A REVIEW ON SMART MANUFACTURING 4.0: ROOTS AND PILLARS

P.K. Chakravarthy
Centurion University of Technology and Management, Odisha
pkchakravarty@cutm.ac.in

ABSTRACT

From Traditional to Modern, From Modern to Smart, The world has evolved in many ways in Manufacturing and Service units. Manufacturing and Services has gone through the extreme level of occupancy in this smart generation. Smart Manufacturing is the emerging technology which evolved and became more computerised, automated and complex. It is an emerging form of integration, production and manufacturing with sensors, image processors, computer platforms, simulations, communication technologies, mathematical modelling and predictive engineering. Smart Manufacturing also integrated with Internet of Things, Cloud Computing, artificial Intelligence, data Science and Visualizations which leads to the best manufacturing systems and patents to the next generation. In this paper, the roots and pillars of Smart Manufacturing system, its origin, current status and future developments are discussed. The pillars of Smart Manufacturing is captured i.e. Manufacturing Technology and Processes, Materials, Data, Predictive Engineering, Sustainability and Resource Sharing and Networking. This system is also integrated with Materials Handling and Supply Chain.

Keywords: *Smart Manufacturing, Pillars, Automated Manufacturing Systems, Manufacturing Traditions and Beyond*

1. Introduction to the Study

Smart Manufacturing has been defined as Collaborative Manufacturing with fully integrated systems that always respond in real time situations to meet the flexibility in the factories, supply chain networks and in customer needs. It is another name of Industry 4.0 in the industrial revolution series. The executive chairman of world economic forum Klaus Schwab who was firs who introduced the phrase Fourth Industrial Revolution in 2015 by the article published Foreign Affairs "Mastering the Fourth Industrial Revolution" was the 2016 theme of the World Economic Forum Annual Meeting. On 10th October, 2016 the forum announced the opening case of its centre for the fourth Industrial Revolution in San Francisco. Schwab includes in this fourth era technologies that combine hardware, software, and biology (cyber-physical systems) and emphasizes advances in communication and connectivity. Schwab expects this era to be marked by breakthroughs in emerging technologies in fields such as robotics, artificial intelligence, nanotechnology, quantum computing, biotechnology, the internet of things, the industrial internet of things, decentralized consensus, fifth-generation wireless technologies, 3D printing, and fully autonomous vehicles. The term Industry 4.0 is originated froma project in the High-tech strategy of the German Government which promoted the Computerised of Manufacturing by using the latest technology. In October 2012, the Working Group on Industry 4.0 presented a set of Industry 4.0 implementation recommendations to the German federal government. The workgroup members and partners are recognized as the founding fathers and driving force behind Industry 4.0. On 8 April 2013 at the Hannover Fair, the final report of the Working Group Industry 4.0 was presented. This working group was headed by Siegfried Dais, of Robert Bosch GmbH, and Henning Kagermann, of the German Academy of Science and Engineering. The synergetic effect between emerging technologies and needs has led to the creation of new manufacturing paradigms characterized by: (1) digitalization and integration of manufacturing resources on cloud-based platforms as adaptive, secure, and on-demand services and (2) smart and connected objects capable of real-time and autonomous decision-making via embedded electronics and analytical/cognitive capabilities. Smart manufacturing involves networking of heterogeneous components and services that reside within the boundaries of a factory (e.g., integration of smart shop–floor devices) or beyond (e.g. Integration of a manufacturing cell with a cloud-based service). These two types of integration are sometimes referred to as vertical and horizontal, respectively. Thus, unlike the traditional "automation pyramid" for manufacturing control where integration problems would arise in intra-enterprise hierarchical structures (i.e., Enterprise Resource Planning (ERP)–Manufacturing Execution Systems (MES)–shop-floor), smart manufacturing calls for the integration of diverse and distributed cloud-based services, enterprises, smart factories, smart devices, and processes. The required integration in turn calls for a seamless exchange of information between these heterogeneous systems which operate under a wide variety of communication standards. The U.S. National Institute of Standards and Technology defines smart manufacturing as "fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs".

2. The Architecture of Choice for Smart Manufacturing

Performance: Arm technology enables workload consolidation with a single, scalable architecture and a portfolio of advanced heterogeneous solutions, helping to reduce hardware infrastructure and energy consumption. Arm-based technology provides the right processing power for a wide range of factory applications, from small control modules to complex robotics using computer vision and machine learning (ML).

Real-Time: Arm technology provides reliability, precision and low latency for efficient, continuous industrial operations, regardless of cycle time requirement. Our extensive portfolio of scalable processors support predictive maintenance and machine-to-machine communications, so equipment repairs can be planned before faults occur and production lines can be monitored and adjusted in real-time.

