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Views and Comments

Robotics in Industry—Their Role in Intelligent Manufacturing

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1. A view of intelligent manufacturing

1.1. Intelligent manufacturing: The coupling of technology and industrialization

A perspective on intelligent manufacturing can be gained by examining the development stages of modern industrial manufacturing [1]. The use of steam engines as prime movers around 1784 marked an essential step of the First Industrial Revolution (Fig. 1), although an early crude form of the steam engine was invented 50 years earlier by Thomas Newcomen. James Watt invented a separate condenser as a cooling cycle to increase the efficiency of steam engines. Watt also applied a governor (i.e., a mechanical speed regulator) to permit the automatic control of speeds. These technology breakthroughs led to the reliable use of the steam engine. Furthermore, Watt obtained support from a financial investor, Matt Boulton, to produce the new engines in quantity. Technology and industrialization were essential ingredients for the eventual success of the first industrial era. Thus, it might be inferred that a successful development stage is marked by the coupling of technology and industrialization. In the same way, intelligent manufacturing is supported by the integral efforts of information technology and industrialization. In fact, China defined its China Manufacturing 2025 initiative as encompassing information technology and industrialization, in the same spirit as the First Industrial Revolution [2].

1.2. The Second and Third Industrial Revolutions: Mass production and logic control

In the Second Industrial Revolution, mass production led to higher productivity. The basic technology in this revolution was the use of paced conveyor lines that supplemented industrial engineering methods. A manufacturing process could thus be broken into multiple stages, each of which contained a limited number of operations for the worker to perform. Conveyors provided a means to move semi-finished products from one stage to another. As a whole, the overall productivity of the process could be increased. For example, Ford applied this technology along with industrialization to produce millions of vehicles at a lower cost.

The Third Industrial Revolution was represented by the invention of programmable logic controllers (PLCs) in 1969 [3]. Although there were several candidate technologies to represent the integration of computers with machines, the PLC was an easy-to-use and reliable controller to program computational logic. Dick Morley, involved with the production of Modicon, came out with the first working controller based on specifications from General Motors' Hydra-Matic. Modicon was also the first to present ladder logic, which was favored by many automation engineers. Odo Struger and his team at Allen-Bradley, together with the 3i company, developed the PLC and registered the PLC name. (3i was acquired by Allen-Bradley, which later became Rockwell Automation.) Allen-Bradley then wisely invested in automotive applications in order to support the PLC fully as a solid, reliable, and easy-to-use control for automation. PLCs became a billion dollar industry within 10 years of their1969 debut.

1.3. Industry 4.0: CMIDAN intelligence and robotics

The Working Group of Industry 4.0 presented their report at the Hannover Messe in 2013. The year 2014 marked the beginning of the Fourth Industrial Revolution, with the introduction of using information technology for manufacturing. The intelligent technologies associated with the Fourth Industrial Revolution comprise six areas, in addition to robotics (Fig. 2), as classified by Foxconn: cloud computing, mobile devices, the Internet of Things, big data, intelligent analytics, and networks (summarized using the acronym CMIDAN). CMIDAN thus represents intelligence in the virtual world, while robotics represents a mechanism to perform physical tasks in the real world. Together, CMIDAN and robotics can yield additional impact in future intelligent manufacturing. Industrialization efforts have been attempted by many researchers and are continuing.

1.4. Fundamentals for intelligent manufacturing: A One, a Two, a Three

The concepts of Industry 4.0 and intelligent manufacturing can be perplexing to traditional manufacturing enterprises. Some companies wonder where to start, and whether such an investment will really pay off. Such skepticism is natural. In the meantime, other companies have moved ahead and have been eager to adopt intelligence in manufacturing. The results have been mixed, however, because injecting new technologies takes time to internalize

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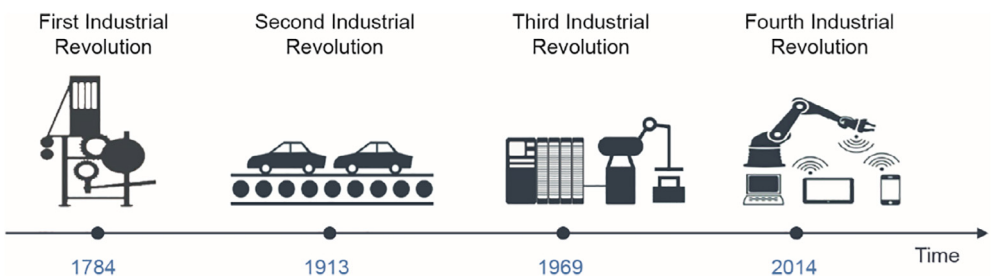

Fig. 1. Industrial manufacturing development stages.

Fig. 2. Six intelligence areas (CMIDAN) plus robotics. (Credit: Terry Gou, Foxconn Technology Group).

and requires adjustments within the company to take effect. Furthermore, it is important to prepare the fundamentals when applying intelligent manufacturing techniques. The fundamental steps can be described using the mnemonic "a One, a Two, a Three" as follows:

1.4.1. A One: One motto

The first step can be summarized with a single catchphrase: Reengineering the intelligent process with modern information technology. Business process reengineering (BPR) was a business management strategy that began in the 1990s [4]. It was intended to reorganize workflow in order to dramatically improve customer service and cut operational costs. A similar reengineering procedure could be adopted for targeted processes in purchasing, operations, engineering, quality, and marketing, utilizing the six intelligent technologies summarized by CMIDAN, along with robotics. This procedure would call for the various departments to rethink and revitalize themselves in light of the new technologies encompassed by CMIDAN in combination with robotics. A pilot project could be planned for demonstration and to tune the process.

1.4.2. A Two: Two basic elements

The second step comprises two basic elements: ① useful data as the source of intelligence, and ② easy-to-use analytics tools to help move toward intelligence. Data provides the basic ingredients for formulating intelligence, with accurate timely data as the key. An excess of unusable data is like noise, without value. Therefore, useful data collection is a basic element of intelligent manufacturing. Analytics tools should be easy to use, in order to allow users to create their own intelligent algorithms from domain knowledge. At the start, analytics can be simple, such as using statistical computations and simple control algorithms. It is always beneficial to have manufacturing engineers gain confidence and perceive the potential value of intelligent manufacturing from the initial data and analytics. After the engineers gain experience, more sophisticated analytics and tools exploring the use of artificial intelligence can be added.

1.4.3. A Three: Three activities

The third step comprises three activities: ① improving interconnection at the data-generation layer, ② applying analytics processing and displays, and ③ using computer-aided tools.

Regarding the first activity, the bottom control layer in a manufacturing system includes robots, computer numerical controls (CNCs), sensors, grippers, and various control devices. This is a core data-generation layer. In factories that were built during the Third Industrial Revolution, many of the machines in this layer already have communications capabilities, albeit with limited data transfers as compared with Industry 4.0 systems. In the intelligent manufacturing era, data generation and transfer capabilities are enhanced. This layer uses more modern sensors, such as high-resolution video imaging (e.g., 8000 pixels per line) and force, torque, inertial, touch, vibration, and temperature sensors to capture manufacturing actions. Data-transmission hardware, data format, and transmission protocols will require upgrading to allow reliable and secure free-flow of data at the data-generation layer.

The second activity comprises applying analytics processing and displays to the upwardly transmitted data as a basis for useful actions. The "intelligent" part of manufacturing lies in this

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