From Networked Robotics to Cloud and Big Data Supercharged Robotics: A Survey and Analysis

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SURVEY PAPER

From Networked Robotics to Cloud and Big Data Supercharged Robotics: A Survey and Analysis

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Abstract

In recent years, with the prosperity of big data and cloud computing, robotics is evolving from conventional networked robotics to internet-scale connected, big data driven, and cloud resources supercharged multi-robot systems. In this survey paper, we present a survey of an advancing, pioneering, and multi-disciplinary field of research at the intersection of wireless sensor networks (WSN), robotics and big data. We discuss the concepts of networked robots. Networked robots refer to multiple robots working together in coordination with different types of embedded computers, sensors, and human users. Networked robotics allows multiple robots and supporting entities to execute tasks that are well beyond the capabilities of a single robot. The recent initiation of cloud technologies is opening new prospects for the provisioning of advanced robotic services based on the cooperation of some connected robots, smart environments and devices powered by the huge computational and storage capability of the cloud servers. We have recently witnessed the emergence of cloud computing on one hand and robotics platforms on the other hand. These two areas have been merging and resulting in the cloud robotics model to offer more distant services. Since networked robots require high computational and processing power, big data is becoming a dominant factor in networked and cloud robotics. This survey paper elaborates the primary concepts of networked and cloud robotics, their applications, challenges as well as the importance of big data in robotics, particularly, networked and cloud robotics and the noteworthy works in these areas.

Keywords: Networked Robotics; Cloud Robotics; Big Data

INTRODUCTION

Mobile robotics appeals the interest of researchers and manufacturers due to its multidisciplinary nature and wide range of real-world applications [1]. Artificial intelligence, embedded systems, human-machine interface, automatic control, computer vision, and real-time systems are examples of areas with direct application in mobile robotics. Networked robotic systems have a great potential in many new applications and they offer practical and viable solutions to many application fields where human involvement may not be feasible. Networked robotic systems refer to numerous robots, robot components and other external entities communicating and collaborating to reach a common goal. The external entities can be sensor networks, computer systems, or human users. The common goal can be search-and-rescue (SAR) [2] missions in dangerous environments or unreachable territories, assistance for the elderly or physically challenged, and surgical operations [3].

Networked robotics applications can be categorized as either multi-robot systems [4] or tele-operated robots. In the first case, a team of networked robots complete a task cooperatively in a distributed fashion by exchanging sensor data and information via the communication network. Examples include collaborative robot manipulators, a team of networked robots performing search and rescue missions, and a group of micro-satellites working together in a desired formation and also multiple mobile sensors (robots) tracking a single target by coordinating and communicating with each other [5]. In the latter case, a human operator controls or directs a robot from distance by sending commands and receiving measurements through the communication network. Application examples include remote control of remote medical surgery [6] and a planetary rover [7].

Networked robotics benefits from cloud computing. Cloud computing uses a sophisticated networked system and presents a clear, concise interface to broaden the capabilities of networked robotics. Robots can operate in environments that are equipped with wireless sensor networks and embedded computers communicating through wireless ad-hoc networks. With the arrival of the internet of things (IoT) [8] and robotics on one side and cloud computing on the other side, people have observed a move in the way robots can cooperate and communicate with their surroundings. Robotics platforms and cloud computing are expected to pioneer the concept of cloud robotics. This paradigm paves the way for various new applications and allows robot sharing for service providing, especially if we consider groups of heterogeneous robots that can perform different types of tasks. Figure 1 illustrates the cloud infrastructure for cloud robotics in industry.

Networked robotics serves as a pioneer towards cloud robotics. For instance, cloud-enabled networked robotics leverages evolving cloud computing technologies to enhance networked robotics reducing analytical duties off the robots [9]. The design objective is to overcome the limits of networked robotics using adaptable resources provisioned by an ever-present cloud infrastructure. The complexity of the robotics operation also makes big data an important topic for robotics. Big data refers to massive data sets with large and complicated data structure for storing, analyzing, and processing. In recent time, robotics operations rely on large amount of data to be processed in real-time and that makes big data a necessary component of robotics functions. Big data is now used for various applications of robotics including healthcare [10]. The integration of big data, networked and cloud robotics paves the way for improvement in different aspects of robotics including automotive and robotics applications [11] as well as designs of robots [12].

