Some robotics concepts for the Industry 4.0 applications

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Abstract: *The advancement in Information and communication technologies has created conditions for using these technologies in many applications including the industry ones. Robotics has been traditionally present in industries, especially in manufacturing. Development of cyber-physical systems, artificial intelligence, smart sensors, Internet of Things, and other relevant technologies enabled certain transformation in the field of robotics which resulted in new robotics concepts that lead towards smart factories and fulfilment of Industry 4.0 requirements. This paper deals with some of these concepts such as cloud robotics, Internet of Robotics Things and collaborative robotics giving their main characteristics and possibilities of application in Industry 4.0 domain.*
Keywords*: ROBOTICS, INTERNET OF THINGS, CLOUD ROBOTICS, INTERNET OF ROBOTIC THINGS, INDUSTRY 4.0*

1. Introduction

The Industry 4.0 concept was first introduced at the Hanover Fair in 2011 with the aim of presenting a new strategic initiative of the German government witch task was creating new industrial production systems that would be based on modern information and communication technologies [1]. This concept and the American concept of the Industrial Internet of Things (IIoT) from 2012 initiated the emergence of other similar concepts such as French Industrie du futur, and Chinese Made in China 2025 [2]. Industry 4.0 is often identified as the fourth industrial revolution, which was initiated by the development of information and communication technologies. Cyber-physical systems, with decentralized control paradigm and advanced techniques for connecting a large number of devices enabled by the advent of the Internet of Things (IoT), are the core of the fourth industrial revolution. This results in the transformation of the classical hierarchical structure of industrial production systems into self-configuring cyber-physical production systems that enable flexible and adaptive mass production. Cyber-physical production systems provide smart manufacturing and smart factories as one of goals of Industry 4.0.

Robotic systems have been used for decades for various purposes, in industry, in everyday life, for entertainment and other. Industrial robots perform specific tasks and replace humans in difficult and dangerous operations. Robotic technology has given substantial contribution in modern industry and plays one of the key roles in Industry 4.0. It is predicted that next generation of robotics and its associated technologies will play more significant role to meet the dynamic needs of collaborative and intelligent manufacturing within the context of Industry 4.0 and Industrial Internet of Things [3].

Traditionally, to perform specific tasks, robots had to be programmed first. The emergence of cloud computing, Internet of Things, intelligent connectivity, artificial intelligence, machine learning and human-robot interaction, to name a few, enabled robots to be much more than preprogrammed machines. Cloud computing enabled robots to share the resources and to use the infrastructure of a cloud. Internet of Things allowed the robots to act as things and using intelligent connectivity to interact with each other. Artificial intelligence and machine learning gave the robots capability to operate using learning algorithms and cognitive decision-making. Robot-human interaction is becoming more and more sophisticated. Now robots can, practically, be connected at any time and anywhere, not just with each other but with anything. All these technologies led to significant transformation in the field of robotics over last decade creating the suitable environment for Industry 4.0 applications.

The advancement in computing, information and communication technologies emerged different robotics concepts such as: networked robotics, cloud robotics, collaborative robotics, cognitive robotics, swarm robotics. All these concepts led to Internet of Robotic Things (IoRT) as the most recent state-of-the-art concept in the smart manufacturing [4].

This paper deals with some robotics concepts giving their main characteristics and possibilities of application in Industry 4.0 domain. In section two, networked robotics, cloud robotics, collaborative robotics, cognitive robotics and Internet of Robotic Things are discussed, and section three considers their applications in Industry 4.0 domain. At the end, some conclusions are given.

2. Robotics Concepts in Industry 4.0

The era of industrial robotics has started in 1960s when robots were used to perform difficult tasks, mostly repetitive ones. This early robotics was enabled with key technologies such as servo and stepper motors, motor drivers and controllers. Introduction of concepts of feedback control systems, data acquisition and networking technologies in the field of robotics provided conditions for appearance of new robotics concepts. These concepts were based on various sensors, embedded and real-time systems, Ethernet and data processing. Today robotic systems relay on deep learning, human-robot interaction, system interoperability, real-time image recognition, voice communication, digital twinning for cyber-physical systems, collaborative cyber-physical systems, human friendly cognitive robots, cloud technologies, and so on. Future robotics needs to fit in the idea of Industry 4.0 using artificial intelligence, machine learning, integration of robots' cognitive skills, virtual/augmented reality and swarm technologies [3]. Nowadays, robotics is a multidisciplinary field in which different control, communication, information and computing technologies combine together with the goal of creating advanced robotic systems that will be capable to meet the requirements of the fourth industrial revolution. Some of these advanced systems are referred to as networked robotics, cloud robotics, collaborative robotics and Internet of Robotic Things, and are briefly described as follows.