Security: Our security solutions are designed to protect hardware, software and networks by preventing physical and remote interference. Our comprehensive approach ensures the right level of robustness to match each application's needs, whether securing cyber-physical systems, protecting data or defending products from counterfeiting and cloning. Arm security products support the Platform Security Architecture (PSA) approach. PSA Certified is an independent certification scheme mapped to key industry standards, including IEC 62443 which is designed to secure industrial automation and control systems (IACS).

Functional Safety: Integrated functional safety is critical to safeguarding the working environment. Arm offers advanced technologies compliant with international safety certifications, such as IEC 61508. Our Safety Ready portfolio supports the highest levels of functional safety required for human-to-machine interaction. A collaborative approach to manufacturing enables autonomous robots to undertake repetitive and mundane tasks reliably, while humans can focus on critical thinking and complex production line decisions.

What Technologies Drive the Digital Industry

- Cloud Services – An alternative in the processing, storage, monitoring, and control of enterprise data and applications;
- Internet of Things (IoT) – Responsible for bringing together the entire ecosystem of communication between equipment, devices, and sensors, which capture and record primary information and generate analytics and answers in real time;
- Big Data & Analytics – A way of managing the flow of data generated by each development stage of production, from engineering to design, testing, and production;
- Engineering Simulation (CAE) – Virtual modelling scenarios of products from early workflow phases that are vital for achieving performance, decreasing the time to market, and efficiently reducing production costs;
- 3D Printing and Additive Manufacturing (AM) – The enterprise capacity of 3D printers is set to play an increasing role in the production of small series personalized products;
- Augmented Reality (AR): Systems like Oculus Rift or Microsoft Holo Lens will play a key role in increasing productivity and accelerating decision-making processes

Basic IIoT Concepts and Glossary of Terms

- **Enterprise Resource Planning (ERP):** Business process management tools that can be used to manage information across an organization.
- **IoT:** IoT stands for Internet of Things, a concept that refers to connections between physical objects like sensors or machines and the Internet.
- **IIoT:** IIoT stands for the Industrial Internet of Things, a concept that refers to the connections between people, data, and machines as they relate to manufacturing.
- **Big data:** Big data refers to large sets of structured or unstructured data that can be compiled, stored, organized, and analysed to reveal patterns, trends, associations, and opportunities.
- **Artificial intelligence (AI):** Artificial intelligence is a concept that refers to a computer's ability to perform tasks and make decisions that would historically require some level of human intelligence.
- **M2M:** This stands for machine-to-machine, and refers to the communication that happens between two separate machines through wireless or wired networks.
- **Digitization:** Digitization refers to the process of collecting and converting different types of information into a digital format.
- **Smart factory:** A smart factory is one that invests in and leverages Industry 4.0 technology, solutions, and approaches.
- **Machine learning:** Machine learning refers to the ability that computers have to learn and improve on their own through artificial intelligence—without being explicitly told or programmed to do so.
- **Cloud computing:** Cloud computing refers to the practice of using interconnected remote servers hosted on the Internet to store, manage, and process information.
- **Real-time data processing:** Real-time data processing refers to the abilities of computer systems and machines to continuously and automatically process data and provide real-time or near-time outputs and insights.
- **Ecosystem:** An ecosystem, in terms of manufacturing, refers to the potential connectedness of your entire operation—inventory and planning, financials, customer relationships, supply chain management, and manufacturing execution.
- **Cyber-physical systems (CPS):** Cyber-physical systems, also sometimes known as cyber manufacturing, refers to an Industry 4.0-enabled manufacturing environment that offers real-time data collection, analysis, and transparency across every aspect of a manufacturing operation.

3. Pillars of Smart Manufacturing

Pillar-1: Manufacturing Technology and Processes

The emergence of manufacturing technologies and processes are expected in future years. New materials, components and products will emerge (Kusiak2016a). Additive manufacturing can serve as an example of a new technology that has prompted the development of new materials, impacted the design and manufacture of products and opened doors to new applications such as biomanufacturing. Manufacturing tools have been designed to integrate various operations, e.g. machines that are capable of horizontal and vertical milling as well as drilling (a machining centre). New hybrid processes will emerge, e.g. hybrids of traditional and additive processes, laser and net-shape manufacturing. Greater integration of processes will occur, e.g. integration of new materials, product design, manufacturing processes, such as discovery of a chemical compound leading to design of a new medication and a delivery device, as well as the manufacture of medication and the device. Big and small area additive manufacturing will expand its prominence in the factories. New generation of low cost robots will enhance factory automation. Sensors and software capabilities will make the new manufacturing equipment smarter and amenable to factory and beyond communication.