In this survey paper, we have discussed the importance and uses of networked robots. We have made an analysis of cloud computing and its connection with robotics. Then we discussed big data driven robotics. We analyzed the challenges associated with networked and cloud robotics and some future outlooks based on some algorithms, methods and frameworks. Finally we have drawn the conclusion of the paper.

NETWORKED ROBOTICS

Robots that can communicate with each other using a network are used for various purposes including teaching and learning in leading fields of computer science such

as cyber security [14]. It is very vital for space exploration [3] and coordination of complex instruments on board of vehicles such as the space station or the space shuttles [15]. NASA's Jet Propulsion Laboratory (JPL) designed a prototype Mars rover named Field Integrated Design and Operations [16]. It was launched in 'Mars 2003' mission. Since the robots are used mostly in areas where human involvement is hazardous, one other area where robots are taking part and working collaboratively is military [3]. [17] discusses about development of a network of cooperative autonomous robotics for military applications (CARMA) that work together to search, track, carry, deploy and retrieve sensor and other small payloads for a variety of purposes. Figure 2 shows NASA's Mars 2020 rover which was launched in July 2020 from the Cape Canaveral Air Force Station in Florida [18].

[19] discusses different kinds of robotic technologies being used in all the three armed forces- Navy, Army and Air. During war time, it will be very beneficial for armed forces if they can send robots to hazardous geographic location instead of human for gathering information of the enemy location and movement [20]. Some of

the robots discussed had been used in the wars of Afghanistan and Iraq. In addition, robots are also very crucial in amassing data from hard to reach areas such as ocean surface [3]. Coordinated mobility, human controlled or automated, is an important aspect in allowing the same sensor to collect data from various locations [21], [22] and [23].

The most significant use of networked or cloud robotics is linked to industry where multiple robots work together in a coordination to manufacture products and maintain precision of the job. Robots have been used in industry for a long period, particularly in areas where automation is necessary. [24], [25] discuss about a project of networked robots which is called PumaPaint project. The PumaPaint project is a networked robot that allows a user to control a PUMA 760 robot to paint through the Internet. This robot has four paintbrushes. The PumaPaint project is an example of industrial networked robot.

The accuracy of robots in accomplishing complex tasks is also observed in medical sector. The main advantage of medical robotics as compared to human operations is that robots can provide high-accuracy operation and precise action on surgical operations. In this field, the Robotics and Intelligent Machines Laboratory of the University of California, Berkeley (UCB) and the Department of Surgery of the University of California San Francisco (UCSF) jointly developed a robotic tele surgical workstation for laparoscopy [22]. Takanobu [26] developed a Mouth Opening and Closing Training Robot that helps patients who have problems with the jaw joint, mastication muscles, or other organs concerning food chewing.

Another very useful application of the networked intelligent autonomous mobile robot is autonomous tour-guide which may provide visitors remote access to the tour-guide through internet to visit specific exhibits like schools, laboratories, museums, factories, etc. The Robot Learning Laboratory at Carnegie Mellon University and the University of Bonn, Germany developed the first museum tour-guide robots RHINO and MINERVA [27].

Another type of networked robots is service robots that may provide services from a distant command. Mizoguchi et al. [28] developed a service robot that offers some useful services in office environment. This service robot picks up documents and printed-out papers and transfer these documents to the people who need them. Thus, it is replacing the job of an assistant.

The robots that are benefited from using the cloud technology have also some specific applications. [4] discusses about the ability of such robots to offload computation-intensive tasks to the cloud. The robots only need to keep necessary sensors, actuators, and basic processing power to enable real-time actions, but the computations can be done in the cloud server. The cloud may have a database or library of services or actions that map to different task requirements and environmental complications. The RoboEarth project [29] is working on making this a reality.

CLOUD COMPUTING SUPERCHARGED ROBOTICS

The idea of cloud computing in robotics dates back to 1997 when Inaba [30] recommended to separate hardware of the robot and the software architecture of the robot. The large-scale parallel computers of that time can be substituted by today's

cloud computing infrastructures. Cloud computing is a computing system where IT services are provided by large low-cost computing units connected by IP networks [31]. Cloud computing presents the idea for sampling-based analyses and it has been widely used in large-scale parallel computing applications with huge success [32]. In the field of multi-robot operations, cloud computing has greatly sped up the development of robotic and automation equipments. Networked robotics leverages emerging cloud computing technologies to transform networked robotics [33]. Running robotics applications in the cloud falls in the category of platform-as-a-service (PaaS) model [34] of the cloud computing literature. Some of the PaaS models are Heroku [35], Cloud Foundry [30] and OpenShift [36].