2.1 Networked Robotics

When robots are required to perform complex operations that can only be realized by collaboration of a large number of robots, networking technologies are introduced into robotic systems, creating networked robotic systems. Networked robotic systems refer to a group of robots that are interconnected by wired and/or wireless communication. Such systems can perform teleoperations in a way that the operator manages and manipulates robots from a remote location, or they can act as multiagent systems in which a group of networked robots perform certain tasks together (Fig. 1). The first approach gives the teleoperated robots, and the second one gives autonomous robots. In networked robotics, multiple robots operate in a wide range of environments performing tasks that require them to coordinate with other robots, cooperate with humans, and act on information derived from multiple sensors [5]. These systems are related to networked control systems and are subject to many communication constraints. These constraints, expressed in terms of network delay, jitter, data dropouts, data loss, etc., disable reliable and continuous communication between robots. Networked robotics was the first step towards the collaborative robotics creating autonomous networked robots capable to act in a group.

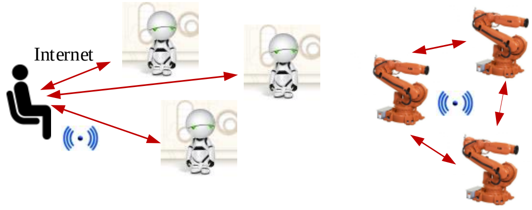

Fig. 1 *Networked robotics concept*

2.2 Cloud Robotics

The limitations of networked robotic systems can be overcome using cloud computing technologies in robotic system. This results in appearance of the concept of cloud robotics [6]. The main goal of cloud robotics is to transfer complex computing from microprocessors embedded into the robots to the cloud using communication technologies. Thus, robots no longer perform complex computing related to signal processing and execution of control algorithms locally, but in the cloud. This significantly relieves the microprocessor resources of the robot and leaves them the possibility of more efficient operation. The concept of cloud robotics was first introduced in [7]. It was preceded by the RoboEarth project, which had a vision of creating a WWW for robotic applications, i.e. large networks and databases in which robots can share information and learn from each other, and which would be available to robots from around the world. In achieving this vision, cloud computing and cloud infrastructure were used, and the results were 3-D models of different environments, speech and face recognition, etc.

The cloud robotics concept framework is given in Fig. 2. [8], where two basic parts can be identified. These are the cloud with its infrastructure (servers, databases, data centers) and networked robots of various types (mobile robots, drones, navigation robots). Communication between networked robots is realized on the M2M (Machine-to-Machine) principle, and between robots and cloud on the M2C (Machine-to-Cloud) principle. At the level of M2M communication, robots communicate with each other wirelessly and thus create a collaborative network of robots. In this way, the computing capabilities of individual robots are combined and dynamic sharing of resources between them is enabled, as well as collaborative decision-making. At the M2C communication level, robots are given access to cloud computing and memory resources, bringing together the big data needed in specific robotic applications in one place, and creating databases that store skills acquired in some previous robotic tasks that facilitate future tasks in a way that robots do not have to acquire skills from the beginning but use those already present in the cloud [9]. Networked robots communicate with each other if they are within range, and to communicate with cloud servers they need to be close to an access point which is an integral part of the cloud infrastructure. Wireless data protocols (ZigBee, Bluetooth, WiFi) are used for communication of networked robots at short distances, and radio and microwave communication at longer distances.

