Infosys®
POWERED BY INTELLECT
DRIVEN BY VALUES

Leveraging the power of Cloud for Robotics

By

Subhasis Dutta

March 22

2012

Cloud Robotics a very recent concept only a few years old, is fast emerging as an important area in robotics. It can accelerate the growth of Robotics Industry like wireless communication, broadband and apps for mobile devices have accelerated the growth of Communication industry. This paper explores the concept of cloud robotics, landscape, possible applications in different domains, startup investment required and potential solutions in short, medium and long term. The intended target audience is analysts who are interested in exploring the current state of robotics along with its applications using cloud platform.

Table of Contents

1. Introduction

We cannot survive or grow without cooperating, sharing and interacting with others. Our ability to think independently, work together, share and reuse our knowledge are some of the factors that has made us the most prosperous species. The same principle applies to robotics as robots besides being machines needs to function with controlled independence. To enable robots to think independently and understand the environment using natural input like vision, sound etc. they need the ability to process information like humans. Using current technology it is not feasible economically to build robots that can function autonomously using techniques like machine learning and vision, real time processing etc., as it requires huge computation and the amount of resource we can stack on a robot is very limited due to size, power and cost issues.

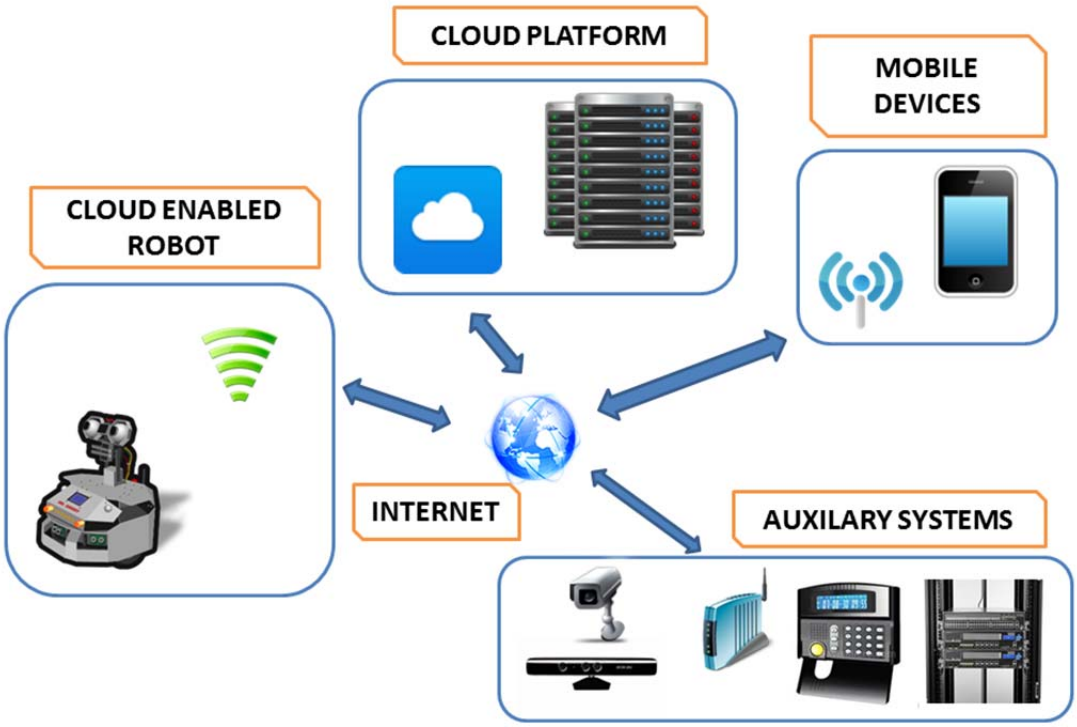
Cloud can enable smaller, cheaper and smarter robots. The infrastructure exists and is rapidly evolving in terms of performance. Fast and reliable wireless network with sufficient bandwidth is enabling physical separation of hardware and software. This makes it possible to offload complex processing 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.

2. Market analysis/Potential market size

Being a new concept only few years old, cloud robotics is presently limited to academic and hobby markets. However, its potential is huge and in a span of 15-20 years it can increase the size of Robotics market to a size comparable to the Automobile sector. Connecting robots to the cloud will help make the concept of robots in homes and work place a reality, make driverless automobiles possible and transform the way robots are used in manufacturing process.

