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The State of Industrial Robotics: Emerging Technologies, Challenges, and Key Research Directions

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The State of Industrial Robotics: Emerging Technologies, Challenges, and Key Research Directions

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ABSTRACT

Robotics and related technologies are central to the ongoing digitization and advancement of manufacturing. In recent years, a variety of strategic initiatives around the world including “Industry 4.0”, introduced in Germany in 2011 have aimed to improve and connect manufacturing technologies in order to optimize production processes. In this work, we study the changing technological landscape of robotics and “Internet-of-Things” (IoT)-based connective technologies over the last 7–10 years in the wake of Industry 4.0. We interviewed key players within the European robotics ecosystem, including robotics manufacturers and integrators,

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original equipment manufacturers (OEMs), and applied industrial research institutions and synthesize our findings in this monograph. We first detail the state-of-the-art robotics and IoT technologies we observed and that the companies discussed during our interviews. We then describe the processes the companies follow when deciding whether and how to integrate new technologies, the challenges they face when integrating these technologies, and some immediate future technological avenues they are exploring in robotics and IoT. Finally, based on our findings, we highlight key research directions for the robotics community that can enable improved capabilities in the context of manufacturing.

1

Introduction

Over the last decade, a variety of initiatives and frameworks for advancement of manufacturing technologies have been proposed around the world, including in the United States, India, China, Russia, and several countries within the European Union (EU) (Henning, 2013). One early example of such a framework is Industry 4.0, which was introduced as a strategic initiative in Germany during 2011 and has since been adopted internationally (Lobova *et al.*, 2019; Lu, 2017). Industry 4.0, also known as the “Fourth Industrial Revolution,” focuses primarily on advancement of cyber-physical systems (CPS), which Rajkumar *et al.* (2010) defined as “physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core.” It has emerged as both a reaction to the digitization of manufacturing and an economic and technological driver inspiring the creation of technologies for the digitization of manufacturing.

According to Lu (2017), the First Industrial Revolution involved water- and steam-powered mechanical production plants at the end of the 18th century, the Second Industrial Revolution involved a transition to electrically-powered mass production, and the Third Industrial Revolution leveraged electronics and information technology to automate

production. The aim of Industry 4.0 is to improve and connect automated systems through advancement of CPS in order to achieve a higher level of operational efficiency, productivity, and interconnectedness within factories, enhancing the optimization of production processes (Lu, 2017).

Central to the vision of Industry 4.0 in the manufacturing context are both manufacturing technologies (such as robotics and other automated systems) and the platforms, infrastructures, and systems that enable coordinated control and connection between them, collectively deemed the “internet of things” (IoT). In this work, we study the technological development of robotic technologies (including both industrial and service robots) and IoT-based technologies (such as cloud computing systems, simulation systems, and data infrastructures) and their adoption within the context of Industry 4.0. In particular, we explore whether such technologies have manifested tangible differences from past capabilities, and whether these technologies have now begun to or have the potential to provide their predicted benefits, 7–8 years after the introduction of Industry 4.0. We study the European context, with a heavy focus on Germany, because the term “Industry 4.0” originated there and has the highest relative presence in normative and legal state documents in Germany compared with other countries that also adopted the term (Lobova *et al.*, 2019), implying that governmental and legislative support for the strategy has been strong there. Further, compared with its European counterparts, Germany has the highest density of industrial robots at 309 per 10,000 employees (International Federation of Robotics (IFR, 2016)).

We interviewed key players within the industrial robotics ecosystem in Germany and nearby European countries in order to investigate the extent to which the technological landscape has changed since the introduction of Industry 4.0. Our interview subjects included representatives from robotics manufacturers and integrators (companies with a dedicated interest in the development and integration of industrial robots); original equipment manufacturers (OEMs), which leverage industrial robots for automated assembly lines; and industrial research institutions which focus on general research challenges related to industrial automation and work with OEMs on domain-specific automation

solutions. Our questions pertained to company details and ecosystem relationships, emerging technologies, IoT-style integration and Industry 4.0, standardization of technologies, the human line worker's role with regard to new technologies, metrics for robotic solutions, potential next directions for technological development, and the challenges companies face related to the integration of new technologies.

Previous works have included interviews of manufacturing employees working with new robotics technologies to better understand the adoption of these technologies in real-world scenarios, with a primary focus on line workers and those closely interacting with the technology on a daily basis (Elprama *et al.*, 2017; Sauppé and Mutlu, 2015; Welfare *et al.*, 2019; Wurhofer *et al.*, 2018). While we consider the line-worker perspective to be valuable and important, we also note the merits of understanding broader ecosystem drivers of new technologies as they relate to the evolving human role in manufacturing. In our approach, we focus on which technologies have been successfully demonstrated and which factors limit the application of new technologies within the industrial robotics ecosystem. We also highlight issues around the integration of these technologies, manufacturer expectations, and challenges around standardization and present key directions for future research as highlighted by industry representatives and stemming from current problems in the application of these technologies.

The remainder of the monograph is structured as follows: in Section 2, we detail our interview process, including the conducting and analysis of interviews. In Section 3, we discuss current and emerging technologies addressed in the interviews or demonstrated during post-interview tours of manufacturing or research facilities. Section 4 describes the processes the interviewed companies follow while deciding when and how to introduce new technologies. Section 5 details some of the challenges the companies face when implementing new robotic solutions. Section 6 lists the primary future directions the companies discussed during interviews. In Section 7, we enumerate some potential directions for robotics research based on the synthesis of key ideas gleaned from the interviews. Finally, Section 8 discusses work related to the study performed in this work, and Section 9 concludes the monograph.

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