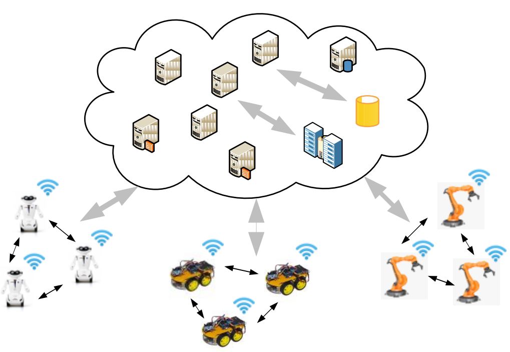

Fig. 2 *Cloud robotics concept*

2.3 Collaborative Robotics

A collaborative robot or a cobot is a robot which has the ability to safely work directly along-side human workers to complete a task [10]. It is specifically designed for direct interaction with a human within a defined collaborative workspace [11]. This workspace is safeguarded space where the robot and a human can perform tasks simultaneously during automatic operation. Human-robot interaction is defined as a state in which robots can safely work in direct cooperation with a human within a defined workspace. The concept of a collaborative robot was first introduced by Colgate as an Intelligent Assist Device (IAD) which manipulates objects in direct collaboration with a human operator [12]. The concept of collaborative robotics is given in Fig. 3. The collaboration between humans and cobots can be achieved in four ways [13]:

- a human operator and a cobot work on separate workpieces, independently, and for their individual manufacturing processes,
- a human operator and a cobot operate on separate manufacturing processes at the same workpiece at the same time,
- a human operator and a cobot perform sequential manufacturing processes on the same workpiece,
- a human operator and a cobot work on the same process on the same workpiece interactively.

Independent and simultaneous collaboration are mostly present in existing industrial applications, while sequential and supportive collaboration are subject to more advanced applications which will be part of future smart manufacturing environments. To achieve the aims of collaborative robotics, cobots need to have improved semantic understanding of the task goal and the actions as well as intents of its human co-workers. This means that cobots need to have cognitive capabilities which enable them to behave in intelligent manner as response to complex goals in a complex working environment. Similarly, the human workforce needs to be able to communicate with the cobots in intuitive way.

Collaborative robotics brings many advantages especially in production systems where cobots provide efficient production by supporting workers with both physical and cognitive tasks [14]. Introduction of cobots changes the role of humans in all areas of their collaborative work. Therefore, the fifth industrial revolution, which should be based on the complete collaboration of people and machines, has already been announced [15].

Fig. 3 *Collaborative robotics concept* [12]

2.4 Internet of Robotic Things

The combination of the Internet of Things and classical robotics emerged the Internet of Robotic Things in which the Internet of Things provides information services necessary for sensing, tracking and monitoring of objects while robotics allows objects to take appropriate actions, interact and behave autonomously [16, 17]. The Internet of Robotic Things represents a new field in robotics that has emerged through various stages of robotics development from networked robotic systems, ubiquitous robotics to cloud robotics. The term IoRT was first introduced in 2014 in ABI's technical report [18], and was referred to a concept in which sensor data obtained from many sensors are combined, processed in local or distributed processors and used to control or manipulate physical objects. Today, the term IoRT is also used to denote multi-agent robotic systems with robust team communication as well as IoT systems in which robots act as sensors.

Internet of Robotic Things in a broader way combines autonomous robotic systems with Internet of Things, intelligent connectivity, distributed and federated edge/cloud computing, artificial intelligence, digital twins, virtual/augmented reality and swarm technologies [19]. Things in IoRT are intelligent objects that interact and communicate using Internet and standard protocols used in wired and wireless networks. Robotic things have the abilities of interaction and cognitive abilities. Interaction between things is obtained with M2M communication, and IoT technologies provide the interaction between things and human. Cognitive abilities are referred to the abilities of robotic things to understand the connections between them and between the environment in which they are located, to understand the relations between objects and to estimate the impact that these relations have on the actions that robots take themselves. Cognitive abilities are obtained by ontologies used within the Internet of Things (semantic sensor networks, semantic web technologies), and Ontologies for Robotics and Automation (ORA) are widely used in the Internet of Robotic Things.

The IoRT concept implies the existence of distributed robotic systems organized in three basic layers (Fig. 4), in which exist wired and/or wireless intelligent connectivity networks, network controller nodes that collect, analyze and send data to other networks, processors that process data and algorithms, and cloud infrastructure.

