International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)
Web Site: www.ijettcs.org Email: editor@ijettcs.org
Volume 4, Issue 5(2), September - October 2015 ISSN 2278-6856

Cloud Computing in Robotics and Automation Systems

Prof. Mayur Raut[1], Aniket Sinkar[2]

[1]Asst. Professor, Department of Electronics and Telecommunication Engineering, SIT, Lonavala, Pune, Maharastra, India

[2]B.E. Student, Department of Electronics and Telecommunication Engineering, SIT, Lonavala, Pune, Maharastra, India

Abstract

With the use of cloud infrastructure and its protocol set of IOT, resources have the capability to provide benefits to robots and automation system. The operation of robots and automation systems are considered to be relying on data through network to support. This survey is organized around four potential benefits: 1) Big Data: access information of images, trajectories and descriptive data; 2) Cloud Computing: demand for statistical analysis, learning and motion planning is done through parallel grinding; 3) collective robot learning: robot sharing trajectories, control policies and outcomes; 4) Human computation: It is use to tap human skills for analyzing images and video, classification, learning, error recovery by using crowd sourcing. We can also improve robot and automation system using cloud by providing access to a) Datasheets, publication, models, benchmark and simulation tools b) open competition for design and system and c) open source software.

Keywords: Internet of Things, Robots and Automation System, Cloud Computing, RoboEarth.

I. Introduction

In Fig.1, broad range of robots and automation system are enhanced by cloud computing. The cloud is defined as "a enable ubiquitous, convenient, on demand network access to shared pool of configurable resources that can be rapidly provision and released with minimum management effort or service provider interaction" by NIST (National institute of Standard and Technology)[115].Google docs who offered online word processing are example of cloud. One can send Microsoft word document over internet but document and software reside locally in Google Docs. With the help of remote server farm, shared data and memory data and code are stored on cloud. Using that one can be free from tension in maintenance, outages, software or software updates. The economies of scale and sharing of data between applicants and user are also provided by cloud [122].

It is broadly defined as data or code from network which is used by robot and automation system to support in operation i.e. where not all measures are integrated on standalone mode. It include many existing system that are involved network teleoperation such as UAVs [100],[116]or warehouse robots[44],[96] and advanced assembly lines, processing plants, home automation and human perform computation system[132],[155]. Because of latency of network, variable quality of service downtown, local processing for low latency responses and periods where network access is unavailable is included by cloud robot and automation system.

The best exemplifies the idea of cloud is Google self-driving car. It contains the information such as maps, images and street views, crowd sourcing collected from satellite for accurate localization. Another idea exemplified is the Kiva system pallets robots which are used in warehouses logistics. Robots are connected wirelessly to control server coordinate routing and share updates on detected environment. James Kuffner defined term 'Cloud Robotics' with potential benefits in 2010[98].The article in IEEE Spectrum follow quickly[70] and Steve Cousins summarize the concept 'No Robot in an Island' in next section.

Fig.1. The use of Wireless networking, Big data, Cloud Computing, statistical machine learning, open source, cloud has potential to generate new robots and automation system to improve performance in wide variety of application such as warehouse logistics, caregiving, package delivery, housekeeping and surgery.

The survey organized around four potential benefits are as follows:1)Big Data: access information of images, trajectories and descriptive data; 2) Cloud Computing: demand for statistical analysis, learning and motion planning is done through parallel grinding; 3) Collective robot learning: robot sharing trajectories, control policies and outcomes; 4) Human computation: It is use to tap human skills for analyzing images and video, classification, learning, error recovery by using crowd sourcing.

II. HISTORY IN BRIEF

Before 30 years, the value of network to connect machines in manufacturing was recognized. General Motors

International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)
Web Site: www.ijettcs.org Email: editor@ijettcs.org
Volume 4, Issue 5(2), September - October 2015 ISSN 2278-6856

introduces manufacturing Automation Protocol (MAP) developed in 1980[80].WWW popularized the HTTP over IP protocol in 1990, a diverse set of incompatible proprietary protocols by vendors [121].

A series of web interfaces to robots and devices for exploration of issues such as user interface and robustness was developed by researchers in late 1990[64], [65] that initiated another sub-domain field named ‘Network Robotics [66], [112]. In 1994 the first industrial robot connected to the web using graphical user interface that can operate by any visitor by inter browser [63]. Work by inabaet.al on “Remote Brained Robots” described advantages of remote computing in robot control which happens in 1997[79]. The establishment of technical committee on network robots by IEEE robotics and automation society that organized large number of workshops in May 2001[10].The chapters on robotics such as network tele-robots and network robots detailed in Springer Handbook [99],[143].

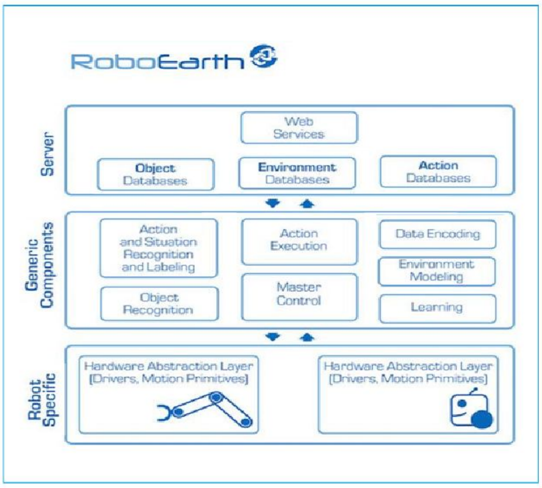

Fig.2. The RoboEarth architecture design for the purpose of robots for sharing data and learn from each other [22][156].

The RoboEarth project which explains “information is shared and learned by robots from each other through giant network and database, in WWW of robots” announced in 2009 [22], [156] as illustrated in Fig. 2 .The RoboEarth team developed system architecture for service of robotics [30], [53] developing cloud network [74], [87] and computing for the purpose of generation of 3D environment models and speech and face recognition under European Union Grant [148].

The broader term ‘Cloud Robotics’ which is introduced by James Kuffner in 2010, supplanted earlier terminologies and has been adopted term by many researchers. How RFID and inexpensive processors could incorporate for share information and communicate each other in vast array of robots and physical objects from inventory to household items [110] described by term ‘Inter Of Things’ [32] which introduced in 2010.

Term “Industry 4.0” which introduced in Germany in 2011, predicts a fourth revolution, it will use network for: 1) Mechanization of production using water and steam power. 2) Mass production using electric power and 3) to automate production use of electronics in industrial revolution [11]. GE (General Electric) describes new efforts where equipment’s such as wind turbines, MRI connect over network to share information and data to help industries like energy transportation and healthcare [55], [93].GE describes this term as a ‘Industrial Internet’ introduced in 2012. The example of industrial internet is optimizing of fuel consumption under any myriad condition [59]. For optimization of fuel consumption in aircraft engines GE uses sensor readings under myriad condition. The big data and cloud computing is used in many industries [25], [113] and being used for optimization of water usage for irrigation [52].

III. BIG DATA IN CLOUD

The vast amount of resources of data which are not possible to maintain in onboard of the robot and automation of the system provided by cloud. The data which extends the processing capacity of conventional systems is called big data. Big data includes images video maps, real time network and financial transactions [102] and vast network sensors [159]. A summary made by U.S National Academy of Engineering that research opportunities and challenges are created by big data [41]. Sampling algorithm is their example. They can provide reasonable approximation to queries to keep running time manageable on data sheet but dirty data is affected those approximations [38], [58], and other challenges are summarized in [29] and [165]. Hunter et al. [77] presents mobile millennium for cloud based transition which uses mobile GPS for gathering information and process it for distribution. It also collect and share data about noise level and air quality (See Fig. 3).

