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Cloud Robotics: A Survey

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Abstract: The idea of cloud robotics attracts many researchers mind in the last few years. Cloud robotics is a term combination of cloud technologies with its mass and services which is combined to serve the huge use of robotics applications. The power of robotics is behind the power of cloud which aims in the process of learning and exchanging knowledge, the use of cloud to process heavy tasks allows use of smaller on-board computers in a robot which needs to perform tasks in an accurate real time. So in realistically the Cloud can make robots lighter, cheaper and smaller. This paper surveys cloud robotics in order to give a clear platform in this technology.

Keywords: Cloud robotics, UAV

I. INTRODUCTION

Cloud Robot can be defined as a system that depends on data or code from a network to support its operation this definition points to future systems and many existing systems that include networked teleoperation or networked groups of mobile robots such as unmanned aerial vehicles (UAVs) [1].

The term cloud Robotics were first introduced by James kuffner In 2010 at google his aim was to introduce a new approach to robotics that takes advantage of the internet as a resource for widely parallel computation and real time sharing of huge data resources [2], in other hand the success of cloud robotics research would help existing and future robotics applications to evolve more as one of the standard service which are based upon cloud Computing. According to the previous introduction we shall points upon three terms namely cloud computing, robotics and cloud robotics.

The cloud robotics is an expression consists of two main terms , the first term is the cloud which is a model for enabling ubiquitous, convenient and on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction , the second term is the robotics which is known as a reprogrammable, multifunctional manipulator designed to move material, parts and tools or specialized devices through various programmed motions for the performance of a variety of tasks .

Finally the term Cloud Robotics can be thought as the term that covers the use of remote computing resources to enable greater memory, computational power, collective learning and interconnectivity for robotics applications [3].

This paper is organized as follow section two points upon literature survey , section three studying cloud computing ,section four focuses on robots as a service ,section five talks about the applications of cloud robotics and finally section six conclude the paper .

II. LITERATURE SURVEY

In our literature survey a twelve cited scientific researches were taken in chronological order and it is referred to by the reference number.Reference [4] defines and describes network robot systems (NRS) projects in Europe and Japan also it represents a summarization of other works on this field, the authors considers distributed systems of networked robots and they proposed an approach to automatically generate at run time a functional configuration of a network robot system to perform a given task in a given environment, showing how dynamically they change this configuration in response to failures. Their approach is based on artificial intelligence planning techniques, also they mentioned that their configuration planner can be combined with an action planner to deal with tasks that require sequences of configurations, the authors illustrates an approach on

a specific type of network robot system called Peis-Ecology, showing experiments in which a sequence of configurations were automatically generated and executed on real robots systems.

Zhang et.al [5] has presented a reusable and customizable cloud computing architecture called cloud computing open architecture (CCOA).Larry and Sergey [6] developed technology for cars that can drive themselves, these automated cars manned by trained operators which have been logged over 140,000 miles, the automated cars uses video cameras, radar sensors and a laser range finder to "see" other traffic as well as detailed maps.Priyanki et.al [7] shows that cloud or internet services aren't dependable for robots to share services over network only but also would optimize the research efforts.Salvini et.al [8] introduces dust bot project which is two types of robots cooperate with external sensory systems to provide two services: door-to-door garbage collection on demand, street cleaning and sweeping.

k. kamei et.al [9] discuss the concept of Cloud Networked robotics, which targets continuous support of daily activities that cannot be satisfied by stand-alone robotic services or by networked robotic services, the Key research challenges were described through an examination of typical daily activities also some challenges in cloud networked robotics were described in this work, but it was found that still many other aspects to be studied such as scalability and dependability.

Ben Kehoe et .al [10] Cloud based object recognition and grasping were discussed, the authors shows that object recognition is performed in the cloud using a variant of the Google Goggles proprietary object recognition engine.

Daniel Lorencik et .al [11] describes the main advantages of cloud computation in terms of scalability, on-demand performance, storage, availability and parallel computing. Gary A et .al[12] takes an overview of current trends in image recognition and cloud robotics, showing how to combine image recognition features with cloud robotics technology.