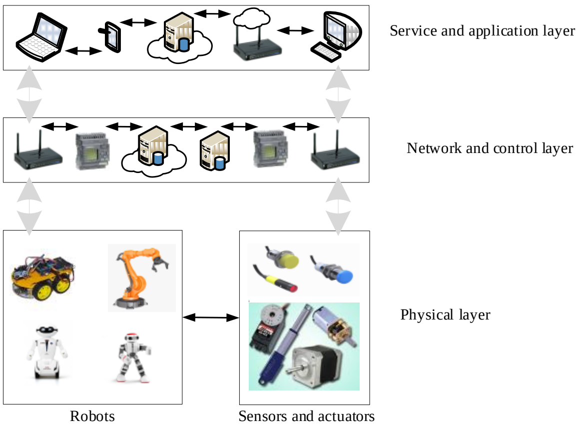

***Fig. 4** Internet of Robotic Things concept*

Future autonomous and connected IoRT systems must be able to sense, locate, think, connect, collaborate, learn and act, as shown in Fig. 5 [19]. All these are necessary for IoRT devices to properly detect, perceive and interpret the environment in which they operate, and to decide what actions to take and how to behave. In the scope of Industry 4.0 IoRT devices should be autonomous robotic systems capable of forming collaborative groups of heterogenous devices to be used in different applications. Here, concepts of networked, cloud and collaborative robotics are combined with each other. Features of Tactile Internet of Things (TIoT) and Internet of Things Senses (IoTS) enable IoRT devices to better interact with humans and cyber world. These features provide IoRT devices to become assistive robotics devices.

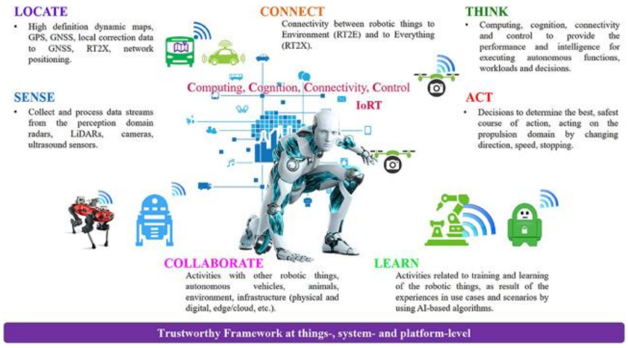

***Fig. 5** Future autonomous and connected IoRT systems* [19]

3. Robotics Concepts in Industry 4.0 Applications

Industry 4.0 concept has nine key technologies [20]: cloud, additive manufacturing, augmented reality, big data analysis, autonomous robots, simulation, horizontal and vertical system integration, Industrial Internet of Things, and cybersecurity. As concepts of networked, cloud and collaborative robotics, as well as IoRT fall under the Industry 4.0 domain, they can be used in various applications. The basic ideas of the Industry 4.0 concept are to take advantage of the global availability of the Internet and the use of the Internet of Things, to integrate technical and business processes, to perform digital mapping and virtualization of the real world, and to build smart factories that combine smart manufacturing and smart products. Smart manufacturing can fully be achieved using different robotics concepts.

Cloud robotics can be efficiently used within smart factories where autonomous robots connected to the cloud perform various tasks. In this sense, the concept of context-aware cloud robotics, which integrates Industrial Internet of Things and cloud robotics, has been proposed in [21]. When autonomous robots have to move around their workspace, they should be provided with navigation abilities. Navigation is a problem that has long been present in robotic systems. It concerns the problems of mapping (exploring the environment using sensors placed on the robot and obtaining the map of it) and localization (the ability of the robot to know its position in the environment it operates in). The use of cloud robotics provides enough space to store big data generated in the mapping process as well as computing resources to process that data while creating maps and searching existing ones. Cloud robotics enables changings in assembling process where robots manage to perform tasks previously performed by humans [22]. It also changed flexibility and extensibility of task scheduling in manufacturing [23].