The real potential of Cloud Robotics is in future markets and as we continue to automate mundane, repetitive or dangerous task. Today profitable market for robotics is limited to industrial automation, scientific exploration, educational and hobby robotics. Currently, the highest growth rate for robots is seen in service robotics sector that is growing at a rate of 30% annually compared to 5% growth rate of industrial robotics sector. The main reason for this growth is due to increasing demand for robots in healthcare and military sector also the consumer market which has shown the highest unit sales. According to International Federation of Robotics report, the total units sold worldwide in 2010 for service robots was 2.213 million whereas only 118 thousand industrial robots were sold. However, the sale of service robots was worth only $3.7 billion compared to industrial robots which generated $17.5 billion. This discrepancy between revenue and unit sales is because of very low unit value of personal service robots that have very limited features and applications (Personal service robots units sold in 2010 was 2.2 million but sales was worth only $538 million). In the short term, connecting these robots to the cloud can help create many innovative applications for mobile devices which can provide value addition to existing robots and for the long term cloud can actually enable many features in robots that are not possible using traditional computation techniques.

3. Landscape



Cloud Enabled Robots can have access to multiple systems through the Internet

Robots connected to cloud through the internet will have access to multiple auxiliary systems like surveillance camera to terabytes of information stored in different data centers. Like a computer, connecting a robot to network will allow us to control and monitor using any portable mobile device like a smartphone. Such a scenario provides huge scope for innovative applications that can range from simple apps that can control a robot from any place on earth to highly complex task of driving our cars or assisting us in our daily work.

1.1. Gaps being addressed

Robots generally have their logic in built and its interaction with external device and network is limited to sending signals for control and monitoring. This limits the amount of processing that a robot can do, which prevents development and use of robots for various applications due to unavailability of required memory and processing power, battery life, portability and cost.

Cloud enables sharing of knowledge base which can enable smarter and efficient robots that are presently not possible using convectional onboard processing technologies. Apart from robotic applications cloud computing will help create non-robotic applications using the data collected by the robots. For example sensor data collected from robot being used for vacuum cleaning can enable many useful applications like finding a lost key using a search engine. The concept behind this is knowledge reuse, when a robot moves it collects data which is used to create 3D image of the world that is used by the robot to identify objects. This same data when stored and connected to a search engine can help locate lost objects simply by providing a brief description of the object. Besides addressing challenges, with technological progress cloud robotics will help create applications which will become a necessity in the future.

4. Illustrative Example

4.1. Project RoboEarth

RoboEarth aims to create a giant network and database repository where robots can share information and learn from each other about how they need to function in an ever changing environment. The goal of RoboEarth is to allow robotic systems to benefit from the experience of other robots, paving the way for rapid advances in machine cognition and behavior, and ultimately, for more subtle and sophisticated human-machine interaction.

In December 2009, RoboEarth project was initiated by European Union as a part of "Cognitive Systems and Robotics Initiative" involving researchers from academia and industry to develop a series of demonstrators to prove the concept. This project has industry involvement from major companies like ABB Robotics, KUKA, Philips, Google etc. The hope is that, with a proof of concept in place, the RoboEarth database can be used as a launch pad for further research and development, leading eventually to standardization, common language protocols and a more modular design of robotic systems.

4.2. MyRobots.com

Myrobots.com was just launched on 31st January 2012, with an aim to connect all robots and intelligent devices to the Internet. This is the first portal that provides web service to connect robots to a centralized system where it can store and use the data in future or for other application. Currently they allow robot developers to only connect, monitor and control any internet enabled robot through their cloud service. It uses ThingSpeak, an open-source data engine created by ioBridge as the basis of its cloud robotics platform. In recent articles in IEEE Spectrum and Forbes it has been hailed as a very innovative concept with a potential to be the Facebook for Robots.

4.3. Google's Driverless Car Project

Cloud Robotics has made driverless cars possible. This is probably the best success story of cloud robotics today. Google has announced a technology that enables cars to run automatically without a driver, even in traffic. To control the car, video cameras, radar sensors, and special sensors are used. All the processing required for high level decision regarding path planning and information storage are carried out remotely on Google cloud. This frees a lot of space in the car that would have been required for holding multiple computers. Besides driving autonomously these cars are being used to collect images required for Google Street View and stored in Google data centers. Google hopes this technology will be able to reduce the risk of accidents on the road and make driverless automobiles a reality.

5. Concept Overview/Possible applications

5.1. Running Robotic application using Web Services

The concept is to develop a cloud based platform that can carry out all the high-level processing required for any robotic platform at the same time connecting to different services and use their technology and data to make decisions.

Robot connects to a Computing Instance on the cloud which computes using information from multiple services

Cloud Robotics will enable robots to use different services that may not be specific to robotic applications. Some of the services that can be developed or enhanced for robotic applications are:

5.1.1. Location Service

In order for a robot to carry out the task of navigation it will require detailed maps of the world. Google Maps provides an ideal solution, its shared maps can be accessed using web services and using API's like Google Earth API essential information can be obtained. This concept has been proven in the Autonomous Car Technology being developed by Google in which they have extensively used the Google Maps service for route planning.

