entertainment, and outer space. Their design is to perform a wide variety of programmed tasks. Robots can support, assist, and extend the services of healthcare professionals. Robots are rapidly changing the face of manufacturing. They may help manufacturers increase precision, repeatability, and productivity [2].

Cloud robotics is an emerging branch of robotics that attempts to incorporate cloud technologies such as cloud computing, cloud server, and cloud storage. When connected or linked to the cloud, robots can benefit from the robust computation, storage, and communication resources available in the cloud [3].

II. WHAT IS A ROBOT?

The word “robot” was coined by Czech writer Karel Čapek in his play in 1920. Isaac Asimov coined the term “robotics” in 1942 and came up with three rules to guide the behavior of robots [4]:

1. Robots must never harm human beings,
2. Robots must follow instructions from humans without violating rule 1,
3. Robots must protect themselves without violating the other rules.

Robotics has advanced and taken many forms including fixed robots, collaborative robots, mobile robots, industrial robots, medical robots, police robots, military robots, officer robots, service robots, space robots, social robots, personal robots, and rehabilitation robots [5,6]. Robots are becoming increasingly prevalent in almost every industry, from healthcare to manufacturing.

Although there are many types of robots designed for different environments and for different purposes/applications, they all share four basic similarities [7]: (1) All robots have some form of mechanical construction designed to achieve a particular task; (2) They have electrical components which power and control the machinery; (3) All robots must be able to sense its surroundings; a robot may have light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), etc. (4) All robots contain some level of computer programming code. Programs are the core essence of a robot since they provide intelligence. There are three different types of robotic programs: remote control, artificial intelligence, and hybrid. Some robots are programmed to faithfully carry out specific actions over and over again (repetitive actions) without variation and with a high degree of accuracy [8].

The field of robotics is heterogeneous and multi-disciplinary. The community of robotics consists of robotics engineers, biologists, computer scientists, mathematicians, to mention a few. The goal of robotics is to create intelligent machines (called robots) that behave and think like humans. Robotics evolved to allow human- or animal-like functions to be carried out by machines, with greater strength, speed, and accuracy, in a roughly human- or animal-shaped machine.

Robotics has four divisions in it [9]:

1. Mobile Robotics - Robots which work and operate on ground (2D space). Example: unmanned ground vehicle
2. Aerial Robotics - Robots which work and operate in air and/or 3D space. Example: Unmanned aerial vehicle
3. Industrial Robotics - Robots used for factory automation. Example: Welding robots, pick and place, etc.
4. Bio Robotics - Robots which mimic animals and humans. Example: Humanoids, cheetah robot, etc.

III. CLOUD BASICS

The Cloud is used as a metaphor for the Internet. Cloud computing is evolving as a key technology for sharing resources via the Internet. It involves delivering services over the Internet at a cheaper cost. The three types of cloud computing are the public cloud, the private cloud, and the hybrid cloud. Cloud providers offer three primary services [10,11]:

- *Software as a Service (SaaS)*: Cloud-based applications run on computers “in the cloud” that are owned and operated by others and that connect to users’ computers via the Internet.
- *Platform as a Service (PaaS)*: This provides a cloud-based environment with everything required to support the complete lifecycle of building and delivering application.
- *Infrastructure as a Service (IaaS)*: This provides organizations with computing resources including processing, servers, networks storage, and data center space on a pay-per-use basis.

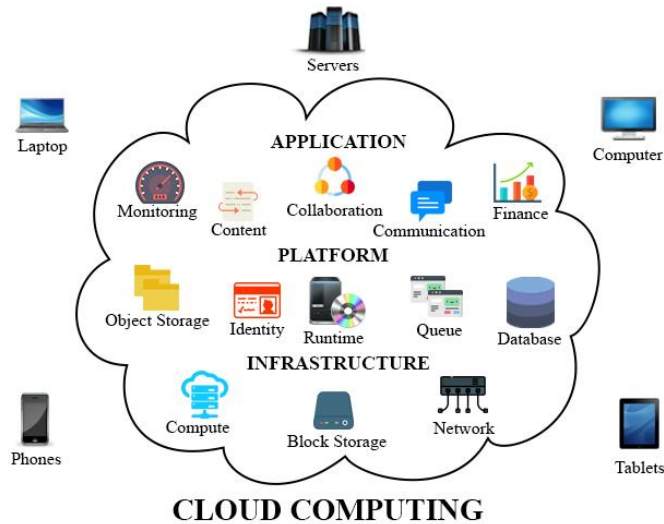


Figure 1: Cloud computing [12].