Basit Qureshi et .al [13] discussed robots and automation systems by summarizing cloud robotics into five types for performance enhancement in robotics and autonomous systems as follow: 1) Remote Brain 2) Big Data and Shared Knowledge-base 3) Collective Learning, 4) Intelligence and Behavior 5) Cloud architectures. Bishwadeep mainaly et .al [14] Elaborate how cloud provided service to robotic applications and highlighting the challenges in cloud robotics.Guoqiang Hu et .al [15] shows how robots shares computation resources, information , data with each other and accessing new knowledge and skills not learned by them.

III. STUDYING CLOUD COMPUTING

Cloud computing is a type of computing that relies on sharing, it can also be thought as the delivery of computing services over the Internet. Cloud services allow individuals and businesses to use software and hardware that are managed by third parties at remote locations as shown in fig.1. Cloud computing is not something that suddenly appeared overnight, this may be due to a time when computer systems were sharing resources and computer applications remotely. Currently, cloud computing represents many services and applications offered through the internet [16].

Fig.1 Cloud computing [17].

Cloud computing architecture, is just like any other system, which is categorized into two main sections which are Front End and Back End. Front end can be an End –User, Client or any application which is using cloud services, while Back End is the network of servers with any computer program and data storage system. Some of the cloud computing providers including Amazon, Google, Yahoo, Microsoft and others that are providing cloud computing services as shown in figure.2.

Fig.2 Cloud Computing Provider [17].

The main aspect in Cloud computing is that it provides a variety of services to the customers and these services include emails, storage, software-as-a-services and infrastructure-as a services [17]. These important points will be clarified into three main points that need to be understood to clarify the nature work of cloud computing:

A. Cloud Computing Characteristics

The main characteristics that cloud computing offers today are:

1. Cost: cloud computing is cost-effective, where the cost is reduced more than the other computing systems.
2. Virtualization: technology allows servers and storage devices to be shared and utilization is increased.
3. Reliability: it is improved if multiple redundant sites are used, which makes well-designed cloud computing suitable for business continuity.
4. Security: could improve due to centralization of data, increased security-focused resources.
5. Maintenance: maintenance of cloud computing applications is easier because they do not need to be installed on each user's computer and can be accessed from different places.

B. Cloud Service Model

Cloud computing is a term that describes a broad range of services and can be classified into three main categories as shown in figure.3:

1. Infrastructure as-a-Service (IaaS).
2. Platform as-a-Service (PaaS).
3. Software as-a-Service (SaaS).

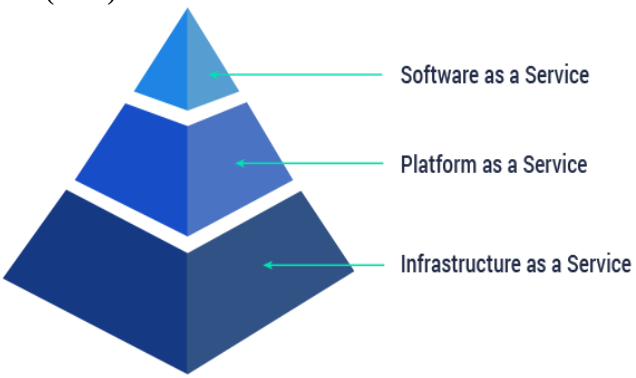

Fig 3.Cloud computing service models [17]

1. Infrastructure as-a-Service (IaaS)

This model is used to access essential IT resources, which includes services that are linked to resources of computing, data storage and the communications channel.

2. Platform as-a-Service (PaaS).

It is a computing platform that allows creation of web applications easily without the complexity of maintaining the software and it is also a delivery model where a Cloud Service Provider (CSP) provides an online software development platform for an organization.

3. Software as-a-Service (SaaS).

SaaS is software that is developed over the internet andit is a delivery model where the software, associated data are hosted in a cloud environment by a third party such as CSP.

C. Cloud Deployment Model

Depending on the organizational structure,the cloud services can be deployed into four primary models as follow:

1. Public Cloud: the cloud infrastructure is provisioned for open use by the general public.
2. Private Cloud: the cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers. It may be owned, managed, and operated by the organization, a third party or some combination of them and it may exist on or off premises.
   We have used this model as described in reference [17], our work in [17] shows a cloud computing system based military application depends on UAVs and military network instead of the internet.
3. Community Cloud: the cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns. It may be owned, managed or operated by one or more of the organizations in the community.