Robotics researchers have begun to explore the advantages of cloud robotics and several systems that address different aspects of the cloud robotics vision. Some of them focus on remote sensor data processing [37] or implementing computationally expensive algorithms in the cloud [38]. The main idea is to offload computational complexity from one specific robot and let the cloud handle it. For instance, [39] discusses about Rapyuta, an open-source cloud robotics platform. Rapyuta enables robots to unload heavy computation by providing secured modifiable computing resources in the cloud. In addition, research groups at Google developed smart cell-phone driven robots [33]. Google also has a cloud-based object recognition system named Google Goggles [40]. [41] describes design and implementation of UNR-PF - platform for cloud based and networked robotic services. This platform is a middleware that provides the developers a level of abstraction from service robotic platform, and provides service robot (e.g. vacuum cleaning) as a cloud service. [4] proposes a cloud robotics architecture which is built on the combination of an ad-hoc cloud formed by an infrastructure cloud and a group of networked robots. They have three elastic computing models- Peer-Based Model, Proxy-Based Model and Clone-Based Model. Each of those elastic computing models shows different robustness in network mobility flexibility, interoperability and connections.

Numerous researchers have begun to study the architecture of cloud technologies in robotic applications. R. Arumugan et. al. [34] models a cloud computing framework (DAvinCi) that offers the robotics platform as a service (PaaS). The platform is built on top of ROS (Robot Operating System), and Hadoop, an open source software for scalable distributed computing. DAvinCi's architecture is based on server nodes which form a private cloud computing environment. Through Hadoop, server nodes offer a distributed file server and a task scheduler. ROS has a master that keeps track of all the processes running in the robot. The server nodes act as ROS master nodes where robots can subscribe for messages and data from other robots or from the Hadoop's distributed file server. Y. Chen et. al. [36] developed a framework supporting robot as a service (RaaS) on cloud computing environments. The bases of the framework are RaaS units and RaaS cloud. RaaS units operate on the robot's on-board processors and have a directory service that clients can interact for discovering the actions and services the robot can support. The architecture adopts a cloud environment (RaaS cloud) where robotic services are available. In order to achieve robot navigation, Riazuelo et al. [42] used a cloud platform for SLAM and it achieved very good results. Ben Kehoe et al. [35] used PiCloud, a commercial cloud computing platform, and in their work, the combination of big data with grasping techniques of robots allowed for 90% reduction in sampling size.

Cloud robotics are enhanced by various frameworks and interfaces. [43] discusses about Open Mobile Cloud Robotics Interface (OMCRI), a Robot-as-a-Service vision-based platform, that provides a unified easy access to remote heterogeneous mobile robots so the access complexity for the users is reduced. OMCRI depends on the Open Cloud Computing Interface (OCCI) and the open cloud standard [44]. It is composed of several modules and specific commands to address each type of robot and they are saved in a separate module to plug into the OMCRI core. Cloud and networked robots are also enhanced and powered by different types of software frameworks. Though it is possible to develop robotic applications over a robotic framework, a software platform offers many added facilities if some necessities are met [3]. A cloud-based architecture for large-scale autonomous robots has been shown in Figure 3.

Figure 3. Cloud-based software architecture for autonomous robots [9].

The architecture consists of three subsystems: (1) Middleware Subsystem which can be considered as the main carrier for the platform. (2) Background Tasks Subsystem, the framework for batch processing including software packages. (3) Control Subsystem, which is the brain of the platform. The subsystems are in horizontal sequence, and the computation, storage, and networking tasks are processed in vertical sequence. Serialization of the three latter functions is processed in the following order: Networking, Storage, and Computation. [9] also proposes another software architecture for collaboration between networked robots based on Robot Operating System or ROS. ROS has several useful features. First of all, ROS can be run between multiple computers in Linux operating system. From one computer, it is possible to send messages which are known as ROS topic messages and from another computer, these messages can be received and read. The process is known as ROS topic publishing and ROS topic subscribing. Figure 4 shows the structure of ROS.