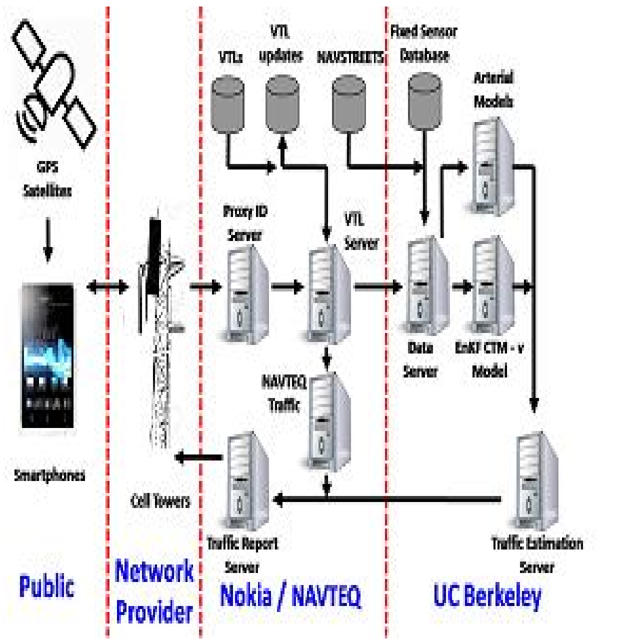

Fig.3. The architecture of Mobile Millennium shows that data can be collected from many sources; it uses Big Data and collective robot learning aspect for cloud robotics and automation system.

Machine learning facilitates large datasheet that demonstrate in context of computer vision. Object and scene recognition use large scale classes datasheet such as ImageNet [50], PASCAL visual object datasheet [56], and others [142], [151] by leveraging Trimble's sketch up 3D ware houses. Manually labelled training data need reduced by Lai et al [101]. Augmented reality application with processing in cloud created with the community photo collection [57], Grammer et al, a object learning technique [72] which is more robust can be provided with the help of combination of internet images with local human operator by querying hidagu pena et al. Multilayer neural network which take advantage of big data [49] is used by deep learning. It is also used for computer vision [97], [140] and grasping [104].

There are some persistent challenges in Robotics, one of them is grasping [40], [120], that determines optimal way to grasp a newly encountered objects. Incremental learning of grasp strategies is facilitated by cloud resources in 3D CAD models online database by matching sensor against it. Examples of sensor data include 2D image feature [75], 3D feature [68] and 3D point clouds as well as demonstrations [94].

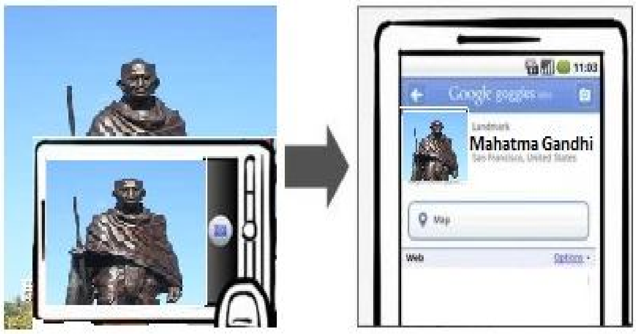

Fig.4. Google's object recognition system facilitates object recognition in the Cloud and it combines enormous datasheet of images and textual labels.

A free image recognition system that is Google Goggles [9] incorporates into a cloud system for the usage of Robot grasping [89] (See Fig. 4). For application such as object recognition to grasping and manipulation [156], the data related to objects and maps are stored by RoboEarth project, and for evaluation of different aspects of grasping algorithms [45], [46] the database is available online that includes grasp stability, robust grasping [162] and scene understanding [128].The e.g. of databases are The Columbia Grasp Datasheet [67], the MIT KIT datasheet [88], the Willow Garage Household Object Datasheet [40]. A cross platform formats for representing data has been defined. Research challenge sensor data like images and point clouds has few number of widely used formats, trajectories relatively simple data has no common standards[129],[147], [149]. Another challenge is working with sparse representation which is used for efficient data transmission. Example of sparse representation is sparse motion planning for Robotic and Automation systems [51], [105].

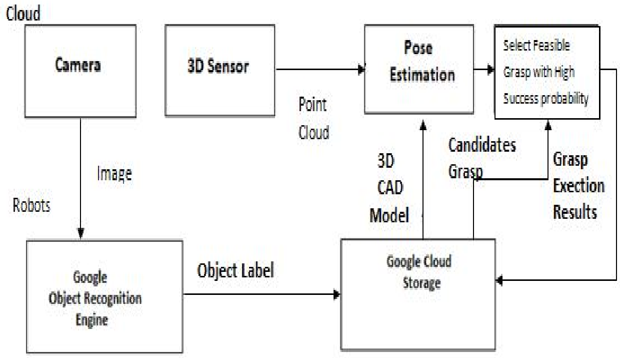

Fig.5. Cloud based object recognition for Grasping. Robots capture the image, and then send it to the Google object recognition server. After processing the image and return data for set of candidate objects with precomputed grasping options, Robot compares CAD models and detected point cloud to refine identification and then perform pose estimation and selects an appropriate grasp. After grasp, execution data on outcome is used to update models in cloud for future reference.

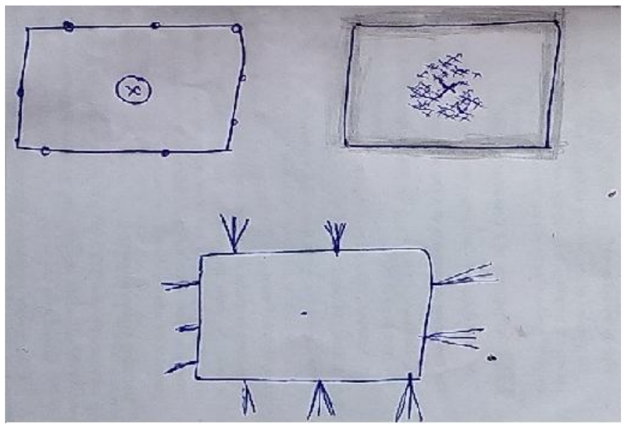

Fig.6. Geometric shape uncertainty grasping using cloud. On top, uncertainties in objects pose and shape.

The large number of datasheets which is collected from different types of sources is 'dirty' with erroneous, duplicated or corrupted data. The example is 3-dimensional position data collected at time of calibration [111]. The robust new approaches are required for dirty data.

IV. CLOUD COMPUTING IN BRIEF

Amazon's elastic compute cloud [1], [2],Google machine cloud [8], Microsoft's azure [12] are the commercial sources which makes wide availability of parallel computation on demand for the purpose of short term computing task [105], [106]. The access is provided to the thousands of remote processors by this system. First these services mainly used by only application developers, but now it used in scientific and technical high performance computing application [20], [86], [114], [152]. Sensing, models and control uncertainty which can be modeled as perturbation in position, orientation, shape and control is central issue in Robot and Automation system [62].The parallel cloud computing can be used in medicine [157]

International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)
Web Site: www.ijettcs.org Email: editor@ijettcs.org
Volume 4, Issue 5(2), September - October 2015 ISSN 2278-6856

and particle physics [141] by computing outcomes of cross product of many possible perturbation in objects and environment pose, shape and robot response for sensors and commands [154]. The compute robust grasp in presence of shape uncertainty is possible with the help of cloud based sampling [90]-[92] (see Fig. 6). By using
Nominal polygonal outline with Gaussian uncertainty around each vertex and center of mass act as an input and it uses parallel sampling to compute a grasp quality matric on lower bound on a probability of achieving force closure.

Robot navigation by performing SLAM in the cloud and next view planning for object recognition and many more computationally intensive Robotics and Automation systems application can be speed up using cloud computing [134], [135]. The demonstration of cloud based formation of ground robots is also possible [153]. Generation of graphs is done by optimal sampling based motion planning methods such as RRT. The algorithm for graph reduction is needed to facilitate data transfer.

