Advances in Industrial Robotics: From Industry 3.0 Automation to Industry 4.0 Collaboration

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Abstract—**In this paper we present recent advances, current and future market trends in industrial robotics. Artificial Intelligence has evolved as the main feature to characterize Industry 4.0, Next-generation robotics utilize this feature to perform tasks collaboratively, as opposed to the currently deployed industrial robots, which were designed mainly for automation, isolated in cages, and highly-controlled environments. Current data show that China takes the lead in the industrial robotics market with 48% of the top-ten market in 2019. The electronics sector took the lead in robot-deployment in East Asia, and is continuously increasing in deploying industrial robotics in other parts of the world. Studies on the challenges associated with this technology, show that the main concern is the lack of trained labor to handle the technologies in next generation industrial robotics.**

***Keywords*- Inteligent Industrial Robotics; Artificial Intelligence; Industrial Internet of Things (IIoT);**

I. INTRODUCTION

The next-generation industrial robotics have unique features over the current-generation robotics in the advanced sensory and perception, and control algorithms, as well as an enhanced data processing capability [1]. In this work, we investigate the future direction and advances in the field of industrial robotics in the age of the fourth generation of industry, and highlights both merits and limitations associated with it. It is worth mentioning that the definition of a robot is still very broad, Joe Engelberger, regarded by many as the "father of industrial robotics", says " I can't define a robot, but I know one when I see one" [2]. Despite that, all robots share three components: sensory system, data processing, and motion, which are described by the formula: sense-think-act [2]. Throughout this paper, the term "robotics" will be used to encompass robotics used for industrial applications, which the IFR refers to as "Industrial Robots", this is opposed to other types of robots which are classified as "Service Robots".

In March 2018, the Chinese president Xi Jinping stated that China places its push towards "intelligent robotics" as a priority for its growth [3]. In January of that year, the Chinese state started a national campaign for its new industrial policy "Made in China 2025", which promotes intelligent robotics and a robot revolution in Chinese manufacturing plants to "turbocharge" its economy [4] [5]. As a result, a robotics revolution is currently taking place in China, and East Asia in general, as evidenced by the statistical data gathered by the International Federation of Robotics (IFR) (see Table 1 and Table 2).

Table 1. Top 10 markets of industrial robotics in 2016 [6] [7]

Rank	Country	Units Sold	% Change
1	China	87,000 units	58%
2	Korea	41,400 units	4%
3	Japan	38,600 units	18%
4	United States	31,400 units	6 %
5	Germany	20,000 units	8%
6	Taiwan	7,600 units	44%
7	Italy	6,500 units	19%
8	Mexico	5,900 units	7%
9	France	4,200 units	16%
10	Spain	3,900 units	No data

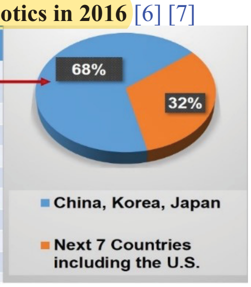
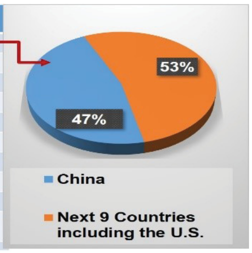


Table 2. Projected Market Size of Industrial Robotics by the end of 2019 [8]

Rank	Country	Units Sold
1	China	170,000 units
2	Japan	45,000 units
3	United States	45,000 units
4	Korea	44,000 units
5	Germany	23,500 units
6	Taiwan	12,000 units
7	Italy	7,500 units
8	Mexico	7,000 units
9	Spain	5,000 units
10	France	5,100 units



According to the 2016 report of the International Federation of Robotics (IFR), the market size of the top three countries China, Korea, and Japan constitutes 68% , that is more than twice the market size of the next seven countries combined (32% including the U.S.). Table 1 lists the top 10 countries in growth of industrial robotics for the year 2016.

978-1-7281-3755-1/19/$31.00 ©2019 IEEE

The IFR executive summary for 2019 projects that China alone will account for about 48% of the top 10 market, with a market almost double that in 2016. Furthermore, the four East Asian countries of China, Japan, Korea, and Taiwan will constitute approximately 75% of the market. These numbers confirm that a robotics revolution is already taking place in East Asia, and soon this revolution is expected to spill over to the U.S. and thus a skilled workforce must be prepared to handle the upcoming "Tsunami" of skill need.