Collaborative robotics is one the fundamental part of smart factories and smart production. The synthesis of cobots in the industry is underway in many different fields. Faster response time, more accurate patterns of movement, alignment capacity, human imitation capability - all of these factors lead to the advancement of cobot production [24]. Human-robot interaction in smart manufacturing should enable stable and cost-effective production. Collaborative robotics has already found its place in automotive industry. The leading automotive manufacturers use the cobots in the repetitive and precise task of equipping the inside of car doors, to apply an adhesive on a car roof, to perform screwing on a drive train in locations that are inconvenient to reach by a human operator, to loosen bolts and carry heavy components to relieve the workforce of these arduous tasks and speed up the manufacturing process, to work alongside humans in the production of direct-shift-gearboxes [25]. Universal Robots as one of the leaders in the cobot market listed the most common tasks that cobot can be used in: pick and place tasks, machine tending, packaging and palletizing of products, process tasks (gluing processing, dispensing, welding), finishing tasks (polishing, grinding, deburring), quality inspection of parts [10].

Internet of Robotic Things is the main enabler of manufacturing change, through which manufacturing is embracing the concepts of Industry 4.0 [23]. Internet of Things paradigm in the robotic systems enabled heterogeneous collaborative context aware robotic things to be used in many smart manufacturing applications. Using artificial intelligence, smart connectivity and interaction, robotic things behave more intelligently than robots belonging to collaborative or cloud robotics. Industrial operations that use information and operational technologies integrate supervisory control and data acquisition (SCADA) systems and programable logical controllers (PLC) connecting them with intelligent connectivity networks. Industrial robotics applications of IoRT include assembly, fault-finding, painting/varnishing, welding/soldering and delivery tasks [19]. All of them need to be performed precisely and in a case of an error, they have to be capable of doing corrections in a real-time. Assembly, painting, welding and delivery tasks require robotic things to have self-localization, navigation and path-planning abilities [4]. Robotic things can be used for logistics, delivery and moving objects (boxes, pallets, tools) between machines or storage areas. Collaborative mobile robotic things such as automated guided vehicles or lightweight mobile platforms can be used as fleets in warehouses and distribution centers and manufacturing intralogistics [19].

4. Conclusion

In this paper, some robotic concepts for Industry 4.0 applications are described. Networked robotics, cloud robotics, collaborative robotics and Internet of Robotic Things were studied as well as possibilities of their use in smart manufacturing. All of these concepts possess specific features which can be used on the way of meeting the requirements of the fourth industrial revolution. They provide flexible mass production without increasing costs, flexible and worker-friendly work environment, efficient use of natural resources and energy, and reduced production, logistics and quality management costs. The most promising concept on this way is Internet of Robotics Things. Although there are numerous examples of using IoRT concept in different application, there are a lot of challenges and difficulties to be resolved before it can be used in future Industry 4.0 applications. Some of the difficulties are related to communication technologies and 5G networks are seen to be a good solution to overcome them. This is the reason why the researchers in the field of IoRT and other advanced robotics concepts are very interested in resolving the problems. Intensive research on these topics is expected to continue in future, as well, and in that way come closer to realization of smart factories and smart manufacturing.