Hybrid Cloud: The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community or public) that remain unique entities, bound by standardized or proprietary technology that enables data and application portability.

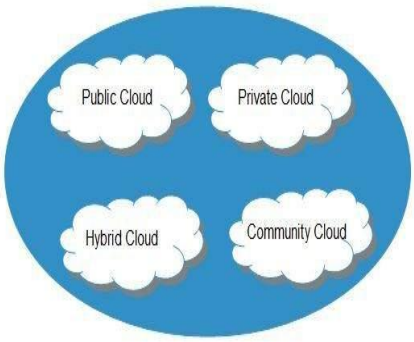

Fig 4.Cloud computing types [17].

IV. ROBOT AS A SERVICE

A robot is a basic assumption of intelligent physical devices or in other word it is a system which by its specifications and appearance or movements conveys a sense that it has intent or agency of its own [28]. There are five essential characteristics representing the basis of understanding cloud robotics:

- On-demand self-service
- Broad network access
- Resource pooling
- Rapid elasticity
- Measured service

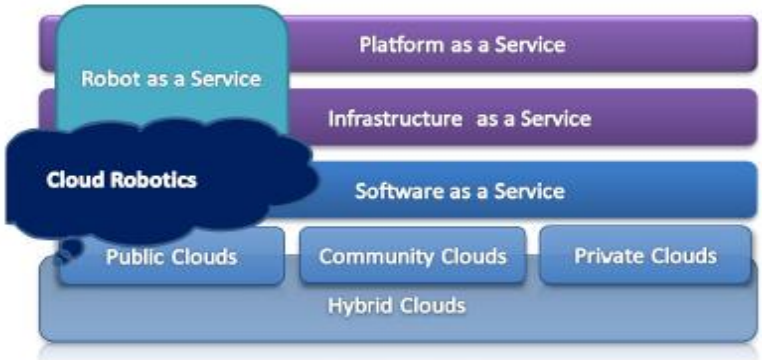

Fig. 5 Cloud computing service models extended with the service layers provided on the top of the cloud, topped by the concept of robot as a Service and cloud robotics [28].

The cloud robotics represents the need for fast, reliable and ubiquitous network connections where the internet infrastructure has gone through radical changes in the past 10 years in terms of bandwidth and Quality of Service and it is now able to support the cloud reliably. As shown in fig.6 using the Cloud for robotics and automation systems introduces many new challenges as discussed in reference [19] such as connectivity. The connectivity inherent in the Cloud raises a range of privacy and security concerns, so that many of these regulations mandate particular controls such as strong access controls and audit trails but require regular reporting [20]. Cloud customers must ensure that their cloud providers adequately fulfill such requirements as appropriate, enabling them to comply with their obligations.

Fig.6 Cloud Robotics [19].

The most important and valuable type of robotics is mobile robotics. A mobile robot is an automatic machine that is capable of mobility. Mobile robots have the capability to move around in their environment and are not fixed to one physical location. Mobile robots can be "autonomous" which means that they are capable of navigating an uncontrolled environment without the need for physical or electro-mechanical guidance devices. Alternatively, mobile robots can rely on guidance devices that allow them to travel a pre-defined navigation route in relatively controlled space (AGV - autonomous guided vehicle). Mobile robots have become more commonplace in commercial and industrial settings for example hospitals have been using autonomous mobile robots to move materials also it is found in industrial, military and security settings[23]. JMR Alamo et.al proposed a mobile cloud robotics architecture that's integrates concepts from cloud robotics and mobile cloud for practical and pedagogical purposes they designed the architecture to work with the popular and relatively inexpensive Lego NXT robot as shown in Fig.7 and Fig.8, the idea is to allow the robots to communicate among themselves and also to connect to a cloud computing platform [23].