The video and image analysis [123], [137] and mapping [119], [136] are also facilitating by cloud. The architecture for efficient planning, the motion of new robot manipulators designed for the purpose of flexible manufacturing floors in which robot and cloud are two parts of computation is proposed by Beckris et al [33].

Some applications such as decluttering room, pre-computing grasp strategies or offline optimization of machine scheduling are not time sensitive, but many has real time demand. It is important to acknowledge that cloud is connected to varying network latency and quality of the service [26], [27], [95], [109].

V. COLLECTIVE ROBOT LEARNING

Cloud collecting of data from many instances such as physical trails and environments for sharing it for robot learning. The example of sharing of data is the system share conditions i.e. initial and desired conditions to control policies associated with it and trajectories and most importantly data on resulting performance and outcomes.

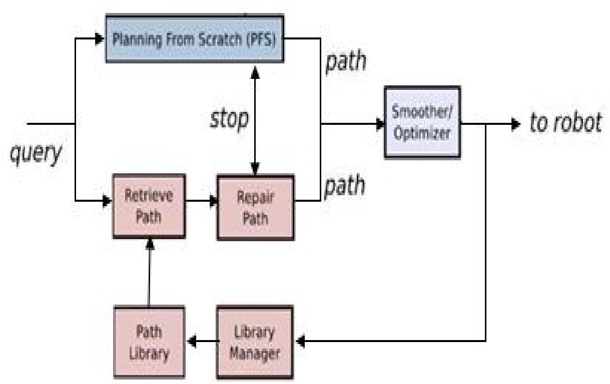

Fig.7. Lightning path planning framework architecture.

The process of collective robot learning by collecting trajectories from many different robots over many tasks and it uses cloud computing for purpose of parallel planning and trajectory adjustment is called 'lightning' [35](See Fig. 7).

Global network also expects such systems for path planning including traffic routing (See fig. 8). For grasping purpose [37], the stability of grasping can be learning from previous grasp on objects. The capabilities of robots with limited computational resources can improved with the help of collective robot learning. My Robot project [13] which is introduced by Roboshop, proposes 'Social network' for robots. The way human benefits from sharing, collaborating and socializing, the robot can be benefited same way by sharing sensor information on giving insight on their perspective of current state [21].

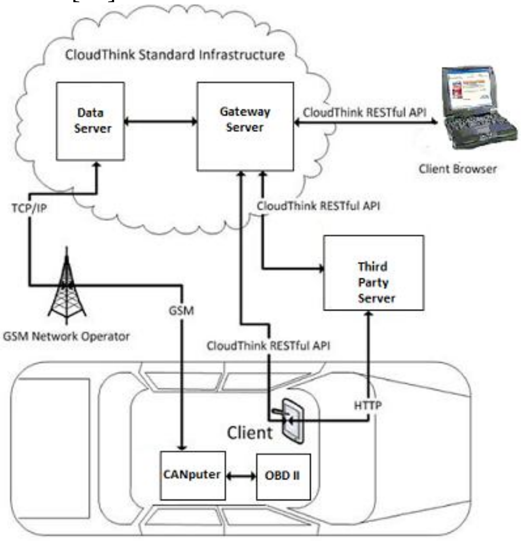

Fig.8. Cloud Think architecture, an open-standard for self-reporting sensing device such as sensors mounted on automobile developed by Wilhem et al. Cloud-enabled sensor network data can be enabled for collaborative sharing of data for traffic routing.

The datasheets such as RoboEarth and Robobrain are updated with the information from connected robots. The Robobrain project can be learning from internet by available resource, simulation and real life robots trails publically [16]. For the purpose of movement of pallets in warehouse KIVA system [44], [96] uses hundreds of mobile with the help of local network to coordinate motion and tracking data.

VI. CROWDSOURCING AND CALL CENTERS

Problems like image labeling for computer vision, learning association between object labels and location can be solved using human skill, experience and intuition [40], [87], [98], [155]. The task which exceeds capabilities of computer is performing human workers in Amazon's mechanical Turk pioneering 'crowdsourcing'. Consider a future scenario where the errors and exceptions reported and detected to humans by Robot and Automation system, instead of automated telephone reservation system.

Leepar et al. developed an interface to grasp execution for operators using a set of different strategies. The result indicates, humans can select more robust and better grasp strategies. The research exploring, how these things used for the purpose of path planning to determine depth layers [73], [82], image normal and symmetry for images [61] and to refine image segmentation. Researchers are working on understanding of pricing models and apply crowd sourcing to grasping knowledge based solution for industrial automation [146]. It has been long history of network robotics in which robots remotely tele-operated by humans on web [63] and expanded resources of cloud and enables new research into remote human operations [103], [144], [164] (See Fig 9).

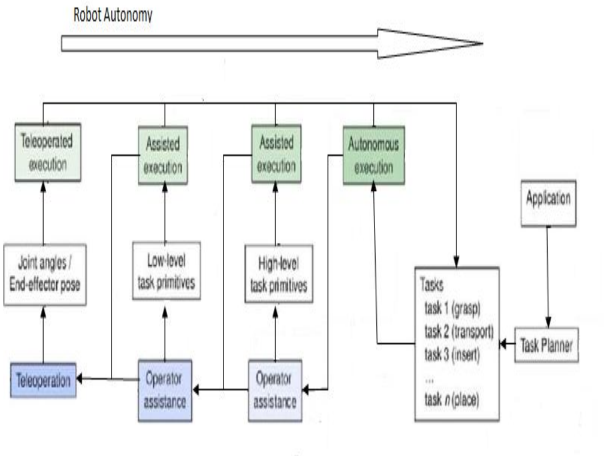

Fig.9. Teleoperation for Tiered human assistance using cloud-based resource.

VII. OPEN-SOURCE AND OPEN-ACCESS

The evolution of cloud robotics and automation is supported by cloud by facilitating human access to: 1) publications, simulation tools, benchmark and models. 2) For design and system open competition and 3) open source software.

The Robot Operating System (ROS) which help software to create robot application by providing libraries and tools [14], [18], [131]. ROS is example of open source software [42], [124] which is widely accepted by community. The ROS is ported to android devices [19], it has been standard akin to Linux and widely used in robot research industry, with ROS industrial project created to support these users [17].The simulation libraries for robotics are open source now which help students and researchers to set up and adapt new system rapidly and sharing of software becomes easy. There are many open simulation libraries such as “Bullet” which is used in video games as a physical simulator [4]. OpenRAVE [15] and Gazedo [7] are open source simulation libraries. The simulation environments specifically geared towards certain application which are OOPSMP,a motion planning library [127] and GraspIt. The nature of open source of these libraries allows them to modify to suit application which they are not originally design for.

The open source hardware, CAD models and technical details of construction are freely available [47]. The Arduino project [3] in which many different sensors and different actuators are available is widely used open source microcontroller. The RAVEN [71] an open architecture laparoscopic surgery robot is developed as research platform and less expensive than commercial surgical robots [23]. The 3D printing majorly impact on open source hardware design and many other fields [60], [81], [108]. Open challenge and design competition for diverse and geographically distributed population innovators facilitates by cloud.

A competition of robot system and software teams to develop robots capable of assisting human in responding to natural and man-made disaster is called as DARPA. Robotics Challenge (DRC) is supported by NIST and Southwest robotics institute [24]. The DRC simulator is given to all contestants through open source cloud based simulation platform for testing the performance of Atlas humanoid robots on variety of disaster response task [5], [7]. The task such as running interactive, real time simulation task in parallel for purpose such as predicting and evaluating performance, validating design decision and training users are permitted by cloud [28].

