Research toward IoT and Robotics in Intelligent Manufacturing: A Survey

Xuejun J. Liu

***Abstract*—The Internet of Robotic Things is an emerging vision that brings together pervasive sensors and objects with robotic and autonomous systems. This survey examines how the merger of robotic and Internet of Things technologies will advance intelligent manufacturing, thus enabling the creation of new, potentially disruptive services. This paper discusses some of the new technological challenges created by this merger and concludes that a truly holistic view is needed but currently lacking.**

***Index Terms*—Internet of things, manufacturing robotics, autonomous systems, intelligent manufacturing, internet of Robotic Things (IoRT), FANUC robot.**

I. Introduction

Robotics and automation skills are highly sought by all industrial companies in the world. Companies like Foxconn have been devoting to efforts in robotics innovation with artificial intelligent. However under the environments of Industrial Internet of Things (IIoT) and Industry 4.0, the challenges include interoperability, reliability, efficiency, and security [1], [2]. With smart robots and semiautonomous machines that can be controlled remotely through virtual interfaces, precision and timely responses are required [3], [4].

The research of intelligent manufacture has been conducted from different perspectives by many researchers in both industrial and academic fields. For examples, Liu, Qing and Guo (2017) analyze key factors affecting the development of the leading companies in Intelligent Manufacturing (IM) and found that industrial chain factor is the critical factor to stimulate the investment of IM [5]. Empirical results also show that capital factor is a significant factor, which will contribute to the development of manufacturing companies to advanced level. The aim of this survey is to explore the potential of integrating IoT with robotic technologies in intelligent manufacturing. This research structure the discussion along the system abilities commonly found in robotic systems, regardless of specific robot embodiment or application domains. Finding a suitable taxonomy of abilities is a delicate task. This study is performed based on the existing efforts and adopt the taxonomy of 9 robotic abilities, which define in the US Robotics roadmap and euRobotics roadmap (see Fig. 1).

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X. J. Liu is with the University of Wisconsin-Stout, Menomonie, WI 54751 USA (e-mail: liuj@uwstout.edu).

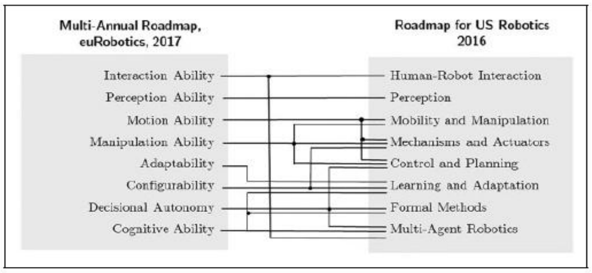

Fig. 1. euRobotics roadmap and US robotics roadmap.

II. IOT and Robotics in Intelligent Manufaturing

A. Basic Abilities

1) Perception ability

Compared to the on-board sensing, IoT can offer robots a wider horizon in time, space and types of information in the context of manufacturing based on data analytics technologies and sensors. Furthermore, on-board sensors provide a dynamic way and flexible way to position the robots [6], [7].

A key challenge of perception in manufacturing environment is that the parts, components or products are spatially and temporally distributed [8]. It is crucial to allow robots to acquire these distributed data. Gnnther *et al.* presents an anchoring system that continually integrates new observations from a 3D object recognition algorithm into a probabilistic world model to maintain a real-time correspondence between the objects and robot [9].

Other authors propose Context-Augmented Robotic Interaction Layer (CARIL) to leverage cognitive representations of shared context as a basis for a fundamentally new approach to human-robotic interaction by giving a robot a worker-like representation of context and ability to reason about context in order to adapt its behavior to that of the worker around it [10].

A key component of robots' perception ability is getting knowledge of their own location, which includes the ability to build or update models of manufacturing environment. Despite great progress in this domain, self-localization may still be challenging in crowded and/or Global Positioning System (GPS)-denied indoor environments, especially if high reliability is demanded. Diaz *et al.* presents a novel approach to determine a close-optimal workpiece pose for different robotic manufacturing processes like welding and milling based on a model-based interpretation of the Product, Process, and Resource (PPR) components defined in an internally developed Computer-Aided Manufacturing (CAM) software. By exploring an interpreted Configuration Space (C-space) using a Degree of Freedom (DoF) of the Robot

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Manufacturing Processes (RMP), Diaz *et al.* found the optimal motions in reaction to infeasible states of the robot (i.e. maximum joint limits and reachability) and a close-optimal workpiece pose.