5. References

1. L. D. Xu, E. L. Xu L. Li, *Industry 4.0: state of the art and future trends*. International Journal of Production Research, (2018) 56:8, 2941-2962
2. A. Rojko, *Industry 4.0 Concept: Background and Overview*. iJIM, Vol. 11, No. 5, 2017, 77 – 90
3. Z. Gaoa, T. Wanyamaa, I. Singha, A. Gadhrria, R. Schmidt, *From Industry 4.0 to Robotics 4.0 - A Conceptual Framework for Collaborative and Intelligent Robotic Systems*, INTER-ENG 2019, Elsevier Procedia Manufacturing 46 (2020) 591–599
4. L. Romeo, A. Petitti, R. Marani and A. Milella, *Internet of Robotic Things in Smart Domains: Applications and Challenges*, Sensors 2020, 20, 3355
5. V. Kumar, D. Rus, G. S. Sukhatme, *Networked Robots*, Mobile and Distributed Robotics, 2008, DOI: 10.1007/978-3-540-30301-5_42
6. G. Hu, W.P. Tay, Y. Wen, *Cloud robotics: Architecture, challenges and applications*. IEEE Netw. 2012, 26, 21–28.
7. J. Kuffner, *Cloud-Enabled Robots*, in IEEE-RAS International Conference on Humanoid Robots, 2010.
8. J. Wan, S. Tang, H. Yan, D. Li, S. Wang, A.V. Vasilakos, *Cloud robotics: Current status and open issues*. IEEE Access 2016, 4, 2797–2807.
9. A.K. Bozcuoğlu, G. Kazhoyan, Y. Furuta, S. Stelter, M. Beetz, K. Okada, M. Inaba, *The Exchange of Knowledge Using Cloud Robotics*. IEEE Robot. Autom. Lett. 2018, 3, 1072–1079.
10. Universal robots, *An Introduction to Common Collaborative Robot Applications*, https://www.universal-robots.com/academy
11. M. Beaupre, *Collaborative Robot Technology and Applications*, Robotic Industry Assosiation - RIA, https://www.robotics.org/userAssets/riaUploads/file/4-KUKA_Beaupre.pdf
12. A. A. Malik, A. Bilberg, (2017). *Framework to Implement Collaborative Robots In Manual Assembly: A Lean Automation Approach*, Proceedings of the 28th DAAAM International Symposium, pp.1151-1160, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-11-2, ISSN 1726-9679, Vienna, Austria, DOI: 10.2507/28th.daaam.proceedings.160
13. M. Knudsen, J. Kaivo-Oja, *Collaborative Robots: Frontiers of Current Literature*, Journal of Intelligent Systems: Theory and Applications 3(2) 2020: 13-20.
14. S. Bragança, E. Costa, I. Castellucci, & P. M. Arezes, (2019). *A Brief Overview of the Use of Collaborative Robots in Industry 4.0: Human Role and Safety*. Wandel Durch Partizipation, 641–650. doi:10.1007/978-3-030-14730-3
15. M. H. Miraz, M. Ali, P. S. Excell, R. Picking, *Internet of Nano-Things, Things and Everything: Future Growth Trends*. Future Internet 2018, 10, 68
16. P. P. Ray, (2016). *Internet of Robotic Things: Concept, Technologies, and Challenges*. IEEE Access, **4**, 9489–9500.
17. P. Simoens, M. Dragone, and A. Saffiotti, *The Internet of Robotic Things: A review of concept, added value and applications*, Internat. Journal of advanced Robotic Systems, 2018: I-II, doi: 10.1177/1729881418759424
18. D. Kara and S. Carlaw, *The Internet of Robotic Things. Technical Report*, ABI Research, 2014.
19. O. Vermesan, R. Bahr, M. Ottella, M. Serrano, T. Karlsen, T. Wahlstrøm, H. E. Sand, M. Ashwathnarayan and M. T. Gamba (2020) *Internet of Robotic Things Intelligent Connectivity and Platforms*. Front. Robot. AI 7:104. doi: 10.3389/frobt.2020.00104
20. M. Rüßmann et al., *Industry 4.0: The future of productivity and growth in manufacturing industries*, report Boston Consult. Group **9**(1), 54-89, (2015)
21. J. Wan, S. Tang, Q. Hua, D. Li, C. Liu, J. Lloret, *Context-aware cloud robotics for material handling in cognitive industrial internet of things*. IEEE Internet Things J. 2017, 5.
22. S. J. Khalid, *Internet of Robotic Things: A Review*, JASTT, Vol. 02, No. 03, pp. 78-90 (2021)
23. L. Romeo, A. Petitti, R. Marani and A. Milella, *Internet of Robotic Things in Industry 4.0: Applications, Issues and Challenges*, 7th International Conference on Control, Decision and Information Technologies (CoDIT'20), 2020, 177-182
24. M. Javaid, A. Haleem, R. P. Singh, R. Suman, *Substantial capabilities of robotics in enhancing industry 4.0 implementation*, Cognitive Robotics 1 (2021) 1–18, https://doi.org/10.1016/j.cogr.2021.06.001
25. S. El Zaataria, M. Mareia, W. Lia, Z. Usmanb, *Cobot programming for collaborative industrial tasks: An overview*. Robotics and Autonomous Systems, 2019 DOI: 10.1016/j.robot.2019.03.003