Pillar-2: Materials

Smart manufacturing does not make a special call for the development of smart materials, e.g. shape memory alloys or functionally graded materials. It may well be that smart materials and smart products will follow their own development paths. Smart manufacturing is open to all types of materials, including organic-based materials and biomaterials, needed to produce future products. The significance of recovering materials from products at the end of their lifecycle will increase. It is conceivable that landfills will become new mines of various materials. Some new materials will require novel processes that must be developed and incorporated in smart manufacturing. Additive manufacturing alone will be a great contributor to the search for new materials and their mixes.

Pillar-3: Data

We are witnessing the renaissance of data in manufacturing. Some of it has been triggered by deployment of sensors, wireless technology and the progress in data analytics. Greater collection of data from diverse sources, ranging from material properties and process parameters to customers and suppliers has begun. The data will be used to power any application to be envisioned, including building predictive models. Moreover, it will be the best source for preserving and extraction of past and new knowledge related to manufacturing.

Pillar-4: Predictive engineering

Predictive engineering is one of the latest additions to the space of manufacturing solutions that will lead to an anticipatory rather than reactive enterprise. Traditionally, the manufacturing industry has focused on using data for analysis, monitoring and control, e.g. productivity analysis, process monitoring and quality control. Six sigma and other data-analysis concepts have had tremendous impact on advances in the quality of manufactured products and services. However, for the most part, traditional efforts have emphasised the past over the future states of manufacturing processes and systems. Predictive engineering offers a new paradigm of constructing high-fidelity models (digital representations) of the phenomena of interest. Such models will allow exploring future spaces, some within the realm of the existing technology and others that have not been seen previously. In the future, today's models will be enriched with both limited-scope models (e.g. behaviour of a supply chain) and those that involve multiple systems (e.g. models that integrate productivity, product quality, energy and transport) to support decisions concerning future production and market conditions. Such wide-scope models may contribute to restructuring the manufacturing industry. It is conceivable that some manufacturing will become highly distributed and some may be centralised. For example, products that are sensitive to the transportation cost, time-to-market and customisation could be produced at locations in the proximity to the customers.

Pillar-5: Sustainability

Sustainability will be of paramount importance in manufacturing. The goals of sustainability efforts will be materials, manufacturing processes, energy and pollutants attributed to manufacturing. The entry points of any major sustain-ability effort are the product and the market. There is no doubt that the greatest sustainability gains are accomplished when the development of products and processes is guided by the sustainability criteria. Examples of possible scenarios include: (i) sustainable product design will drive manufacturing, (ii) sustainable manufacturing processes will impact the design of products and (iii) simultaneous development of sustainable materials, products and processes will take place. Additive manufacturing represents the second scenario in which a process has resulted in new designs of components and products. Sustainability is not about what is manufactured but how it is performed. It is the main force behind providing equal footing for remanufacturing, reconditioning and reuse with manufacturing. Because of sustainability, the line between manufacturing and service will remain blurry. For example, reconditioning a used product is not a traditional manufacturing activity, however, it may enter the new manufacturing dictionary.

Pillar-6: Resource sharing and networking

As manufacturing is becoming digital and virtual, much of the creative and decision-making activities will take place in the digital space. While at some level the digital space may be highly transparent, the physical manufacturing assets with their know-how will be protected. This digital-physical separation will allow for shared use of resources acrossbusinesses, including the ones that compete.