Simple IoT-based infrastructures and range based techniques on signals emitted by off-board infrastructure, such as a radio frequency identification (RFID) [11], Wi-Fi access points, and visible light or by IoT devices using protocols such as Ultra-Wideband (UWB), Zigbee, or Bluetooth lowenergy [12].

2) Motion ability

A major challenge of today's manufacturing in the context of Industry 4.0 and Cyber-Physical Manufacturing Systems is to be flexible and adaptive whilst being robust and economically efficient. Specifically, the implementation of motion planning processes for industrial robots need to be refined concerning their variability of the motion task and the ability to adaptively deal with variations in manufacturing environment. The ability to move is one of the fundamental added values of robotic systems. FANUC 200iC Lr Mate with 6 DOF robot arm has been designed to control the motions in order to minimize execution time, the effort and energy consumed by actuators [13].

While mechanical design is the key factor in determining the intrinsic effectiveness of robot mobility, IoT connectivity can assist mobile robots by helping them to control automatic doors and elevators, for example in assistive robotics and in logistic applications [14]. Meyes *et al.* propose a reinforcement learning (RL) based, cognition-enhanced six-axis industrial robot for complex motion planning along continuous trajectories as e.g. needed for welding, gluing or cutting processes in production [14]. FIROS is a recent tool to connect mobile robots to IoT services by translating Robot Operating System (ROS) messages into messages grounded in Open Mobile Alliance APIs. Such an interface is suited for robots to act as a mobile sensor that publishes its observations and makes them available to any interested IoT service [15].

In application scenarios such as Multi-Robot System, where communication infrastructure may be much more complicated, mobile robots may need to set up ad hoc networks and use each other as forwarding nodes to maintain communication. While the routing protocols developed for mobile ad hoc networks can be readily applied in such scenarios, lower overhead and increased energy efficiency can be obtained when such protocols explicitly take into account the knowledge of robot's planned movements and activities. Schuster *et al.* considers an autonomous multi-robot pick-and-place process for the manufacturing of aerospace structures, which consists of the steps picking, transfer, dropping and post-drop treatment. Autonomous production is achieved by combining computer vision assisted gripping, automated transfer path generation and generic process execution in one system.

3) Manipulation ability

The use of robots working with humans offers new possibilities in the execution of assembly tasks through sense the manufacturing environment. A common model needs to be established describing how a task will be executed in a collaborative manner. Once the robots have acquired the relevant features of manufacturing model, like tasks, their positions and contours, the sequence of torques to be applied on the joints can be calculated via inverse kinematics, enables a collaborative flexible manufacturing assembly station while supporting dynamic re-scheduling of manufacturing operations towards an adaptive and more efficient execution of the production schedule [16].

The added value of IoT is in the acquisition of manufacturing model, including those that are not observable with the robot's sensors but have an impact on the manufacturing process, such as the distribution of mass. Some researchers attached RFID tags to objects that contain information about their size, shape and grasping points [17]. Deyle *et al.* embedded RFID reader antennas in the finger of a gripper: Differences in the signal strength across antennas were used to more accurately position the hand before touching the object [18]. Longer range RFID tags were used to locate objects in smart factories [19], as well as to locate the robots themselves [20].

B. Higher Level Abilities

1) Decisional autonomy

Some researchers use Artificial Intelligence (AI) planning techniques for task allocation (TA) in manufacturing industry based on predictive models of manufacturing environment and of the possible actions [21].

Thus, the quality of robots' actions critically depends on the quality of these models and of the estimate of the states. In this respect, the improved situational awareness that can be acquired by an IoT environment can lead to better actions. Karlsson *et al.* explore knowledge of the intentions of the humans inferred through an IoT environment to generate robots' actions that respect constraints on human interaction [22]. In addition, IoT devices may dynamically challenge classical multi-agent planning approaches in terms of widening the scope of robot decisional autonomy by making more actors and actions available, such as controllable machines and equipment [23].