Many robotic frameworks, especially mobile robotics frameworks such as ARIA [46], Player [47], and Orca [48] are characteristically dispersed in the sense that a client program can communicate over the network with a robot running any of these frameworks. In [49], researchers introduced REALcloud, a cloud platform for

development of robotic applications which has the capability to control robots over the network. They utilize REALabs platform for networked robots and maintain several cloud infrastructure services such as session validation service that grants access and virtual machine (VM) management service for VM-deployed applications to robotic resources. The core of their proposed architecture is Workflow Management System; it provides layered service infrastructure and is based on popular Grid framework. [50] presents ‘Robot-Cloud’ framework for low cost robots that allows offloading resource intensive computation to the distant cloud nodes. The framework uses Service Oriented Architecture (SOA) to provide services of object recognition, path planning and map building. By utilizing well-known robotic software packages, such as ROS [51] and Webots [52], it provides development platform that also delivers as a service. Thus, this framework supports three service delivery models used in modern clouds.

BIG DATA DRIVEN ROBOTICS

Big Data [53] is a field in computer science that deals with large volume of data as well as the computing power of the data. Big data is used to process data fast enough to make the processing more efficient. Because of the massive data processing involved in robotics, big data is becoming a significant element in robotics domain, particularly networked and cloud robotics that involve huge computation and processing. [54] discusses about availability of big data and related new learning methods that open the opportunities to remove many of the commonly made notions and interpretations in the mappings between perception and action in robotics. The paper talks about big data techniques that face new challenges when applied to robotics problems, which are characterized with a high-dimensional input space as well as a high-dimensional, continuously valued output space. Thus, finding the appropriate task-specific mapping between these two spaces is often even more challenging, for instance, in the fields of computer vision or natural language processing that emphasises on the semantic understanding of a perceptual input.

Moreover, robots often need to calculate the next best action within milliseconds to be able to react to unforeseen events with potentially harmful results if they fail to do so. Furthermore, the structure of robotics problems is often different from most of the machine learning problems that rely on the availability of a large amount of identically and independently distributed data points. Instead, a robot must make decision in a sequence where selecting one action affects the next observed data points. This is also a reason for the very limited availability of large robotic data sets that is more impeded by the intricacy of running large-scale tests on expensive and difficult-to-maintain robotic hardware.

Big data has been used in cloud robotics. A general cloud robotics architecture which leverages the established and growing big data technologies has been discussed in [55]. The framework was expected to allow future research to create and build upon a standardized platform in which research can be easily repeated, validated, and compared. The architecture had the potential to change the affordability of features and capabilities available to high performance and expensive robots. Cloud robotics and cloud-based operations of big data systems have similar purposes and characteristics. The more established and complete big data frameworks have the possibility to be leveraged by cloud robotics. The paper suggests that though big data has the characteristics of reliability, durability, scalability and fault tolerance, the overall characteristics of an end-to-end architecture must be adopted as not all components will need such functionalities. A general architecture also needs to be modular and allow for components to be exchanged with alternative or more relevant technologies as they evolve.

The RoboEarth Platform is a collection of software modules that create and facilitate the ‘World Wide Web for Robots’ [56]. The platform’s objective was for robots to exchange their collected data to enable robots to cooperatively learn from one another. Big data techniques were used to learn and obtain useful information such as obtained data, and make this available to robots in RoboEarth’s online database. Robot learning is a significant big data problem. A robot learns throughout its life-cycle. A robot updating at about 100 times a second, running more than 8 hours a day, with several dozen sensors can produce gigabytes or terabytes of raw observation data every year during its life. A particular challenge in off-policy, life-long learning is to choose actions in such a way that provides useful training data for potentially hundreds of thousands or millions of prediction learners with different needs and [57] provides an analysis in this regard. The paper elaborates the role of surprise and curiosity in learning. The paper explains different contexts when a robot or an agent needs to deal with unexpected or surprising events and how surprise and curiosity can be used to adjust a robot’s behavior in a changing world. The paper provides the first empirical demonstration of surprise and curiosity based on off-policy learning improvement on a mobile robot. The approach discussed in the paper involves high dimensional features, massive temporal streams and many independent off-policy learners that are common in lifelong robot learning. Importance of big data in agents that depend on learning from experiences were deeply elaborated in the paper.

