Transactions on Computer Science and Intelligent Systems Research
ISSN: 2960-1800, eISSN: 2960-2238 | Volume 4
ICCIA 2024

Innovation and Challenges of Smart Metrology in the Industry 4.0 Era

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Abstract. Smart Metrology refer to a way of measure thing by advance technology, those technology include IOT, AI and Deep Learning. It's not only just a way of measure thing, but also provide manufacturing some way to manage themselves, especially within the framework of Industry 4.0/5.0. in this article, we will talk about some cutting-edge technology and typical case, from there, we will learn and get some basic metrology data. Finally, the challenges and trends will be discussed including some influence.

Keywords: Industry 4.0, Smart Metrology, Metrology Data, Digitalisation.

1. Introduction

Nowadays, with the development of modern society and manufacturing demands, Metrology begin to take a more and more important position in daily industry production, such as for the purpose of fill the needs of Deep Learning and Neural Networks, low process chip is always needed and it always performances better than high process chip. Fig 1 shows us the M3 chip of new MacBook pro, it's M3 chip's performance better than 16-inch MacBook Pro with M1 Max chip (Apple. 2023). To build such a powerful chip, the help of the Aligner is needed, and it's goes without saying that most of the core technology is based on the smart metrology.

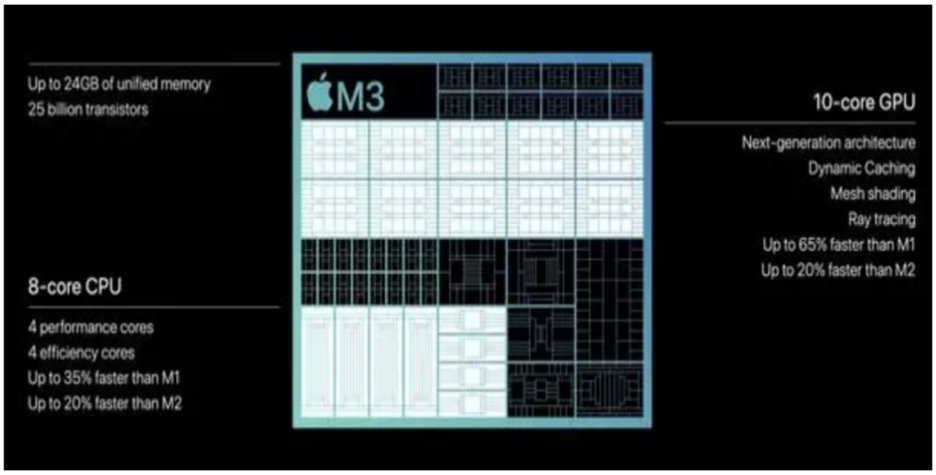

Fig. 1 M3 chip composition [image by Apple inc.]

This paper is focused on the smart metrology in the industry area. The main idea is to find out what is the position for smart metrology in manufacturing, especially till now, the age of Industry 4.0, to the future, Industry 5.0. In addition, the topic of digitalization will be discussed, because with the improvement of IOT, Virtual Reality and AI, digital technology is developing very rapidly, which do supports the development of smart metrology. Next thing will be the influence of the smart metrology, including how smart metrology influence the manufacturing to accomplish zero-defect and zero-waste and how smart metrology influence the manufacturing processes to make them more efficient.

2. Digitalisation with Smart Metrology

Table 1 shows what changes has been taken towards metrology, obviously, metrology has changed dramatically over the past centuries. From rough to precise and change from continuous exploration

to science. Especially in the 18th to 19th centuries, some scientist like Galileo Galilei strengthens the basic theory of metrology, they invented many new tools related to metrology during that period, deviation and statistical method were also introduced into the metrology during that period due to their work. All in all, with the contribution of those scientist, specifically after the advent of the computer science, digitalization begins to be introduced into the metrology, and with the help of digitalization technology, metrology becomes more precise and automated.

Table 1. The development of metrology

Stage	Main Feature
Ancient Civilization	Measurements of Length, Area and Volume were invented
Renaissance	Galileo Galilei's contribution, Advances in Mathematics and Science
The First Industrial Revolution	Statistics, Error Analysis, the establish of Bureau international des poids et mesures (BIPM)
Late 19th and early 20th centuries	Engineering Metrology, GIS
early twenty-first century	Combination of Computer Science and Metrology
Industry 4.0	Automated measurements using databases

The supports which digitalization leaves to the smart metrology are as following:

Sensor Technology: digitalization can use the way of 3D modeling and laser radar to help people measure some complex surfaces which traditional measurement methods can't. like fig 2 shows, A laser radar is a high-performance, high-precision, non-contact measurement system using two heterodyne infrared lasers (Lindqvist, R.P. et al. 2023), which can measure the complex surfaces without physically touching. Besides, the help of laser can also guarantee accuracy.