2) Interaction ability

Due to high variants and small lot sizes, a conventional use of robots behind fences does not fulfill the requirements of today's production anymore. Therefore, the importance of mobile robot systems is increasing. In order to best use the capabilities of these robots, teams consisting of several robots or a robot and a human are built. For a cooperative work between robot and human, interaction systems are necessary. Interaction ability is the ability of a robot to interact physically, cognitively and socially either with the operators or other systems in manufacturing environment. This part focuses on how IoT technologies can facilitate human–robot interaction in manufacturing environment. Interaction ability focuses on how IoT technologies can facilitate human–robot interaction in manufacturing environment. IoT sensors can make human–robot interaction more robust in manufacturing environment. The IoT can provide information on the position and state of parts and equipment to disambiguate natural language instructions that are often vague or contain implicit assumptions [24].

In recent years, cognitive robots have started to find their way into manufacturing halls. However, the full potential of these robots can only be exploited through an integration of the robots with the Manufacturing Execution System (MES), a new and simpler way of programming based on robot skills, automated task planning, and knowledge modeling, and enabling the robots to function in a shared human/robot workspace with the ability to handle unexpected situations.

Some researchers propose the implementation of a collaborative robot to reduce the incidence of occupational risks among the employees of an assembly station and thus increase their safety and improve the performance of the entire assembly line. The collaborative robot was configured by using the console method, which found that the collaborative robot frees employees from potential occupational risks. Moreover, wearable sensors, on-board sensors and external cameras provide a broader scene to improve gesture recognition. For example, Wolf *et al.* presented a sleeve that measures forearm muscle movements to command robot motion and manipulation [25]. In addition, the added value of IoT in interaction ability is for remote interaction through tele-interaction robots [26].

3) Cognitive ability

With the rapid rise in robot presence in a variety of life domains, understanding how robots influence people's emotions during human-robot interactions is important for ensuring their acceptance in society. Mental health care, in particular, is considered the field in which robotics technology will bring the most dramatic changes in the near future. By reasoning on and inferring knowledge from experience, cognitive robots are able to understand the relationship between themselves and the environment, between objects, and to assess the possible impact of their actions. In an intelligent factory, introducing edge computing is conducive to expanding the computing resources, the network bandwidth, and the storage capacity of the cloud platform to the IoT edge, as well as realizing the resource scheduling and data uplink and downlink processing during the manufacturing and production processes [27].

Occupational risk factors (e.g. awkward postures, excessive effort, and repetitive movements) are a growing concern in the manufacturing industry due to their relationship with the incidence of musculoskeletal disorders (MSDs). In this sense, collaborative robots developed purposely for performing manufacturing tasks have emerged as an attractive solution to the problem. The added value of IoT in cognitive ability is that the emotion recognition and interaction of the Affective Interaction Intelligence Robot (iRobot), with the IoT cloud platform as the infrastructure and AI technology as the core competitiveness, can improved both the chip assembly and the production efficiency [27].

C. System Level Abilities

1) Configurability

Configurability considers as the ability that the robotic system is configured for given tasks or reconfigured for different task [28]. In manufacturing environment, IoT is beneficial for software configurability and collaborative configuration multiple devices that contribute various capabilities and cooperate to perform complex tasks or jobs. For example, assembly line has been set up as a multi-agent system, which equips with self-descriptive capability for the purpose of reducing changeover and set-up time [29].

The Internet of Things (IoT) and Artificial Intelligence (AI) have been driving forces in propelling the technical innovation of intelligent manufacturing, promoting economic growth, and improving the quality of people's lives. In an intelligent factory, introducing edge computing is conducive to expanding the computing resources, the network bandwidth, and the storage capacity of the cloud platform to the IoT edge, as well as realizing the resource scheduling and data uplink and downlink processing during the manufacturing and production processes. Moreover, the emotion recognition and interaction of the Affective Interaction Intelligence Robot (iRobot), with the IoT cloud platform as the infrastructure and AI technology as the core competitiveness, can better solve the psychological problems of the user.