Ultra affordable educational robot challenge organized by American robotics network with support of IEEE Robotics and Automation society in summer 2012. It activated overly 28 designs including the modified surplus SONY game controller uses vibration motor to drive wheels and lollipops for inertial counterweight for contact sensing by thumb switches. The SONY controller is grand prize winner.

VIII. CHALLENGES AND FUTURE DIRECTIONS

The connectivity inherent in cloud raises range of privacy and security concerns [133], [139]. The data generated by cloud connected robots and sensors is included in those concerns, because they include data like images and video from private homes and corporate trade secretes [130], [161].The potential of Robots and systems attacked remotely is introduced by cloud. Researchers at university of Texas at Austin demonstrated that hack and remotely control UAV drones is possible via inexpensive GPS spoofing systems in evaluation study of Department of Homeland Security (DHS) and Federal Aviation Administration [76]. These concerns raise the new regulatory, accountability and legal issues related to the safety, control and transparency. For ethics and policy research “We Robot” conference organized annually [160].

To cope up with time varying network latency, quality of service is needed with new algorithms. Faster data connection both wired and wireless reducing latency, but algorithms must be designed in such way that degrade gracefully when cloud resources are very slow, noisy and unavailable. The best example of that is “anytime” load balancing algorithms which is used for speech recognition in smart phones. It sends the speech signal to cloud for analysis and simultaneously process it internally and use best results available after delay [35]. When cloud is used for parallel-processing, it is invigorating that algorithms oversample take into account that some remote processors may fail or experience long delays in returning value. Algorithms are needed to filter unreliable input and balance the cost of human intervention when human intervention is used.

The framework is required for moving Robotics and automation algorithm into cloud that facilitates this transaction. The cloud provides three possible levels for frameworks implementation. Infrastructure as a Service (IaaS) is a lowest level, in which bare operating system (OS) are provided on machines in cloud. The second level is, Platform as a Service (PaaS) which provide more structure, including application framework and database access, when restricting the choice of programming language and database models. Software as a Service (SaaS) is the highest level, exemplified by difference between Google Docs, a Cloud based word processor and Microsoft word, which is downloaded and installed locally.

Rapyuta which is a cloud computing platform included by RoboEarth project [118], is a PaaS framework for movement of computation off of robots to Cloud. The PaaS aspect can be extended to use the SaaS paradigm, which offers many advantages to robots and automation system. A data to be sent to a server allows by an interface with the help of SaaS that processes it and returns outputs, which relives of the burden to maintain data and software and allow companies to control proprietary software. This approach is called Robotic and Automation as a Service. Consider to Scenarios for a Graduate student setting up a robot work cell. Work cell purpose is to pick up and insect parts as they come down an assembly line, that requires object recognition and localization, grasp planning and motion planning. The work cell consists of a 7-DoF Fanuc industrial arm with parallel-jaw gripper and a Microsoft Kinetic RGBD sensor.

In Scenario 1 (with ROS), the software runs locally. The well-known open source library of robotic software ROS provides access to over 2000 open source ROS packages. Currently only Ubuntu Linux operating system supports ROS. Because of Ubuntu is popular, the graduate student's computers run OSX. Some softwares are only available as a source distribution, which requires download and installation of dependencies, but many ROS packages are provided for the purpose of simplified installation. The graduate student must set up a new machine with Ubuntu and resolve all library dependencies.

REFERENCE

[1] "Amazon Elastic Cloud (EC2)." [Online]. Available: http://aws.amazon.com/ec2/
[2] ‘'Amazon Web Services" [Online]. Available: http://awsamazon.com
[3] “Arduino." [Online]. Available: http://www.arduino.cc
[4] ‘'Bullet Physics Library." [Online]. Available: http://bulletphyScs.org
[5] "CIoudSim." [Online]. Available: http://gazebosi m.org/wiki/CI oudS m/
[6] For Big -Data Scientists, Janitor Work Is Key Hurdle to Insights."[Online].Available:http://www.nytimes.com/2014/08/18/technology/for-big-data-scientists-hurdle-to-insights.is.janitor-work.html
[7] " Gazebo." [Online].Available: http://gazebosim.org/
[8] “Google Compute Engine." [Online]. Available: https://cloud.google.com/productscompute-engine
[9] "Google Goggles" [Online]. Available: http://www.google.com/ mobilelgoggles/
[10] "IEEE Networked Robots Techni cal Committee." [Online]. Available: http://www-uwrscsumn.eduLider/td
[11] "Industry 4.0." [Online]. Available: http: //www. bm bf.de/erV19955. ph p
[12] “Microsoft Azure." [Online].Available: http://www.win-dowsazure.00m
[13] "MyRobots.com." [Online]. Available: http://myrobots.com
[14] "Open Source Robotics Foundation." [Online]. Available: http: //www.osrfoundation.org
[15] "OpenRAVE." [Online]. Available: http://openrave.org/
[16] " RoboBrain." [Online]. Available: http://robobrai n. me
[17] " ROS- Industrial ." [Online]. Available: http://rosindustrial.org
[18] “ ROS (Robot Operating System)." [Online]. Available: http://rosorg
[19] " Rosjava, an Implementation of ROS in Pure Java with Android Sup- port." [Online]. Available: http://cloudrobotics.00m
[20] "TOP500." [Online]. Available: http://www.top500.org/liati2012/06/100
[21] " What is MyRobots7 [Online]. Available: http://myrobots.com/wiki/about
[22] What is RoboEarth?" [Online]. Available: http://www.roboearth.org/ what-is-RoboEarth
[23] "An Open -Source Robot-Surgeon." The Economist, 2012. [Online]. Available: http://www.economid.com/node/2154£3489
[24] "DARPA Selects Southwest Research Institute to Support DARPA Robotics Challenge: Market Watch, 2013.
[25] Accenture Inc., "A New Era for Energy Companies Cloud Computing Changes the Game." 2012. [Online]. Available: http://www.accenture.com/SiteCollectonDocumentSPDF/Acceriture-New-Era-Energy-Companies-Cloud-Computing-changes-Garne. pdf
[26] B. Added, S. Amari. and J. -J. Lesage, "Analytic calculus of response time in networked automation systems," IEEE Trans Autom. Sol. Eng. (T –A), vol. 7, no. 4, pp. 858-869, Oct. 2010.
[27] B. Added, S. Amari, and J. -J. Lesage, "Client-sarver networked automation systems reactivity: Deterministic and probabilistic analysis: IEEE Trans Autom. sci. Eng. (T –A), vol. 8, no. 3, pp. 540-548, Jul. 2011.
[28] C. Aguero. N. Koenig, I. Chen, H. Boyer, S Peters, J. Hsu. B. Gerkey, S. Paepcke, J. Rivero, J. Manzo, E. Krotkov, and G. Pratt, "Inside the virtual robotics challenge: Simulating real-time robotic disaster response," IEEE Trans. Autom. sci. Eng. (T –A): special Issue Cloud Robot. Autom., vol. 12, no. 2, pp. 494-506, Apr. 2015.
[29] M. Armbrust, I. Soica, M. Zaharia, A. Fox, R. Griffith, A. D. Jowph, R. Katz, A. Konwindi, G. Lee, D. Patterson, and A. Rabkin, "A view of cloud computing," Commun. ACM, vol. 53, no. 4, p. 50, Apr. 2010.

[30] R. Arumugarn, V. Enti, L. Bingbing, W. Xiaojun, K. Baskaran, F. Kong, A. Kumar, K. Meng, aid G. Kit, " DAvinCi: A cloud computing framework for service robots," in Proc. Int. Conf. Robot. Autom (ICRA.), 2010, pp. 3084-3089.

[31] D. Astely, E. Dahlman, A. Furud<a, Y. Jading, M. Lindardm, and S Parkvall, "LTE: The evolution of mobile broadband," Commun. Mag., vol. 47, no. 4, pp. 44-51,2009.