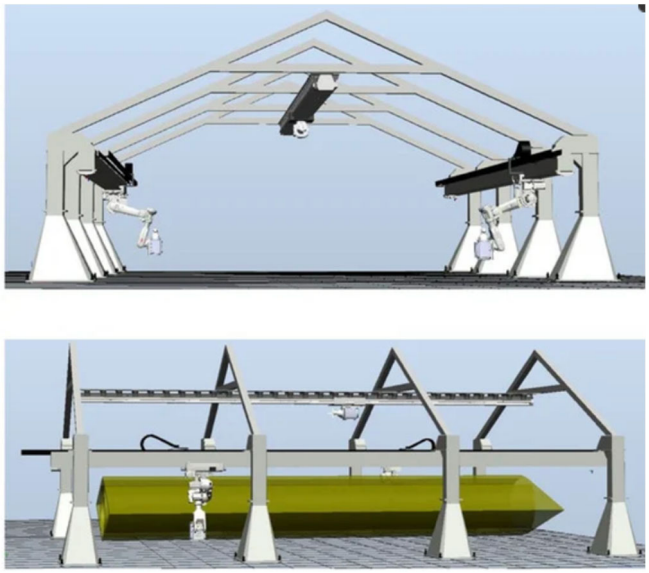

Fig. 2 automated large-volume dimensional measuring system [image by Richard P/ Royal Institute of Technology]

Data Analysis: digitalization can let manufacturing use the way of IOT, AI and Machine Learning to analysis the date, which was measured, furthermore, those way can help manufacturing get a better understanding of the date and take appropriate measures.

Data Visualization: digital technology can show the measurement results by Graphs, charts, dashboards, which can help operator analysis and get a better understanding of the data.

Automation and Integration: during the process of industrial production, digital Metrology can be combined with the Automatic Control System, which improve the efficient of the production.

3. Zero-defect and Zero-waste with Smart Metrology

To achieving zero-defect and zero-waste, engineer have no choice but to pay attention on smart metrology, because smart metrology can deeply affect the manufacturing process to achieving zero-defect and zero-waste, and there are many cases which related. On the one hand, as we all know, machine tool takes a very important position in manufacturing, and use much knowledge of metrology. Bosch, as one of the first companies which propose the concept of Industry 4.0, they developed a new kind of CNC called Perforex, like fig 3 shows, and based on this CNC, they create a metrology system called Rittal, this metrology system not only can accurately measure parts but also can marking of machined parts by its own label printer. This measuring system has helped to accelerate workshop processes, and to reduce waste material and therefore costs (KG, R.G.& Co. 2023). Frankly speaking, even this CNC and metrology system is expensive for the small workshop which needs at least cost 21,450 euros, but the potential benefits is very large.

Fig. 3 CNC called Perforex [image by Bosch]

On the other hand, 3D virtual model construction is also a typical case for manufacturing to achieving zero-defect and zero-waste. 3D reconstructed model with colour texture will not only aid machine vision tools to be easily implemented, but also will pave way for the use of machine learning algorithms (Siddiqi, M.U. et al. 2018), and by 3D model, metrology system can easily identify and calculate the location of important components, making sure manufacturing avoid any defect and waste, avoid the costs on defect.

All in all, there are many ways for smart metrology affect the manufacturing in achieving zero-defect and zero-waste, from the two cases, it's not hard to find out the major ways can be divide into two, which is hardware and software.

4. Drivers, Enablers and Barriers

There are many elements drive and enable the future metrology systems, the majors are as following:

Technological Innovation: obviously, technological innovation is not only the drivers but also enablers for future metrology systems. IOT and AI both ask scientist to come up with new technologies to fill the needs of manufacturing.

Diversity Needs: with the development of modern society there are many things which need to me measure, so it's goes without saying that there will be many new metrology systems to measure different thing in the future.

Policy: due to the influence of manufacturing, if one country wants to be powerful, they can't ignore the importance of metrology, so many countries publish policy to drive the development of metrology systems.

But we must know there are still some potential obstacles for metrology systems. For one thing, there are so many countries in the world, although BIPM was established, but metric diversity is still the major barriers. For another, the knowledge of metrology changes rapidly which leaves a big barrier for talent development, and this cause it's hard to find qualified people to use metrology systems.

5. Metrology Data

Like table 2 shows, there are many metrology data.