Furthermore, in 2016, for the first time, the electronics industry exceeded the automotive industry in demand for industrial robotics in the Asian markets of China, Japan, and Korea. Worldwide, the electronics sector's share of the robotics market rose steadily to 32% in 2017, almost equal to the automotive sector (33%) [8]. This ratio is quickly changing, and the electronics and metal industries are quickly becoming dominant robotic markets. This change indicates that sectors that have not been historical markets for industrial robotics, are now adapting to this robotics revolution, which adds even more pressure on the need for skilled technicians.

Furthermore, the IFR expects that the total number of industrial robots in 2020 will be double the number in 2014. This change in technology requires "targeted training and further education for employees" [9]. Moreover, the IFR forecasts that intelligent robots will take the lead in the robotics industry in the upcoming years [10].

II. Background and Overview of Next-Generation Industrial Robotics

The robotics industry evolved independently from artificial intelligence (AI) technologies, however, over the last few years, cutting edge AI technologies were deployed in self-driving vehicles, advanced autopilots, and in surgical robots, in addition to the military applications. Industrial robotics witnessed a slower advance of artificial intelligence when compared to the medical and military fields. When artificial intelligence is coupled with industrial Robotics, the new technology is referred to as "Intelligent Industrial Robotics".

Figure 1 shows the relationship between industrial robotics and artificial intelligence [11]. Next Generation Intelligent Industrial Robotics have an advanced computing capability coupled with an advanced sensing and perception system, which allows them to self-learn and work in a free mobile environment.

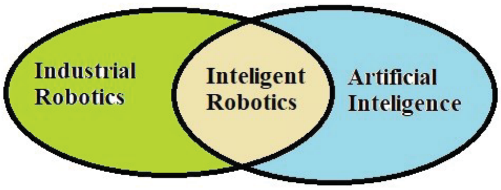


Figure 1. Artificial intelligence in industrial robotics results in Intelligent robotics.

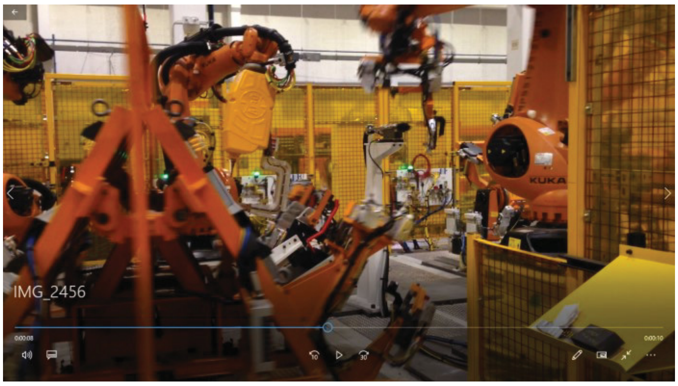


Figure 2. The current-generation industrial robotics operate in isolated and highly-controlled environments, and do not have the ability to self-learn.

Although intelligent robotics have been used in medical and military applications, they however, have only recently started penetrating industrial applications. This is mainly because for a technology to be used on an industrial level, it has to have established and standardized protocols for corrective and predictive maintenance, and trained technicians that are widely available with established training programs. The introduction of the new technology of intelligent robotics means manufacturers will need technicians that are trained to handle the new change in technology.

There are two primary advantages of deploying the next-generation intelligent industrial robotics, in place of the current generation of robots:

- **The ability of intelligent robotics to self-learn:** The Intelligent robots can self-learn the optimal process and solve problems. For example, an intelligent robot can self-learn to twist itself for the best grip of a part, and the part infront of it does not have to be in an exact orientation to be handled by the robot. This is contrast to the current-generation robotics which cannot self-learn, and any slight change in the orientation of the part to be picked, can cause the robot to jam and cause a production line to stop. The improvement in the process after the machine self-learns can be as much as a "**million fold**" [10].

- **The mobility, free movement, and ability to collaborate:** the high flexibility achieved from intelligent robotics improves productivity and safety significantly. The current generation of industrial robots are isolated in cages, and only operate in highly-controlled and deterministic environments for safety [12] [13]. As a result, the National Institute of Standards predicts that intelligent robotics can save manufacturers at least $40.4 billion annually [12].

III. Characteristic Technologies of the Next-Generation Intelligent Industrial Robotics:

Artificial Intelligence: the methods employed here primarily rely on algorithms based on neural networks. They can simplify troubleshooting processes and reduce costs significantly for manufacturers. Some sensory systems include optical scanners ad vision systems with the proper image processing algorithms [14] [15]. Industrial robotics that have the machine learning and advanced perception capability have been already deployed in industry as Collaborative robots. Compared to traditional industrial robots, Co-bots are more dynamic and compact in size, and equipped with an advanced computing capability coupled with an advanced sensing and perception system to sense human presence around them. Ground studies conducted at Toyota, Ford, and Mercedes Benz indicate that deploying co-bots resulted in increased production [2]. The IFR forecasts that collaborative robots will take the lead in the robotics industry in the upcoming years [10].