5.1.2. Natural Language processing Service

For a robot to work with humans seamlessly it will need to understand and speak in different human languages. This will require the robot to be connected to a Natural Language Processing expert system. Google Translate provides an ideal platform for NLP activities, it can be used to translate human request to machine understandable format and vice-versa.

5.1.3. Image Recognition Service

Understanding the surrounding is one of the primary tasks for a robot this requires image and object recognition systems. A good example is Google Goggles, presently just an image recognition application that can detect a book, logos and even landmarks and provide search result related to the object. Google intends to launch Goggles API that can be used by other applications to detect objects using images taken. This can be very useful as robots using images from its vision sensor can obtain information regarding its environment.

5.1.4. Knowledge Repository and Reuse Service

Having greater knowledge of environment and how to react to unknown circumstances is the most critical functionality required for making robots work in open with humans. Once setup and standardized, RoboEarth

database can help perform task that a robot has very less information of using data shared by other robots. This will be one of the most vital service as it is impossible to program robots for every task it can face, what this service provides is an on demand information comprising of data about of the environment collected by other robots or learning models that can be used to devise a strategy to perform a task that was never done before.

5.1.5. Communication Service

Communication plays the most important role in a system where the decision making system is remotely located. It is very important to have a reliable and failsafe communication system to connect the local process on robot to the high level processes on the cloud and if the system fails it should be able to gracefully power down or connect using surrounding ad-hoc networks. Robot Operating System (ROS) an open source platform still in active development aims to provide such a communication infrastructure. ROS at its core is a message passing system, based on anonymous publish and subscribe architecture. This project was started at Stanford a few years back and received active participation from the open source community and recently major robotics companies have publicly supported this architecture.

5.2. 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.

6. Potential enterprise applications / Domains with benefits

The internet is an open network that can be accessed and continually updated by robots from around the world. But having an open and public model at enterprise and commercial level may not be feasible because of the following reasons:

1. Enterprise may be reluctant to store, process or share the data collected by their service robots in a public cloud. Example: A robot simply being used to monitor the security inside an office building will require 3d sensing to explore as well as avoid and obstacle. However this 3d sensing if transferred to a public cloud whose data can be accessed by any external device or robot even for reuse may not be acceptable to many enterprises because of security reasons. As this data can provide sensitive information of any file scanned by robot sensors and even the schematic of the building.
2. For a robot to function, it needs to know how to do a certain task .This can be learned from training data or steps shared by the robot developer or an application developer. However the developer might not want to share the data or process publicly because of commercial interests.

Currently industrial sector is the highest revenue source for the robotics sector. But with new innovation coming up many sectors are showing huge demand. The sectors that are witnessing huge growth in demand for robotics are:

6.1. Hi-Tech Sector

The hi-tech sector comprising of exploration, aerospace, military, new technology and software sector are witnessing high demand for professional service robots. The biggest challenge for robotic application in this sector is processing of huge amount of data and real time response to unpredicted situations, cloud robotics can help meet this challenges.

6.2. Healthcare Sector

Healthcare has huge potential for robotic assistance for performing critical operations, monitoring and helping patients. Today we have surgical robots like da Vinci Surgical System using which doctors can carry out operations remotely and more precisely, however specially trained doctor still have to control the robot every time the same operation is being done. Cloud can help automate the operations by storing operation procedures during manual operations and building learning models using the data collected. This can be used to perform similar operations with less doctor involvement which will help carry out more operations at lesser cost as doctor service cost will get minimized.

6.3. Manufacturing Sector

Today robotics equipment's for the manufacturing sector is quite mature and most of the large scale industry use robots in the factory floor. However, monitoring all the systems and using production data for analysis is highly limited. Connecting industrial robot systems to a cloud and storing production, machine health data etc. can help in better analysis of manufacturing process and also help in faster detection of faulty systems.

6.4. Retail Sector

Robots can be a great tool for promoting certain product, collecting customer feedback and monitoring customer behavior or activity as they will attract customers. Another advantage robots have is data collected will be more accurate as the feedbacks will be direct customer feedback rather than feedback collection through salesmen which are usually inaccurate. However this data collected from different robots at different retail centers need to be stored and processed together to make any sense for forecasting or making strategy. Cloud helps provide a centralized system that can collect data and control all connected robots.

6.5. Consumer Sector

Personal service robots like vacuum cleaner, robotic toys have shown the highest unit sales consisting of 2.2 million sales out of 2.3 million sales in 2010 however the value of these sales has been very low. Cloud can help in providing value to these low value robots by helping them connect to different devices like home security system, or smartphones there by helping create many innovative applications. For example, simple vacuum cleaners like Roomba when connected to home security system and owner's smart phone can help scare an intruder or keep watch on children or pets in the house.