[32] L. Atzori, A. Iera, aid G. Morabito, "The Internet of things A survey," Comput. Netw., vol. 54, no. 15, pp. 2787-2805, Oct. 2010.

[33] K. Bekris, R. Shome, A. Krontiris. and A. Dobwri. "Cloud automa- tion: Precomputing roadmaps for flexible manipulation," IEEE Robot. Autom. Mag.: Special Issue on Emerging Advances and Applications in Automation, 2014, under review.

[34] W. Beksi and N. Papanikolopoulos, "Point cloud culling for robot vision tasks under communication constraints" in Proc. Int. Conf. Intell. Robot. Syst. (IROS), Chicago, IL, USA, 2014.

[35] D. Berenson, P. Abbeel, aid K. Goldberg, "A robot path planning framework that learns from experience," in Proc. Int. Conf, Robot. Autom. (ICRA), May 2012, pp. 3671-3678.

[36] B. Bhargava, P. Angin, and L. Duan, "A mobile -cloud pedestrian crossing guide for the blind," in Proc. Int. Conf. Adv. Cornput. Commun., 2011.

[37] J. Bohg, A. Moraes, T. Asfour, and D. Kragic, "Data -driven grasp synthesis—A survey," IEEE Trans Robotics (T-RO), no. 99, pp. 1-21, 2013.

[38] V. Chandrawkaran and M. I. Jordal, "Computational aid statistical tradeoffs via convex relaxation," Proc. Nat. Acad. sci. USA, vol. 110 no. 13, pp. E1181 -E1190,2013.

[39] M. Ciocarlie, K. Hsiao, E. G. Jones S. Chitta, R. Rusu, and I. Sucan, "Towards reliable grasping and manipulation in household environments" in Proc. Exp. Robot. Int. Symp. (I Delhi, India, 2010.

[40] M. Ciocarlie, C. Pantofaru, K. Hsiao, G. Bradski, P. Brook, and E. Dreyfuw. "A side of data with my robot," IEEE Robot. Autom. Mag., vol. 18, no. 2, pp. 44-57, Jun. 2011.

[41] Committee on the Analysis of Massive Data; Committee on Applied and Theoretical Statistics; Board on Mathematical Sciences and Their Applications; Division on Engineering and Physical Sciences; National Research Council, "Frontiers in massive data analysis," The National Academies Press. Washington, DC, USA. 2013.

[42] L. Dabbish, C. Stuart, J. Tsay, and J. Herbdeb, "Soda coding in github: Transparency and collaboration in an open software repository," in Proc. ACM Conf. Comput. Supported Cooperative Work, 2012, p. 1277.

[43] S. Dali bard, A. Nakhaei, F. Lamiraux, and J. -P. Laumond, "Manipulation of documented objects by a walking humanoid robot," in Proc. I EEE-RAS I nt. Conf. Humanoid Robot., Dec. 2010, pp. 518-523.

[44] R. D'Andrea, "Guest editorial: A revolution in the warehouse: A Retrospective on KIVA systems and the grand challenges ahead," IEEE Trans. Autom. sci. Eng. (T –A), vol. 9, no. 4, pp. 638-639, Oct. 2012.

[45] H. Dang and P. K. Allen," Learning grasp stability," in Proc. Int. Conf. Robot. Autom. (ICRA), May 2012, pp. 2392-2397.

[46] H. Dang, J. Weisz, and P. K. Allen, "Blind grasping: Stable robotic grasping using tactile feedback and hand kinematics" in Proc. Int. Conf. Robot. Autom. (ICRA), May 2011. pp. 5917-5922.

[47] S. Davidson, "Open -source Hardware," IEEE Design Test Comput., vol. 21. no. 5, pp. 456-456, Sep. 2004.

[48] G. de Croon, P. Gerke, and I. Sprinkhuizen-Kuyper, "Crowdsourcing as a methodology to obtain large and varied robotic data sets," USA,2014.

[49] J. Dean, G. Corrado, R. Monga, K. Chen, M. Davin, M. Mao, M. Ranzato, A. Senior, P. Tucker, K. Yang, Q. V. Le, and A. Y. Ng, "Large scale distributed deep networks" in Advances in Neural Information Processing Systems 25, F. Pereira, C. Burgas, L. Bottou, and K. Wkinberger, Eds, 2012, pp. 1223-1231.

[50] J. Deng, W. Dong, socher, L. -J. Li, K. Li, and L. Fei-Fei, " Imagenet: A large -scale hierarchical image database," in Proc. IEEE Conf. Comput. vision Pattern Recognit., 2009, pp. 248-255.

[51] A. Dobson, A. Krontiris, and K. E. Bekris, "Spars roadmap spanners" Algorithmic Foundations of Robotics X, pp. 279-296,2013.

[52] Droplet, "Cloud Powered Water Sprinkler System," 2014.

[53] Z. Du, W. Yang, Y. Chen. X. Sun, X. Wang, and C. Xu, "Design of a robot cloud center," in Proc. Int. Symp. Autom. Decentralized Syst., Mar. 2011, pp. 269-275.

[54] E. Dumbill, "Defining Big Data," [Online]. Available: Forbes Data Driven Blog, 2014

[55] P. C. Evans aid M. Annunziata. "Industrial Internet: Pushing the boundaries of minds end machines," General Electric. Tech. Rep., 2012.

[56] M. Everingham, L. Van Gool, C. K. Williams, J. Winn, and A. Ziswrman, "The PASCAL visual object classes (VOC) challenge," Int. Comput. Vision, vol. 88, no. 2, pp. 303-338,2010.

[57] S. Gammeter, A. Gassmann, L. Bossard, T. Quack, and L. Van God, "Server -side object recognition and client-side object tracking for mobile augmented reality," in Proc. IEEE Conf. Comput. Vision Pattern Recognit.. Jun. 2010, pp. 1-8.

[58] J. Garcia, "Using cloud computing as a HPC platform for embedded systems," 2011, Unpublished work. [Online]. Available: http://www.atc.us.eslclescargaStfmHPCCIoud.pdf

[59] General Electric, "The caw for an industrial big data platform: Laying the groundwork for the new industrial age," 2014. [Online]. Available: httpsllgesoftware.conVIndustrial Big Data Platform.pdf

[60] N. Gershenfeld, Fab: The Coning Revolution on Your Desktop –from Personal Computers to Personal Fabrication. New York, NY, USA: Basic Books, 2007.

[61] Y. Gingold, A. Shamir, and D. Cohen -Or, "Micro perceptual human computation for visual tasks," ACM Trans. Graphics vol. 31, no. 5, pp. 1-12, Aug. 2012.

[62] [62] J. Glover, D. Rus, and N. Roy, "Probabilistic models of object geometry for grasp planning," Robotics &lance and Systems (RS, vol. IV, pp. 278-285,2008.

[63] K. Goldberg, "Beyond the web: Excavating the real world via mosaic," in Proc. 2nd Int. World Wide Web Conf., 1994, pp. 1-12.

[64] K. Goldberg and B. Chen. "Collaborative control of robot motion: Robustness to error," in Proc. I EEE/RSJ Int. Conf. Intel!. Robot. *Syd.*, 2001, vol. 2, pp. 655-660.

[65] K. Goldberg, M. Mascha, S. Gentner, N. Rothenberg, C. Sutter, aid J. Wegley, "Desktop teleoperation via the world wide web," in Proc. Int. Conf. Robot. Autom. (I CRA), Nagoya, J an, 1995, pp. 654-659.

[66] Beyond V1abcams An Introduction to Online Robots, K. Goldberg and R. Siegwart. Eds Cambridge, MA, USA: MIT Press, 2002.

[67] C. Goldfeder, M. Ciocarlie, and P. Allen, "The Columbia grasp database," in Proc. Int. Conf. Robot. Autom. (ICRA), May 2009, pp. 1710-1716.