Advanced Sensing and Perception and Navigation Guidance systems: Force torque sensing to vision systems allow robots to work freely and collaboratively with humans, rather than in isolated environments.

Utilization of Augmented Reality Technology in Robotics Controllers: It was shown in literature and in some of the recent generations of industrial robots that the robot controllers can be connected to an Augmented reality application to enable the operator to visualize robot intentions, locations, and states such as target location and if selected objects are correct or not. In addition to that, it can be used when communication channels are limited such as when wearing gloves limits use of the teaching pendant, or when physical barriers exist. Thus complete human-robot communication, and controllability can be performed at the network level without having to be in the field with the robot [16] [17]. This capability also allows for cooperative interface between humans and robots rather than performing tasks independently. Studies show that cooperative work is the most optimized form for production when compared to processes in which humans and robots work independently.

The Industrial Internet of Things Platforms and Wireless Communication Capability: the Internet of Things technology is probably the most prominent technology in the current manufacturing era with the annual spending on IoT expected to climax at $450 billion in 2023 [18]. Connectivity of intelligent robots is essential for an optimal utilization of their functionalities. The well-known robotics manufacturer FANUC launched in 2016 the FANUC Intelligent Edge Link and Drive (FIELD) industrial internet of things platform. ABB Robotics followed in 2017 with the launching of its "Ability" platform. These systems are developed to achieve mass production with a high flexibility for customization in real-time [19] [20]. Table 3 below shows some IIoT platforms and their sizes as of 2018 [21] [22].

Table 3. Common Industrial Internet of Things platforms and their sizes as of 2018

IIoT platform	Owner	Year launched	Size as of 2018
Ability	ABB Robotics	2017	7000 robots
FIELD	FANUC Robotics	2016	Not reported, but there are at least 18,000 Robots and CNCs connected to the iZDT app of the FIELD platform
Connyun	Kuka Robotics	2016	One million devices
Predix	General Electric	2016	The largest IIoT platform in the world. Number of devices not reported.
MindSphere	Siemens	2017	More than 30 million devices. Second largest in the world.

IV. Challenges Associated with Next-Generation Industrial Robotics

Despite the tremendous improvements in productivity and safety in the workplace that will result from deploying next-generation robotics, current data evidence shows that there will be a shortage of 2 million jobs in advanced manufacturing in the next decade due to a big skill gap [23]. According to a research conducted by Deloitte in partnership with the Manufacturing Institute, about 2.7 million jobs in advanced manufacturing will be vacant due to retiring workforce over the next decade [23]. In addition to that, natural growth in business will result in another 700 thousand jobs; with only 1.4 million jobs are expected to be filled.

Furthermore, there are indicators that the skill gap may be larger than expected. Accenture reports that, in a survey, 84% of manufacturing executives indicated that the workforce is unprepared to adopt Industrial Internet of Things (IIoT) [24] [25] [26] [27]. IIoT is just one aspect of intelligent industrial robotics. Dr. Inaba of Fanuc Robotics, the world's largest robot manufacturer, states that to overcome competitiveness due to labor cost, manufacturers "robotize and put in IT (Interner of Things) function" [22]. This is yet another indicator for the need for only highly-skilled labor who are trained to handle robotics with IoT and artificial intelligence, as manufacturers eventually will have to robotize in order to stay competitive.

From the above discussion, all data evidence suggests that there will exist a profound need for technicians and engineers that are trained to handle intelligent industrial robots in the upcoming years. The lack of trained technicians can significantly slow down manufacturers from adopting intelligent robot technologies, and as a result reduce their overall competitiveness and production. A workforce pool should be created soon to handle the quickly advancing adoption and utilization of intelligent industrial robotics.

V. CONCLUSION

In this work we show the current and future forecast of the industry drive in the field of industrial robotics. Current data show that there is a revolution of industrial robotics taking place in the world, and particularly in East Asia. Current studies show significant positive impact that resulted from deploying the next-generation industrial robotic, which are characterized by the use of artificial intelligence, the main feature of Industry 4.0. The shift from current-generation to the next-generation industrial robotics is a shift from Automation to Collaboration.

Some of the challenges associated with the shift to next-generation industrial robotics, include a severe need for a trained workforce that can handle these technologies.

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