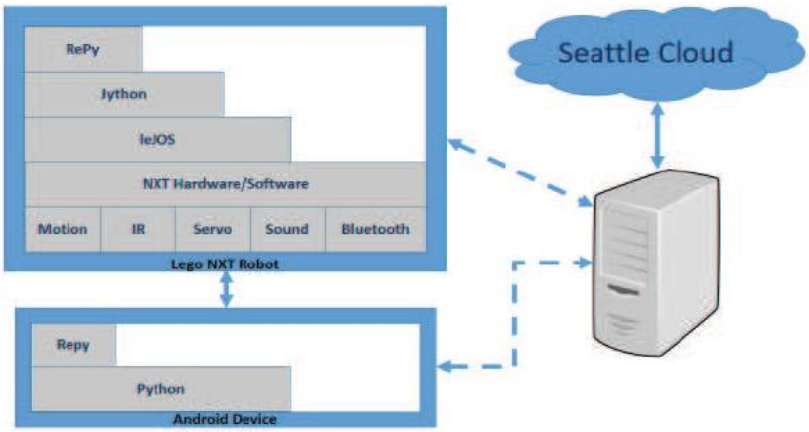

Fig 7. Hybrid Lego NXT Mobile Cloud Robotics Architecture [23].

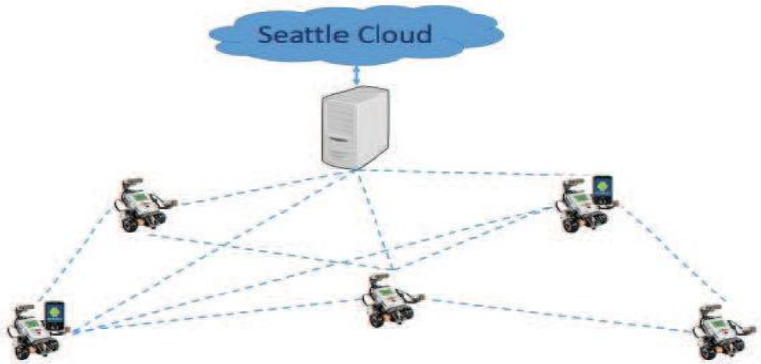

Fig. 8 Network of Robots for Hybrid Lego NXT [23]

V. APPLICATIONS OF CLOUD ROBOTICS

Cloud Robotic is a fascinating research topic, yet it has to identify its target applications and finds its particular domains. It is believed that CR is a way to introduce cognition into the domain of robotics, which is envisioned and strongly supported by the European Union through the FP calls. A possible area where CR may appear is of home robots, built on the thin-client model where the devices use the cloud infrastructure for distributed computing and storage.Also to show the applications of cloud robotics the experiments designed on the Google Object Recognition Engine and the PR2 robot have been conducted showing the important of cloud robotics in the field of object recognition [24], but the most promising application areas of service robotics are healthcare and homecare this was found by notice various new systems that have emerged, supporting minimally-invasive tele surgery or telepresence robots acting as a remote agent for a visiting doctor. However, due to the criticality of the tasks (in the case of any adverse events) medical applications are reluctant to trust task-computation on the cloud.Nevertheless, homecare is a much more promising application, where many of the daily tasks of the aging people should be taken over by robots [25].

In the case of autonomous Unmanned Arial Vehicles (UAV), the cloud is an important element allowing the reduction of on-board computational requirement and thus the amount of battery [26].

Another possible yet far-fetched domain of CR is space research, since we have already deployed thousands of satellites and deep space vessels with various computational capabilities it would be beneficial to recollected these devices into a distributed space computing network that could support data processing and situation analysis, or other future exploration tasks involving robots [27].

VI. Conclusion

Cloud robotics is an evolutionary jump for robots, a transformational change of paradigm, where the communication with peers (robot-to-humans) has become an essential characteristic of a system, it all has become possible through extension of physical limitation of a single agent using the resources of the cloud.

At the current stage of development, robots can use their sensory information—including cameras, sonars, 3D scanners—to perform extended search on large data bases and the internet to identify any unknown object or situation they may encounter. Then, they use this online knowledge to create a plan how to deal with the situation.

The results for that action are fed back to the cloud so other systems can immediately get access to the knowledge, this distributed problem-solving and knowledge-sharing is the essence of CR and the approach could be extended generally to any CPU-heavy task.

In the foreseeable future, a swarm of simple robots and robotic devices will join a CR network, exploiting the advantage of cloud technologies, we shall witness the rise of distributed intelligence in robotics that allows the creation of a global database for navigation, mapping, and planning task execution and beyond. The increasing number of robots with up to date knowledge will become a true helping hand for humans.

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