[68] C. Goldfeder aid P. K. Allen. "Data -driven grasping," Auton. Robot., vol. 31, no. 1, pp. 1-20, Apr. 2011.

[69] B. Gouveia, D. Portugal, D. Silva, and L. Marques "Computation sharing in distributed robotic systems: A case study on SLAM," IEEE Trans Autom. Sci. Eng. (T - ASE): Special Issue Cloud Robot. Autom, vol. 12, no. 2, pp. 410-422, Apr. 2015.

[70] E. Guizzo, "Cloud robotics: Connected to the cloud, robots get smarter." IEEE spectrum Automaton Blog, 2011.

[71] B. Hannaford, J. Rown, D. Friedman, H. King, P. Roan, L. Chang, D. Glozman, J. Ma, S. Kosari, and L. White, "Raven II: Open platform for surgical robotics research," IEEE Trans. Biomed. Eng., pp. 954-959,Apr. 2013.

[72] E. Hidago-Pena, L.F. Mari n-Urias, F. Montez Gonzalez Marin-Hernandez, and H. V. Rios -Figueroa, "Learning from the Web: Recognition method based on object appearance from Internet images" in Proc. ACM/IEEE Int. Conf. Human - Robot Interaction, 2013, pp. 139-140.

[73] J. Higuera, A. X u, F. Shkurti, and G. Dudek, "Socially -driven collective path planning for robot missions," in Proc. Conf. Comput. Robot Mission, May 2012, pp. 417-424.

[74] G. Hu, W. Tay, and Y. V\k.n, "Cloud robotics: Architecture, challenges and applications," IEEE Network, vol. 26, no. 3. pp. 21-28,2012.

[75] K. Huebner, K. Welke, M. Przybylski, N. Vahrenkanp, T. Asfour, and D. Kragic, "Grasping known objects with humanoid robots: A box based approach," in Proc. Int. Conf. Adv. Robot., Munich, Germany, 2009.

[76] Humphreys, Todd, Cockrell School researchers demonstrate first successful 'spoofing' of UAVs," 2012. [Online]. Available: http://www.engr.utexaseduffeatures/h umphreysspoofing

[77] T. Hunter, T. Moldovan, M. Zahari a, S. Merzgui , J. Ma, M. J. Franklin, P.Abbeol,andA. M. Bayen, "Scaling the mobile millennium system in the cloud," in Proc. 2nd ACM Simp. Cloud Compu. (CC), Cawais, Portugal, 2011, pp. 28:1-28:8.

[78] D. Hunziker, M. Gajamohan, M. VVaibel, and R. D'Andrea, "Rapyuta: The roboearth cloud engine," in Proc. IEEE Int. Conf. Robot. Autom. (I GRA), Karlsruhe, Germany, 2013, pp. 438

[79] M. Inaba, "Remote -brained robots," in Proc. Int, Joint Conf, Artif. Intell., 1997, pp. 1593-1606.

[80] J. D. Irwin, The Industrial Electronics Handbook. Boca Raton, FL, USA: CRC Press, 1997.

[81] P. F. Jacobsand D. T. Reid, Rapid Prototyping & Manufacturing: Fundamentals of stereo lithography. Dearborn, MI, USA: Soc. Manuf. Eng., 1992.

[82] A. Jain, D. Das, and A. Saxena, "Planit: A crowdsourcing approach for learning to plan paths from large wale preference feedback," Tech. Rep., 2014.

[83] N. K. Jangid, "Real ti me cloud computing," in Data Manage. Security, 2011

[84] M. Johnson -Roberson, J. Bohg, G. Skantze, J. Gudafson, R. Carlson, B. Rasolzadeh, and D. Kragic, "Enhanced visual wane understanding through human -robot dialog," in Proc. Int. Conf. Intel!. Robot. (I ROS), Sop. 2011, pp. 3342-3348.

[85] S. Jordan, T. Haidgger, L. Felde, and I. Rudas “”the rising prospects of cloud robotic applications" in Proc. Int, Conf. Comput. Cybern. (I CCC), Jul. 2013. pp. 327-332.

[86] G. Juve, E. Deal man, G. B. Berriman, B. P. Berman, and P. Maechling, "An evaluation of the cost and performance of scientific workflows on Amazon EC2," J. Grid Cornput., vol. 10, no. 1, pp. 5-21. Mar. 2012.

[87] K. Kamei, S Nishio, N. Hagita, and M. Sato, "Cloud networked robotics" IEEE Network, vol. 26, no. 3, pp. 28-34,2012.

[88] A. Kasper, Z. X ue, and R. Dillmann, "The KIT object models database: An object model database for object recognition, localization and manipulation in service robotics," Int. J. Robot. Res. (IJRR), vol. 31, no.8, pp. 927-934, May 2012.

[89] B. Kehoe, A. Matsukawa, S Candido, J. Kuffner, and K. Goldberg, "Cloud -based robot grasping with the google object recognition engine," in Proc. Int, Conf. Robot. Autom. (I CRA), Karlsruhe, Germany, 2013, pp. 4263-4270.

[90] B. Kehoe, D. Berenson, and K. Goldberg, "Estimating pal tolerance bounds based on adaptive cloud -bawd grasp planning with dip," in Proc. IEEE Int. Conf. Autom. Sci. Eng. (CA), Seoul, Korea, 2012, pp. 1106-1113.

[91] B. Kehoe, D. Berenson, and K. Goldberg, "Toward cloud – bawd grasping with uncertainty in shape: Estimating lower bounds on achieving force closure with zero -slip push grasps" in Proc. Int. Conf. Robot. Autom. (I CRA). St. Paul, MN, USA, May 2012, pp. 576-583.

[92] B. Kehoe, D. Warrier, S Patil, and K. Goldberg, "Cloud - based grade planning for tolerance parts using parallelized Monte Carlo S9M-piing," IEEE Trans. Autom. Sci. Eng. (TA): Special Issue Cloud Robot. Autom., vol. 12, no. 2, pp. 455-470, Apr. 2015.

[93] J. Kelly, "The industrial internet and big data analytics: Opportunities and challenges," 2013. [Online]. Available: http://wikibon.org/wiki/v/The Industrial Internet and Big Data Analytics%3AOpportunities and Challenges

[94] D. Kent and S. Chernova, "Construction of an object manipulation database from grasp demonstrations," in Proc. Int. Conf. Intell. Robot. ,at. (I ROS), Chicago, IL, USA, 2014.

[95] W. -J. Kim, K. and A. Ambike, "Red -time operating environment for networked control systems" IEEE Trans Autom. Sci. Eng. (T -ASE), vol. 3, no. 3, pp. 287-296,2036.

[96] KIVA, "KIVA Systems," 2014. [Online]. Available: www.kivasystemscom.

[97] A. Krizhevdcy, I. Sutd<ever, and G. E. Hinton, "imagenet classification with deep convolution neural networks: in Advances in Neural Information Processing Systems 25, F.

Pereira, C. Burgas, L. Bottou, and K. Minberger, Eds., 2012, pp. 1097-1105.

[98] J. Kuffner, "Cloud -enabled robots," in Proc. IEEE-RAS I nt. Conf. Humanoid Robot., Nashville, TN, USA. 2010.

[99] V. Kumar, R. Daniela, and G. S. Sukhatme. "Networked robotics," in

[100] V. Kumar and N. Michael, "Opportunities and challenges with autonomous micro aerial vehicles," Int. J. Robot. Res (IJRR), vol. 31, no. 11, pp. 1279-1291,2012.

[101] K. Lai and D. Fox, "Object recognition in 3D point clouds using web data and domain adaptation," Int. J. Robot. Res (IJRR), vol. 29, no. 8, pp. 1019-1037, May 2010.