Table 2. metrology data

Type	Acquisition Methods	Processing Methods
Production Data	Sensors and Monitoring Systems	By using data collection systems and data analysis tools
Quality Data	Inspection and Measurement	Analyze using statistical methods
Energy Consumption Data	energy monitoring systems and meters	Monitor and conduct efficiency analysis using energy management software
Raw Material Data	purchase records and supply chain management systems	Optimize procurement and inventory management to reduce costs
Personnel Data	payroll records and training records	Analyze employee information and efficiency using human resources management systems
Environmental Data	environmental monitoring equipment	Monitor environmental data to ensure compliance and take necessary actions

From those metrology data shows in the table 2 we can easily see that there do have some data which is relevant with each other. Firstly, production and quality data are relevant with each other. Because in some occasion, the productivity of production can directly influence the quality of product. Besides, production data is related with energy consumption data, the more product you produce, the more energy you cost. Finally, energy consumption data is relevant with environmental data, because higher energy consumption sometimes means higher environment destroy.

So in order to increase productivity by using the data given in the table, there is one thing which we need to put into consideration. The environmental data, because the concept of protecting the environment is gradually gaining popularity today. So, for a manufacturing company, take care of the environment can help them gain great profit.

6. Challenges and Trends under the period of Industry 4.0/5.0

Even though the previous section says there are some elements drives and enable the future metrology systems. the challenges in metrology used for manufacturing within the framework of Industry 4.0/5.0 is still can't be ignore. Firstly, like fig 4 shows, nanomaterial is being put into many applications under the age of Industry 4.0/5.0. For manufacturing which want to use nanomaterials as their product, they have to research some metrology systems to measure the nanomaterials, because normal metrology system can't fill the demand. Besides, many metrology systems were connected by IOT, which leaves manufacturing's data confidentiality a big trouble. So, every coin have two sides, IOT have lots of convenient, but it also have it's disadvantages. Last but not least, like previous sections during the period of Industry 4.0/5.0, manufacturing has to pay attention to personnel training, especially Industry 4.0/5.0 bring us lots of new technology.

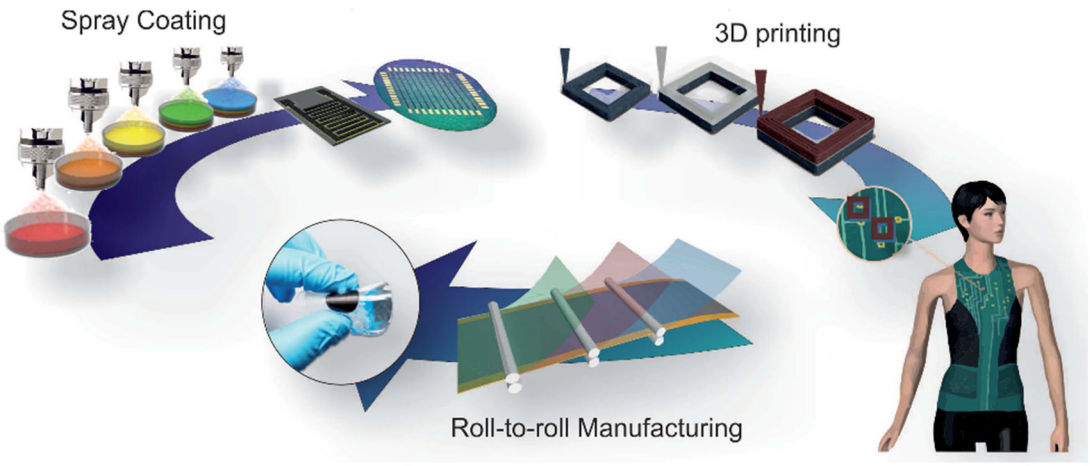

Fig. 4 Nanomaterials enable the production of next-generation energy storage systems by different manufacturing methods. [Supercapacitor array image by Husam N. Alshareef/King Abdullah University of Science and Technology (KAUST); figure wearing smart textiles image by Kristi Jost/Drexel University]

There are still some trends for in metrology used for manufacturing exist. Such as IOT, it's not only a challenge but also a trend, we can just stay at home and waiting metrology system leaves us the result, besides, when metrology system was connected with other system. It's will improve production process efficiency. In addition, Digital Twins allows manufacturing measure the product by 3D moldering, this technology will change the metrology system largely, because it not only reduces the R&D expenses, but also make product more precise.

7. Conclusion

All in all, smart metrology has many influences towards different aspects. For science, smart metrology makes us measure the thing more precise, which is good for science research, especially for specific areas like nanomaterials. For economic and society, smart metrology will let manufacturing produce better product and gain great profits and leave a deep change to our society, but those manufacturing need thinking about environmental production. Because when better product was produced, energy consumption will increase.

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