There is a challenge in areas of advanced manufacturing and logistic, where faster reactions should be made to the disruptions through flexible adaptation to achieve production objectives. The added value of IoT in configurability is that IoT contributes to this problem through the exchanges of continuous data stream to interact with physical world. Moreover, configurability could be integrated with the decision ability to improve the ability of self-configuration based on IoRT system by considering digital interactions among the actors [30]. Some researchers point out that, to make a mobile robot with real-time vision system adapt to the highly dynamic environments and emergencies under the real-time constraints, a significant account of processing power is needed. Instead of pushing the limit of software development and computational resources, and to reduce the system computation time and improve system fault-tolerance, an embedded platform can dynamically reconfigure a mobile robot system on the fly by integrating Field Programmable Gate Arrays (FPGA) and embedded processors in a system-on-chip (SOC) environment, which has been applied to a real-world mobile robot and the experimental results demonstrate its feasibility and efficiency [31]..

2) Adaptability

Adaptability allows the robot to adapt to different manufacturing scenarios, such as unforeseen events, changing tasks or unexpected human behaviors. Mobile robots are used in smart manufacturing for machining, cutting, welding and assembling [31]. Robots should be able to adapt to the variations of product type, manufacturing procedure and process, batch size, and so on. Gealy *et al.* explore the adjustment of drip rate of single water emitter through the robot in order to control the level of irrigation, which is one of the most notable examples that show the robot has been utilized to control IoT devices. Some systems that support the adaptations of IoRT have been developed, such as IoT home automation based on OSGi and recurrent neural networks.

Some researchers pointed out that soft robotics are more adaptable to withstand heat, water and heavy weights, which allows them to operate under conditions that electrical equipment would not be able to withstand. This is particularly useful for manufacturers that use flammable or toxic chemicals during the manufacturing process.

3) Dependability

Dependability represents multifaceted attributes, which cover the reliability of software robotic component and hardware, safety when collaborating with other robots or humans and the degree to which IoT system should be continuing to achieve predetermined objectives and missions although the unforeseen circumstances or the failures occur [20]. The means of dependability are classified as forecast faults or conflicts, robust system engineering, and fault tolerance. IoT technology can provide useful tools, such as a network of small transceivers, embedded sensors in clothing and on the helmet, to realize forecast faults or conflicts in manufacturing environment.

From perspective of robust system engineering, IoT protocols have been explored to deal with these industry concerns regarding the reliability, cost or security, such as Zigbee Pro and Wireless Hart. Fault tolerance of Iot and Robotics should allow the systems to continue working even while the components or subcomponents failed since IoRT enables redundancy of sensors, information and actuation.

III. Conclusion

IoT and Robotics are two domains and each covers a myriad of concepts and technologies. This survey has explored the added values of the crossover of IoT and Robotics based on 9 system abilities in the context of intelligent manufacturing. The advantages of IoT explored by the roboticists and researchers are mainly M2M protocols and distributed perceptions. Conversely, the IoT has been mostly explored the robot for the active sensing strategy. Current IoT incarnation in intelligent manufacturing mostly focus on the domains of vertical applications, such as Industry 4.0, precision agriculture and AAL. Therefore, IoRT shall advance beyond the terms of 'Robot-enhanced IoT' or 'IoT-aided robot'. This review is expected to stimulate the scholars and researchers from both IoT and Robotics to explore towards the ecosystems of cloud, IoT agents and robots that integrates both in order to promote the development of intelligent manufacturing.

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Xuejun J. Liu received the B.S. degree in manufacturing engineering from the Dalian Jiaotong University, Dalian, China in 2001, the M.S. degree in industrial and manufacturing engineering from Nanjing University of Aeronautics and Astronautics (NUAA), Nanjing, China, in 2007, and the M.S. degree in industrial and manufacturing engineering from New Jersey Institute of Technology (NUAA), NJ, in 2012.

He joined the University of Wisconsin-Stout, Menomonie, in 2018 and is currently a lecturer in the Department of Engineering and Technology. His current research interests include automation, controls and instrumentation, manufacturing process, computer aided manufacturing, manufacturing system design and simulation, electrical systems.

Mr. Liu served as an editor of Journal of Mechanical Engineering Research. He has been a member of Society of Manufacturing Engineers (SME) since 2017 and a member of International Project Management Committee (IPMC) since 2005.