[102] Q. Le, M. Ranzato, R. Monga, M. Davin, K. Chen, G. Corrado, J. Dean, and A. Ng, Building high-level features using large scale unsupervised learning," in Proc. Int. Conf. Mach. Learn., Vancouver, BC, Canada, 2012, pp. 8595-8598.

[103] A. E. Leeper, K. Hsiao, M. Ciocarlie, L. Takayama, and D. Gossow, "Strategies for human -in -the -loop robotic grasping," in Proc. ACM/ IEEE Int. Conf, Human -Robot Interaction. 2012, pp. 1-8.

[104] I. Lenz, H. Lee, and A. Saxena, "Deep learning for detecting robotic grasps," Int. J. Robot. Res (IJRR), to be published.

[105] Z. Li, L. O'Brien. H. Zhang, and R. Cai, "On the conceptualization of performance evaluation of laaS services" IEEE Trans Services Cornput., to be published.

[106] Z. Li, H. Zhang, L. O'Brien, R. Cai, and S. Flint, "On evaluating commercially cloud services a systematic review" J.sot. soft. Vol. 86, no. 9, pp. 2371-2393.2013.

[107] P. Lin, K. Abney, and G. A. Bekey, Robot Ethics: The Ethical and Social Implications of Robotics Cambridge, MA, USA: MIT Press. 2011.

[108] H. Lipson and M. Kurman, Fabricated: The New world of 3D Printing. New York, NY, USA: wiley, 2013.

[109] B. Liu, Y. Chen, E. Blawh, and K. Pham, "A holistic cloud –enabled robotics system for real-time video tracking application," in Future inform. Technol., 2014, pp. 455-468.

[110] C. -H. Lu and L. -C. Fu, "Robust location -aware activity recognition using wireless sensor network in an attentive home," IEEE Trans Autom. Si. Eng. (T –A), vol. 6, no. 4, pp. 598-609,2009.

[111] J. Mahler, S. Krishnan, M. Laskey, S. Son, A. Murali, B. Kehoe, S. Patil, J. VVang, M. Franklin, P. Abbeel, and K. Goldberg, "Learning accurate kinematic control of cable driven surgical robots using data cleaning and Guassian process regression" in proc. IEEE Int. conf. Autom Sci. Eng. (CA), Taipei, Taiwan, 2014.

[112] G. McKee, "What is networked robotics?: Informatics in Control Automation and Robotics vol. 15, pp. 35-45,2008.

[113] McKinsy Inc., "Big data and the opportunities it creates for semiconductor players," 2012. [Online]. Available : http://www.mckinsy.com/-/media/McKinsy/dotcom/dientseryice/Semiconductordl ssue\Autumnn12012JF0FdBig_data_and_the opportuni- ties it_creates for_semiconductor_players.ashx

[114] P. Mehrotra, J. Djomehri, S. Heistand, R. Hood, H. in. A. Lazanoff, S. Saini, and R. BisNas, "Performance evaluation of Amazon EC2 for NASA HPC applications," in Proc. 3rd workshop on Scientific Cloud Computing Date—science Cloud' 12,2012, pp. 41-50.

[115] P. Melt and T. Grance, "The NIST definition of cloud computing," National Institute of Standards and Technology, 2009.

[116] N. Michael, D. Mellinger, Q. Lindsey, and V. Kumar, "The GRASP multiple micro UAV testbed," IEEE Robot. Autom. Mag., vol. 17, no. 3, pp. 56-65,2010.

[117] A. Miller and P. Allen, "Grasplt! A versatile simulator for robotic grasping," IEEE Robot. Autom. Mag., vol. 11, no. 4, pp. 110-122, Dec. 2004.

[118] G. Mohanarajah, D. Hunzi ker, M. bel, and R. D'Andrea, " Rapyuta: A cloud robotics platform," IEEE Trans Autom. Sci. Eng. (T –A), vol. 12, no. 2, pp. 481-493, Apr. 2015.

[119] G. Mohanarajah, V. Uwnko, M. Singh, M. Waibel, and R. D'Andrea, "Cloud -bawd collaborative 3D mapping in real-time with low-cost robots: IEEE Trans Autom. S. Eng. (T –A): Special Issue Cloud Robot. Autom., vol. 12, no. 2, pp. 423-431, Apr. 2015.

[120] M. MOUS311 and M. Kamel, "An experimental approach to robotic grasping using a connectionist architecture and generic grasping functions," IEEE Trans Syst., Man, Cybern., Part C, vol. 28, no. 2, pp. 239-253, May 1998.

[121] M. Narita, S. Okabe, Y. Kato, Y. Murakwa, K. Okabayashi, and S. Kanda, "Reliable cloud-based robot services," in Proc. Conf. IEEE Ind. Electron. Soc., 2013, pp. 8317-8322.

[122] National Science Foundation, "Enabling a new future for cloud com- puting," 2014. [Online]. Available: http://nsf.govinewsnewssumm.jsp?cntn id=132377

[123] D. Nister and H. Steweni us, "Scalable recognition with a vocabulary tree," in Proc. IEEE Conf. Comput. Vision Pattern Recognit. (CVPR), 2006, vol. 2, pp. 2161-2168.

[124] D. Nurmi, R. Wolski, C. Grzegorczyk, G. Obertelli, S. Somen, L. Youwff, and D. Zagorodnov, "The eucalyptus open -source cloud -computing system," in Proc. IEEE/ACM Int. Symp. Cluster Comput. Grid, 2009, pp. 124-131.

[125] G. Oliveira and V. Ider, "View planning for cloud -bawd active object recognition," Dept. Comput. Sci., Univ. Minnesota, Minneapolis, MN, USA, Tech. Rep. 13-025,2013.

[126] E. Flaku, K. E. Bekris, B. Y. Chen, A. M. Ladd, and L. E. Kavraki, "Sampling -bawd roadmap of trees for parallel motion planning," IEEE Trans Robotics (T-RO), vol. 21, no. 4, pp. 597-608,2005.

[127] E. Flaku, K. E. Bekris, aid L. E. Kavreki, OOPS for motion planning: An online, open -source, programming system," in Proc. Int. Conf. Robot. Autom. (I CRA), Apr. 2007, pp. 3711-3716.

[128] M. Popovic, G. Kootstra, J. A. Jorgensen. D. Kragic, and N. Kruger, Grasping unknown objects using an early cognitive vision system for general scene understanding," in Proc. Int. Conf. Intell. Robot. Syst. IRO , Sep. 2011, pp. 987-994.

[129] E. Prestes, J. L. Carbonera, S. Rama Fiorini, V. A. M. ,Jorge, M. Abel, R. Madhavan, A. Locoro, P. Goncalves M. E. Barret°, M. Habib, A. Chi bani S. Gerard, Y. Amirat, and C. Schlenoff, " Towards a core ontology for robotics and

automation." Robot. Auton. Syst., vol. 61, no.11, pp. 1193-1204,2013.

[130] A. A. Proi a, D. Si mshaw, , and K. Hauwr, Consumer cloud robotics andvthe fair information practice principles Recognizing the challenges andvopportunities ahead," Minnesota J. Law, Sci. Technol., to be published.

[131] M. Quigley, B. Gerkey, K. Conley, J. FauS, T. Foote, J. Leibs, E. Berger, R. Wheeler, and A. Ng," ROS: An open -source robot operatingvsystem," in Proc. I CRA workshop on Open Source Software, Kobe, Japan. 2009.

[132] A. J. Quinn and B. B. Bederson, "Human computation: A survey and taxonomy of a growing field," in Proc. GCHI Conf. Human Factors Comput. Syst., 2011, wr. CHI '11, pp. 1403-1412.

[133] K. Ren, C. Wang, and Q. Wang et al., "Security challenges for the public cloud," IEEE Internet Comput., vol. 16, no. 1, pp. 69-73,2012.