The main objective of cloud computing is to make a better use of distributed resources and solve large scale computation problems. For example, cloud computing can focus the power of thousands of computers on one problem enabling researchers to do their work faster than ever. Thus, cloud computing may be regarded as a distributed system that offers computing services via a computer communication network, usually the Internet (TCP/IP). Resources in the cloud are transparent to the users and the users need not know the exact location(s) of the resources. They can be shared among a large number of users, who should be able to access applications and data from anywhere anytime. Before the advent of cloud computing, a team of experts was required to install, configure, test, run, secure, and update servers and applications.

IV. WHAT IS CLOUD ROBOTICS?



Figure 2: Cloud robotics [13].

The term “cloud robotics” was coined by James Kuffner of Google in 2010. Cloud robotics is an Internet-based system that combines robotics, cloud computing, deep learning, big

data, Internet of things, and other emerging technologies. It is implemented in several multi-robotics operations. Cloud robotics is different from general automation because of its reliance on cloud technologies. Cloud computing empowers robots by offering them faster and more powerful computational capabilities. Figure 2 illustrates a typical cloud robotics [13]. Figure 3 shows the relationship between cloud robots and robot physics and artificial intelligence [14].



Figure 3: Relationship between cloud robot and robot physics and artificial intelligence [14].

The key features of the cloud computing architecture are [15]:

- The computing tasks of the cloud infrastructure are dynamic.
- With cloud robotics, a common pool of networks and servers can be shared.
- Cloud robotics introduces rapid elasticity because the resources can be scaled up and down based on demand.
- The “brain” of cloud robotics is in the cloud.
- The computing task can be entrusted to the cloud, which can result in better battery life and less robot load.

The cloud robotics provides the following services:

- Self-service: the end user does not require an expert to configure and operate a robotics solution.
- Shared resources: the end user doesn’t own robots. Instead, robots are rented on a monthly basis.
- Elasticity: re-configuration to fit the business process and to allow for upward or downward scaling with minimal effort
- Ubiquitous access: the state of the robotics system and its sub-components can be observed and controlled from anywhere by anyone who has the appropriate authorization.
- Open interfaces: interfaces are well-defined, making it easier for third-party integration. The transactions are transparent for the relevant stakeholders.

Several attempts have been made to build safe, secure, and flexible real-time operating system for robots. Since applications for cloud robotics need to be developed in a platform, majority of the cloud application developers choose ROS (Robot Operating System), which is an open-source middleware. ROS provides a graph-like structure for cloud robotics. It provides an eco-system to support cloud robotics. It is a collection of tools, libraries, and conventions that can simplify the task of creating complex robot behavior across a wide range of robotic platforms. A library for ROS that is a pure Java implementation that allows Android applications to be developed for cloud robotics. In essence, we use ROS to develop robotic applications and cloud robotics to maintain them [16].

V. APPLICATIONS OF CLOUD ROBOTICS

Robots can perform feats no current machines can accomplish. Robotics systems are being applied to real-world situations. The powerful combination of robotics and cloud computing opens the door to completely new possibilities. Some popular applications of cloud robotics include autonomous mobile

robots, medical cloud robot, assistive cloud robots, and industrial cloud robots. These are briefly explained as follows [3]:

- **Autonomous Mobile Robots:** Mobile robots must securely navigate warehouses, factories, and distribution centers while avoiding workers and machinery. Google's self-driving cars are typical examples of cloud robots. The cars can access Google's enormous database to monitor its own location position and avoid collisions. Each car can learn something about environments, roads, and traffic conditions, and it sends the information to the Google cloud for the benefits of other cars.
- **Cloud Medical Robots:** A medical cloud robot can connect to the cloud to provide the patients with clinical treatment as well as assist doctors. The robot may consist of various services such as a disease database and electronic medical records, and medical expert system.
- **Assistive Robots:** An assistive cloud robot can be used for life monitoring for elderly people, especially for those with chronic diseases. The robot collects the health status of patients and exchanges the information with cloud expert system or doctors. The robot can provide support to prevent the elderly from falling down. It can also notify the care giver through the network in case of an emergency.
- **Industrial Robots:** This kind of robots are utilized in industries for diverse purposes. Several industrial processes such as painting, machining, material handling, welding, and assembling are now being replaced with automated industrial robots. Industrial robots trained by machine learning become more aware of people and surroundings. They can assist companies to get things done with fewer errors. In manufacturing, such cloud-based robot systems could learn to handle tasks such as threading wires or cables, or aligning gaskets from a professional knowledge base. Another potential paradigm is shopping-delivery robot systems. Figure 4 depicts cloud robotics in an industrial environment [17].

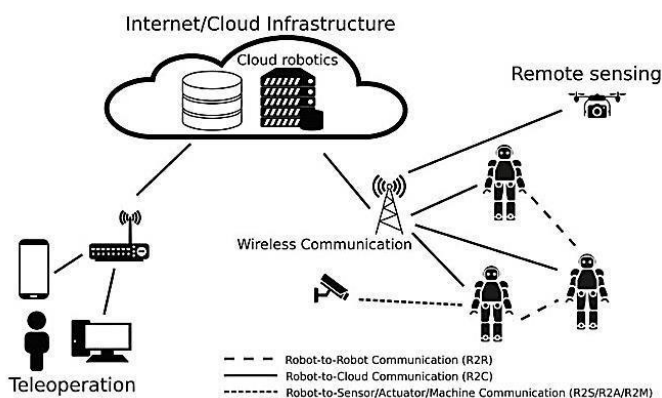


Figure 4: Cloud robotics in an industrial environment [17].

- **RoboEarth:** This robotic system was funded in 2010 by the European Union's Seventh Framework Programme specifically to explore the field of cloud robotics. The goal of RoboEarth is to allow robotic systems to benefit from the experience of other robots. RoboEarth's database stores knowledge generated by humans and robots. The knowledge base includes

software components, maps for navigation, task knowledge, and object recognition models. RoboEarth architecture is shown in Figure 5 [18].

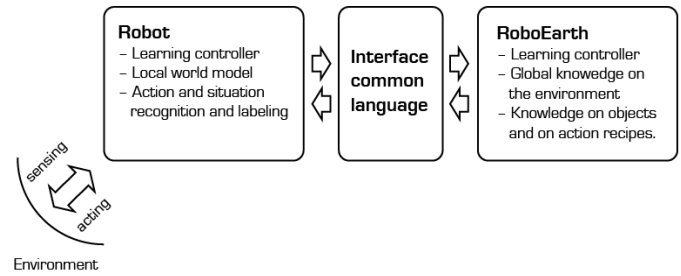


Figure 5: RoboEarth architecture [18].

- **Networked Robots:** Cloud computing is transforming the potential of robotics by enabling multi-robotic teams to fulfil complex tasks in the cloud. These networked robots are connected as a team of robots through a wired or wireless communication network. They address the problem associated with standalone robot systems. They share data with each other and solve a task in a cooperative manner. The main challenge facing networked robots is due to resource constraints, learning constraints, and communication constraints. The hardware constraints of each individual robot limit its computing and storage capacity resulting in a collective limitation of the networked robots. Networked robots maintain machine-to-machine communication [19].

Other applications include facial recognition, natural language processing, logistics, security, surveillance, guidance, education, and personal assistance.