Industrial cloud robotics (ICR) [58] integrating distributed industrial robot resources has become the center of attention due to its convenient access, cheap

computing cost and better network infrastructure. Energy efficiency is very important for ICR. The application of energy efficient manufacturing significantly reduces energy consumption for ICR. In this context, [59] discusses about the importance of the big data analysis and energy condition perception to achieve the goal. It discusses an architecture that emphasises on distributed energy perception condition and big data analysis. It also proposes a big data analysis model and the status of the ICR based on the perceptive data of ICR related to energy consumption. It then presented the relationship between big data and the analysis model. The system architecture contains four parts- the distrusted perception, virtualization and servitization, big data storage and processing, analysis, and function. The architecture has a particular focus on Hadoop technology for its reliable, efficient, scalable, economical characteristics. For the hardware architecture of the system, a master-slave pattern has been adopted. The files in the system are managed by the main node and the slave nodes in HDFS system. For efficient management and scheduling of nodes in the cluster to finish the execution of parallel programs and data processing, the MapReduce programming model [60] has been used. The whole storage and processing system also needs a database that is compatible with data from different structures and capable of storing large amounts of data.

A major work on grasp planning using big data has been proposed in [61]. It proposes a new large-scale database comprising grasps that are applied to a large set of objects from various categories. The grasps are generated in simulation. Data-driven methods had effectively been applied to complicated problems in natural language processing and vision. Having big datasets is a key element to use methods such as deep learning due to a big number of open parameters that need to be optimized. For an action like robotic grasping that involves managing complex hardware, generating ten thousand of examples is not feasible. In their work, they proposed a new database including a large set of grasps supplied for a large set of objects in the OpenRAVE simulator [62]. The proposed database helps investigate the application of machine learning techniques that need large amounts of training data to learn the mapping from a grasp to grasp quality so data handling is the key for the success of the database.

Big Data analytics in health care is currently one of the most encouraging innovative approaches to growing knowledge of health factors and, ultimately, to expanding the distribution of health care. Health care participants now have unprecedented types and quantities of data available to them. Nowadays, robots are used in the healthcare industry for serving elderly population. That raises the question of ethical issues in collection of sensitive health information of patients. [63] discusses about related ethical issues in care robotics, particularly the development of an assistive care robot of the European H2020 project MARIO (“Managing active and healthy aging with use of caring service robots”). The project’s objective was to develop an assistive care robot for persons with mild and early moderate dementia. [64] provides an empirical study on stakeholder’s perspective on robotics, artificial intelligence and big data in healthcare. [65] performs a similar analysis on the legal situation of artificial intelligence, robotics and big data in healthcare.

Big data amasses a vast amount of stored data for applications including robotics, internet of things (IoT), and healthcare system. Though the IoT-based healthcare

system plays a crucial role in big data industry, in some cases, the sensing can be difficult to predict the accurate result. A proposed system [10] with artificial intelligence and IoT for Parkinson's disease can immensely enhance the performance. This research clearly identifies the role of robots in Parkinson's disease and their interaction with big data analytics. To process the research scheme, data was accumulated from big data. In addition, laser scanned scheme with piecewise linear Gaussian dynamic time warp machine learning was introduced. The primary role of robots is to predict the walker motion and provide physical training to the patient. The performance of proposed approach was then evaluated with previous works.

CHALLENGES AND FUTURE OUTLOOKS

Although a robot can share its computation workload with other robots, the overall effectiveness of the robotic network is limited by the collection of each robot's resources, including onboard computers or embedded computing units, memories, and storage space [4]. Common protocols for machine-to-machine (M2M) communications include proactive routing, which involves the periodic exchange of messages so that routes to every possible destination in the network are maintained [66]. Proactive routing needs high computation and memory resources in the route discovery and maintenance process. Mobile robotic frameworks use specialized network protocols for supporting client-server interactions, a design decision that constrains the integration of robots with the organizations' distributed applications.

The first restriction is linked to software development and integration. In order to maintain specific network protocols, client-side code must make use of the API (Application Programming Interface) supplied by the framework. It is difficult to integrate modern communication devices such as mobile phones into a mobile robotics application. Generally, this integration requires an intermediary device running in between the accessing devices and the mobile robot (e.g., a Java servlet) with noticeable drawbacks in terms of performance and complexity.

The second restriction relates to the way networks currently function. A common network design uses private IP (Internet Protocol) addresses and firewalls. Thus, a host configured with private IP address can connect with other networks only through routers configured with specialized forwarding functions that accomplish protocol and address translations. Some examples are HTTP (Hypertext Transfer Protocol) proxies and NAT (Network Address Translation). As proxy and NAT functions are restricted to well-known networking protocols, the specialized protocols employed by the robotic frameworks are commonly blocked when private IP addressing is employed.