The Roots of Smart Manufacturing

The modern era manufacturing has its roots in the past half century. The progress in computer and machine-building technology has led to automation in manufacturing. Today's machine tools are largely run by computer programmes rather than human operators. Materials and components are transported by automated material handling systems and stored in automated storage and retrieval systems. Depending on the scope and degree of automation of a manufacturing floor and the integration of various functional production areas, different terms have been used to describe automated manufacturing since 1980s, ranging from flexible manufacturing cells and flexible manufacturing systems to computer-integrated manufacturing and intelligent manufacturing. The last term was coined around 1990 and marked with the establishment of the Journal of Intelligent Manufacturing (Kusiak1990a) and publication of the book, Intelligent Manufacturing Systems (Kusiak1990b) both under development for years prior to appearing in print. At about the same time Japan has embarked on research in intelligent manufacturing that has led to the establishment of the Intelligent Manufacturing System (IMS) Programme in support of industrial research in 1995. It was realised that the industry of one country alone could not reshape manufacturing and that international cooperation was needed. Major companies from Japan, United States, Korea and European counties have initiated collaborative efforts on the future of manufacturing, with Japan having the largest number of actively involved corporations. In the United States, much of the IMS activities have taken place under the umbrella of the Next Generation Manufacturing Systems (NGMS) Programme that was established as a not-for-profit venture. Later, the IMS Programme was expanded, with the European Union establishing research efforts in intelligent manufacturing (see Groumpos1995).Manufacturing is evolving, and it is bound to take place in different forms. In recent years, the concept of internet of things has attracted attention of the manufacturing community. It focuses on integration of the physical assets of manufacturing with the cyberspace to form cyber-physical systems. This new concept has been embraced by individual companies, industrial consortia, regions and countries. There is no generally accepted definition of smart manufacturing. According to the National Institute of Standards and Technology (NIST) smart manufacturing is fully integrated, collaborative manufacturing system that responds in realtime to meet changing demands and conditions in the factory, in the supply network and in customer needs. Smart manufacturing integrates manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, data intensive modelling, control simulation and predictive engineering. Smart manufacturing utilises the concepts of the cyber-physical systems, internet of things (and everything), cloud computing, service-oriented computing, artificial intelligence and data science. Once implemented, these overlapping concepts and technologies will make manufacturing the hallmark of the next industrial revolution. A general concept of a smart manufacturing enterprise is illustrated in Figure1.The concept in Figure1includes two basic layers, the manufacturing equipment layer and the cyber layer, linked by the interface. The manufacturing equipment has its own intelligence, while the system-wide intelligence is provided by the cyber layer.

Beyond The Manufacturing Tradition

The manufacturing of the future will naturally expand into non-traditional areas such as: Healthcare largely driven by the need to customise products, from the implants and medications to the hospital and home care supplies; Biomanufacturing fuelled by the promise of tissue and organ printing. Both small area additive manufacturing (e.g. surgical equipment) and large area additive manufacturing (e.g. hospital beds, furniture) will be the key drivers in the healthcare industry. In addition, the domains that might have been considered as marginal will gain more prominence, e.g.: Remanufacturing and reconditioning are bounded to grow especially when novel design practices will bed employed

Disassembly and reuse will become growing contributors to the circular economy. Sustainability, increasing cost of traditional materials and limited availability of traditional materials (e.g. rare metals) will support the circular economy.

Conclusion

Automated factories were envisioned and demonstrated decades ago. In general, the industry has retreated from pursuing the vision of total automation for valid business reasons. There is no doubt that some smart factories will be highly automated. However, smart manufacturing is not about the degree of automation of the manufacturing floor; it is about autonomy, evolution, simulation and optimisation of the manufacturing enterprise. The scope and time horizon of the simulation and optimisation will depend on the availability of data and tools. The level of 'smartness' of a manufacturing enterprise will be determined by the degree to which the physical enterprise has been reflected in the cyber space. This paper offers a vision of smart manufacturing. Its essence was encapsulated in six pillars differentiating it from the manufacturing as we know it. The pillars were supported with ten conjectures characterising smart manufacturing.

References

1. D. Zuehlke (2010). Smart Factory - towards a factory - of - things, Annu. Rev. Control, 34(1):129 – 138.
2. W. Wahlster (2013).SemProm Foundations of Semantic Product Memories for the Internet of Things. 49(1) Springer.
3. E. Abele, J. Kluge, U. Naeher (2006). Handbuch Globale ProductionMunchen**:** Carl Hanser.
4. Chandran. S, Poklemba. R, Sopko. J, Šafár. L (2019). Organizational Innovation and Cost Reduction Analysis of Manufacturing Process. **2**7(1):183–188.
5. J. Belissent (2010). Getting clever about smart cities**:** New opportunities require new business models, Forrester Research.
6. Monostori, L (2014). Cyber-physical production systems: Roots, expectations and R&D challenges, in Procedia CIRP, 17(1):9–13.
7. D. S. Eric, K. Kyoung-sook, E. Subrahmanian, R. Lee, F. J. de Vaulx, Y. Murakami, K. Zettsu, R. D. Sriram, (2013). A Vision of Cyber - Physical Cloud Computing for Smart Networked Systems. National Institute of Information and Communications.
8. Gubbi. J, Buyya. R, Marusic. S,Palaniswami. M (2013). Internet of Things (IoT): A vision, architectural elements, and future directions, 29(7):1645–1660.
9. Belissent. J (2010). Getting clever about smart cities: new opportunities require new business models.
10. Raji, R. S (1994). Smart networks for control, Spectr. IEEE, 31(6):49 – 55.