VI. BENEFITS

Robots with their various applications have brought significant economic and social impacts to human lives. The advantages of robotics include heavy-duty jobs with precision and repeatability. It has increased automation in the workplace. Machine learning and cloud technologies being used to develop robots that are better, smarter, faster, and more useful than ever before. Cloud robotics has become a gamechanger because it has made robots capable of performing various tasks that they could not perform earlier. It has also made robots economical and easier to install. Benefits of cloud robotics include access to big data sets, open-source algorithms, code and programs, massively powerful parallel or grid computing and the sharing of information between robots. Compared to conventional robots, cloud robots will generate new value chains, new technologies, new architectures, and new business models.

Other benefits of cloud robotics include [13]:

1. Cloud based robotics provides shared knowledge, database on real time. This makes robots smarter, cheaper, and smaller.
2. Cloud computing allows robots to take advantage of powerful computational, storage, and communication resources.
3. Cloud computing makes it possible to build lightweight, low-cost, smarter robots with an intelligent "brain" in the cloud.
4. Cloud robotics systems are endowed with powerful capability while reducing costs.
5. Cloud robotics can transfer heavy computer task to the cloud. This leads to cheaper, lighter, and easy

hardware maintenance. Hardware and software updates can be in real time without losing data.

6. Any old robot which is full on rust and dust can be reuse properly by using hardware and software of cloud infrastructure.

VII. CHALLENGES

Robotics has faced numerous challenges, notably questions regarding efficacy, safety, and cost-effectiveness. The concentration of computing resources in a cloud computing environment poses security threats. Controlling a robot's motion which relies heavily on (real-time) sensors and feedback of controller may not benefit much from the cloud. Other technical challenges that tend to stand in the way of the efficient performance of cloud robots include the following:

- Real-time Requirements: Tasks that involve real-time execution require on-board processing may not benefit from cloud computing. Maintaining a balance between the real-time requirements of different situations and performance accuracy is a difficult task.
- Slow Response: Cloud-based applications can be slow due to high-latency responses.
- Remoteness: There could be times when the robots are unable to connect to the network, due to security reasons or physiographical reasons. This is where edge computing comes into the picture as a solution.
- Network: Imagine a robot losing its connection to the network or cloud when on a war-like mission or a surgical one. If the robot loses connectivity to the network, it can run through these clusters of resources. Swarm robots also use this same technique and it is very interesting to learn.
- Fault Intolerance: A fault in the network could render a cloud robot "brainless."
- Ethics: Some ethics for cloud robotics must be considered. Who should be held responsible for a robot that is out of control and causes damages?
- Technical complexity: The extremely technical nature of cloud robotics solutions drives away those who are not experts in the field.
- Large capital expenditure: Substantial amount of capital is needed for implementing a cloud robotics solution.
- Proprietary interfaces: Non standardized APIs between software/hardware components are creating fragmentation and limiting innovation.

These current challenges prevent cloud robotics from going mainstream.

CONCLUSION

Cloud robotics is a rapidly developing technology made possible by the growing number of powerful cloud computing services available. It may be regarded as off-loading some of a robot's processing into the cloud to allow it to share resources. It is a category of robotics that utilizes cloud technologies, including cloud computing, cloud storage, and other Internet technologies. This concept is gaining popularity worldwide because it is making future robots more productive and efficient.

Although cloud robotics is a relatively recent concept and is still in its infancy in most nations, large corporations such as Microsoft, Google, and IBM are investing heavily in its development. Technological advancements in artificial intelligence and related technologies will increase the adoption of cloud robotics. More information about the use of cloud

robotics can be found in the book in [20] and the following journals devoted to robot-related issues:

- *Robotica*
- *Robotics and Autonomous Systems*
- *Advanced Robotics*
- *Journal of Robotic Systems*
- *Journal of Robotics*
- *Journal of Robotic Surgery*
- *Journal of Intelligent & Robotic Systems*
- *Journal of Mechanisms and Robotics-Transactions of the ASME*
- *Intelligent Service Robotics*
- *IEEE Journal on Robotics and Automation*
- *IEEE Robotics & Automation Magazine*
- *IEEE Robotics and Automation Letters*
- *IEEE Transactions on Robotics*
- *International Journal of Medical Robotics and Computer Assisted Surgery*
- *International Journal of Robotics Research*
- *International Journal of Social Robotics*
- *International Journal of Humanoid Robotics*

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