Lastly, security is not addressed by many robotic frameworks. These frameworks are not able to distinguish access from different users, domains, and applications in order to avoid security threats on the robotic resources, and to verify if users or applications are authenticated and authorized to access the resources [67].

One of the major advantages of cloud robotics is the capability of offloading computationally intensive tasks to the cloud for execution. However, the decision to offload a specific task requires a unified framework that can handle a list of intricate issues. First of all, the offloading strategy should consider several factors, including the amount of data exchanged, and the delay deadline to complete the task [4].

In addition, the decision should also consider whether it is more advantageous to execute the task within the group of networked robots. Finally, given a pool of cloud resources spread across different data centers, it is a challenge to distribute virtual machines optimally to execute the offloaded task and to manage live VM migrations.

There are several ideas and algorithms that have been proposed to overcome different challenges associated with networked and cloud robotics. They shape the future direction of networked robotics as they help solve problems for networked and cloud robotics. Cyber-physical systems are one of the emerging areas for networked and cloud robotic systems. [68] presented a distributed node repositioning algorithm based on fuzzy logic for addressing the issue of simultaneous failures of wireless network connectivity in harsh environments and evaluated it via conducting experiments using Khepera IV robots. Their scheme saves energy while restoring and maintaining network connectivity in wireless sensor and robot networks (WSRN) which is a special class of Cyber-physical systems. For improving the performance of navigation for autonomous exploration, a new cooperative exploration strategy was proposed for multiple mobile robots, which reduces the time for overall task completion and energy costs compared to conventional ways to efficiently navigate the networked robots during cooperative tasks [69]. Their approach was developed using dynamic Voronoi partitions that minimizes duplicated exploration areas by assigning different target locations to individual robots. The development of an IoT/cloud integration framework supporting autonomous robot functionalities have been discussed in [70]. The framework was simulated for a large operational environment autonomous robot monitoring application and results showed simultaneous interaction and an effective exchange of data among the system components. The developed framework involved static and dynamic nodes with a fuzzy logic-based event classification system. To address the issue of delay in communication in networked robotic systems, [71] presented learning and adaptation method for self-evolving control of networked mobile robots. [72] discussed multi-target tracking problem of networked heterogeneous collaborative robots with parametric uncertainties and external disturbances in the task space, where robots can be kinematic redundant or non-redundant. The authors designed a uniformly distributed controller-estimator algorithm for the problem. In order to improve the tracking performance of networked robots, a prescribed-performance-like control (PPLC) incorporated with adaptive technique and switching control technique for nonlinear teleoperation systems was presented. These algorithms and methods pave the way for enhancements in the performance of networked and cloud robotics in the future.

CONCLUSION

This paper discusses various applications of networked robots and the new trend of cloud and big data supercharged robotics. We extensively discuss how robots can interact with each other to perform a common task using various cloud and big data techniques. Particularly, software platforms and frameworks allow researchers to explore various advantages of collaborative robot operations. We summarize the pros and cons of these platforms and frameworks. Finally, we highlight some of the

challenges in cloud and big data supercharged robotics and provide some future outlooks.

Abbreviations

SAR: search-and-rescue; IoT: internet of things; JPL: jet propulsion laboratory; CARMA: cooperative autonomous robotics for military applications; UCB: University of California, Berkeley; UCSF: University of California San Francisco; PaaS: platform-as-a-service; ROS: robot operating system; RaaS: robot as a service; OMCRI: open mobile cloud robotics interface; OCCi: open cloud computing interface; VM: virtual machine; SOA: service oriented architecture; ICR: industrial cloud robotics; MARIO: managing active and healthy aging with use of caring service robots; M2M: machine-to-machine; API: application programming interface; IP: internet protocol; HTTP: Hypertext Transfer Protocol; NAT: network address translation; WSRN: wireless sensor and robot networks; PPLC: prescribed-performance-like control

Declarations

Ethics approval and consent to participate

Not Applicable

Consent for publication

Not Applicable

Availability of data and materials

Not Applicable

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Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Muhammed Tawfiq Chowdhury conducted the survey. Feng Yan reviewed the paper and suggested improvements.

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