6.6. Automobile Sector

Robotics 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 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. Most of the data storage is done on Google's cloud servers which controls of the car through wireless network. Logistics companies will benefit hugely by using this technology as they will be able to operate non-stop in a more optimized manner.

7. Infosys current strengths/enablers

As an IT solution's provider, a big opportunity for Infosys lies in providing customized solutions and computing infrastructure required by enterprise or even personal robot platforms to store and process in cloud. Infosys can also collaborate with robot hardware manufacturers and provide the cloud services required by their robotic platforms.

There is also a big opportunity for getting Patents and building Intellectual Property in following fields:

1. Creation and execution of action plans in real time for different robotic applications.
2. Building and updating maps for unknown and known environment.
3. Creation and detection of 3d object model.
4. Creation of learning models from data collected.
5. Mining information from past data.

These technologies are not fully developed at present and many academic institutions and organizations are involved in fundamental research in these fields, which can ultimately enable robots to function in real world. Apart from developing expertise in the above fields, we will require system integration and IT enabled capabilities like:

1. Networking robots and its sensors to a central or distributed computing system.
2. Storing and retrieving data of mapped environment.
3. Infrastructure for storing and sharing data.
4. Secure transmission and storage of information.

8. Investment Required

For developing small scale prototypes, capital expenditure is mostly for hardware purchase mostly consisting of mechanical parts, embedded systems or pre-built kits. Most of the software except a few like Solid Works and MATLAB are either open source so the cost involved in software procurement or licensing is negligible. The cost for a small scale robotic project can range from $100 to $10K depending on the hardware requirements.

The biggest challenge is for developers as knowledge in multiple fields is required for developing robotic applications. Some of the important skills required are expertise in hardware and software architecture for robotic systems, embedded systems, knowledge of sensors, prototyping using simulation, wireless communication, machine learning, motion planning, systems integration and even web based technologies for building application on the cloud.

9. Potential solutions in Short, Medium and Long Term

9.1. Short Term (6 months – 2 year)

In the short term the top most priority is required in building the skill set required for development. There is also a huge opportunity for building IP in different robotic fields mostly in networking, machine learning and object recognition. Integration of auxiliary systems and mobile devices to the robotic ecosystem is an area where many innovative applications are coming up this area can provide a lot of opportunities that can be exploited commercially.

9.2. Medium Term (2 year – 5 years)

The demand for robotic appliance is increasing rapidly mostly in consumer, military, healthcare and automobile sector. Developing capabilities for cloud enabled solutions like 3d object modeling, real time task planning & scheduling, ability to use external services for robotic applications and creation of learning models for different task have great potential as robots start working in human environment.

9.3. Long Term (5 years – 15 years)

In the long term, the potential for cloud enabled robotic solutions are limit less as in the future almost every robot that walks on the earth will need to be connected to centralized systems. Every system will be dependent on robotic systems for most of their work. Having a strong infrastructure to provide services to these robots will be very essential.

10. Conclusion

The field of robotics is filled with problems for which we still don't have a feasible solutions this provides a huge opportunity for innovative applications. Applications of Cloud Robotics is not only limited to Robotics market as it can help create and enhance the functionalities of embedded systems, create many innovative mobile apps also the data collected can be used for various analysis required for understanding various trends or forecasting future demand.

We are moving towards a future where Network is the computer. Almost all the robots that are to work in the real world environment will need to be connected to a central or distributed system for high level planning and extensive processing required to function in real world. Cloud robotics can help solve three of the basic problems of robotics i.e. how to make robots learn from their past experiences, how robots can share their new-found knowledge instantaneously with their peers and how to avoid thousands of robots solving the same essential problems over and over again.

Cloud computing for robots of the future is not an optional requirement but a mandatory one.

11. Reference

1. Robo Earth: World Wide Web for robots. November 2011. Available from http://www.roboearth.org/project-scope . Internet. Retrieved 21 January 2012.
2. Myrobots.com
3. Cloud Robotics: Connected to the Cloud, Robots Get Smarter by Erico Guizzo. 24 January 2011. Available from http://spectrum.ieee.org/automaton/robotics/robotics-software/cloud-robotics . Internet. Retrieved 21 January 2012.
4. Cloud Robotics Google I/O 2011 http://www.youtube.com/watch?v=FxXBUp-4800
5. http://www.forbes.com/sites/alexknapp/2011/12/22/myrobots-com-aims-to-be-facebook-for-robots/
6. http://spectrum.ieee.org/automaton/robotics/robotics-software/is-myrobotscom-the-facebook-for-robots-verdict-maybe