[134] L. Riazuelo, J. Civera, and J. M onti , "C2TAM: A cloud framework for cooperative tracking and mapping," Robot. Auton. Sist., vol. 62, no. 4, pp. 401-413,2013.

[135] L. Riazuelo, M. Tenorth, D. D. Marco, M. Salas, L. Mownlechner, L. Kunze, M. Beetz, J. D. Tardos, L. Montano, and J. M onti el , RoboEarth web -enabled and knowledge -based active perception," in Proc. I ROSworkshop on Al -Bawd Robotics Tokyo, Japan, 2013.

[136] L. Riazuelo, M. Tenorth, D. Marco, M. Salas, D. Galvez-Lopez, L. Mownlechner, L. Kunze, M. Beetz, J. Tardos, L. Montano, and J. Montiel , "RoboEarth semnatic mapping: A cloud enabled knowledge –based approach," IEEE Trans Autom. Sci. Eng. (T –A): Special issue CloudRobot. Autom., vol. 12, no. 2, pp. 432-443, Apr. 2015.

[137] J. Sameron-Garcia, F. Diaz –del, I nigo-Blawo, and D. Cagigas "A tradeoff analysis of a cloud -based robot navigation Assistant using stereo image processing," IEEE Trans. Autom Eng. (T-A) special issues cloud robot Autom. Vol. 12,no 444-45, Apr 2015

[138] M. Samadi, T. Kollar, and M. Veloso, "Using the web to interactively learn to find objects," in Proc. AAA] Conf. Artif. Intell., 2012, pp. 2074-2080.

[139] C. Schmitt, "Security and privacy in the era of big data," 2014. [Online] Available: http://www.renci .org/wp-content/uploads/2014/02/0313VVhitePaper-iRODS.pdf

[140] P. Sermanet, D. Eigen, X. Zhang, M. Mathieu, R. Fergus, and Y. LeCun, "OverFeat: Integrated recognition, localization and detection using convolutional networks" CoRR 2013.

[141] M. Senior, T. Fifield, and N. Katayama, " Belle Monte-Carlo production on the Amazon EC2 cloud," J. Phys,: Conf. Series, vol. 219, no. 1, Apr. 2010.

[142] N. Snavely, S. M. Seitz, and R. Szelisky, "Photo tourism: Exploring photo collections in 3D," ACM Trans Graphics (TOG), vol. 25, no. 3, pp. 835-846,2006.

[143] D. Song, K. Goldberg, and N. Y. Chong, "Networked telerobots," in Springer Handbook of Robotics B. Siciliano and O. Khatib, Eds. Berlin, Germany: Springer-Verlag, 2004.

[144] A. Sorokin, D. Berenson, S. S. Srinivasa, and M. Hebert, " People helping robots helping people: Crowdsourcing for grasping novel objects," in Proc. Int. Conf. Intell. Robot. Syst. (IRO , Oct. 2010, pp. 2117-2122.

[145] A. Sorokin and D. Forsyth, "Utility data annotation with Amazon me- chanical turk," in Proc. IEEE Conf. Comput. Melon Pattern Rec,ognit. workshops, Jun. 2008, pp. 1-8.

[146] M. Stenmark, J. Malec, K. Nilsson, and A. Robertsson. "On distributed knowledge bases for small -batch assembly," IEEE Trans Autom. Special Issue Cloud Robot. Autom., vol. 12, no. 2, pp. 519-528, Apr. 2015.

[147] M. Tenorth and M. Beetz, "KnowRob: A knowledge processing infra- structure for cognition -enabled robots" Int. J. Robot. Res (I JRR), vol. 32, no. 5, pp. 566-590,2013.

[148] M. Tenorth, A. Clifford Perzylo, R. Lafrenz, and M. Beetz, "The RoboEarth language: Representing and exchanging knowledge about actions, objects, environments" in Proc. Int. Conf. Robot. Autom. (I CRA), May 2012, pp. 1284-1289.

[149] M. Tenorth, A. C. Perzylo, R. Lafrenz, and M. Beetz, "Representation and exchange of knowledge about actions, objects environments in the roboearth framework," IEEE Trans Autom. Sci. Eng. (T –A), vol. 10, no. 3, pp. 643-651, Jul. 2013.

[150] The African Robotics Network (AFRON), -Ten dollar robot' design challenge winners" 2012. [Online]. Available: http://robotics-africa.org/design challenge.html

[151] A. Torrsba, R. Fergus, and W. T. Freeman, "80 million tiny images A large data set for nonparametric object and scene recognition," IEEE Trans Pattern Anal. Mach. Intell., vol. 30, no. 11, pp. 1958-1970, 2008.

[152] R. Tudoran, A. Cosan, G. Antoniu, and L. Bouge, "A performance evaluation of azure and nimbus clouds for scientific applications" in Proc. Int. workshop on Cloud Computing Platforms—CloudCP'12, 2012, pp. 1-6.

[153] L. Turnbull and B. Samanta, "Cloud robotics: Formation control of a multi robot system utilizing cloud infrastructure," in Proc. IEEE South-east on, 2013, pp. 1-4.

[154] J. van den Berg, P. Abbeel, and K. Goldberg, "LQG-MP: Optimized path planning for robots with motion uncertainty and imperfect state information," Int. J. Robot. Res (IJRR), vol. 30, no. 7, pp. 895-913, Jun. 2011.

[155] L. von Ahn, "Human computation," Ph.D. dissertation, Carnegie Mellon Univ., Pittsburgh, PA, USA, 2009.

[156] M. VVaibel, M. Beetz J. Civera Galvez-Lopez K. Haussermann, R. Janssen, J. Montiel, A. Perzylo, B. Schiellle, M. Tenorth "RoboEarth," IEEE Robot Autom. Mag. Vol. 18, no. 2, pp. 69-82, Jun. 2011.

[157] H. VVang Y. Ma, "Toward real-time Monte Carlo Simulation using a commercial cloud computing infrastructure.," Phys. Med. Bio., vol. 56, no. 17, pp. N175 - N181, sp. 2011.

[158] J. Wang, S. Krishnan, M. J. Franklin, K. Goldberg, T. Krasca, and T. Milo, "A Sample -and -clean framework for fast and accurate query processing on dirty data," in Proc. ACM SGMOD Int. Conf. Manage. Data, Snowbird, UT, USA, 2014.

[159] L. Wang, M. Liu, and M. Q. -H. Meng, "Real-time multi-sensor data retrieval for cloud robotic systems," IEEE Trans. Autom. Sci. Eng. Special Issue Cloud Robot. Autom., vol. 12, no. 2, pp. 507-518, Apr. 2015.

[160] We Robot, "V'b robot conference," 2012. [Online]. Available: http: //robots.' aw.miami.edu/
[161] R. H. VIkber, "Internet of things -new security and privacy challenges" Comput. Law Security Rev., vol. 26, no. 1, pp. 23-30,2010.
[162] J. Waize and P. K. Allen. "pose error robust grasping from contact wrench space metrics" in Proc. IEEE I nt. Conf. Robot. Autom. (I CRA), May 2012, pp. 557-562.
[163] [163] E. Wilhem, J. Segel, S. Mayer, J. Pmfgen, M. Tiefenbeck, M. Bicker,S. Ho, R. Dantu, and S. Sarma, "CloudThink: An open standard for projecting objects into the cloud." 2013. [Online]. Available: http://cloud-think.com/
[164] Willow Garage. "Personal service robotics with tiered human -in -the-loop assistance," NSF SBIR Award 1256643, 2013.
[165] Q. Zhang, L. Cheng, and R. Boutaba, "Cloud computing: State –of the -art and research challenges," J. Internet Services App., vol. 1, no. 1, pp. 7-18, 2010.