Cyber Physical Manufacturing Metrology

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Cyber Physical Manufacturing Metrology

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Abstract: The Cyber Physical Manufacturing Metrology (CP2M) is based on integration of the Cyber Physical Manufacturing (CPM) and connection between Internet of Things (IoT) and Cloud technology (CT). These are high-level methodologies for development of new generation manufacturing metrology systems, which are more intelligent, flexible and self-adaptable. CP2M generates Big Data, horizontally by integration (network of machines/CMMs, processes and sensors) and vertically by control (usually defined over five levels) which should be analytically processed and managed by the CP2M. In this paper was given, a detailed analysis of the current framework of development the CP2M. A brief overview of the concept CP2M research, particularly in Serbia is given as well.

1. Introduction

Industry 4.0 is the digital transformation of manufacturing and related industries and value chain creation processes, based on intelligent of machines and processes for industry by information and communication technology. Industry 4.0 is used interchangeably with the fourth industrial revolution. This is a new era in the organization and control of the industrial value chain, common call Industry 4.0.

The original definition of Industry 4.0, as proposed in 2011 year [1,2]: “Industry 4.0 is a German-government-sponsored vision for advanced manufacturing. Smart industry or Industry 4.0 refers to the technological evolution from embedded systems to cyber-physical systems” … “Industry 4.0 represents the coming fourth industrial revolution on the way to an Internet of Things, Data and Services. Decentralized intelligence helps create intelligent object networking and independent process management, with the interaction of the real and virtual worlds representing a crucial new aspect of the manufacturing and production process”.

This definition contains several key words, and the most important is – advanced manufacturing including advanced metrology. This means that advanced manufacturing/metrology is the basis for the fourth industrial revolution, with industrial manufacturing being integrated into digital technologies on the Internet. Industry 4.0 is the original German term. In the same context, the following terms are used worldwide: a smart factory (metrology), and intelligent manufacturing (metrology) [3].

If we perform a comparison between the development of technological systems and manufacturing metrology, we will also to come the stages of development of metrology systems, as shown in figure 1.

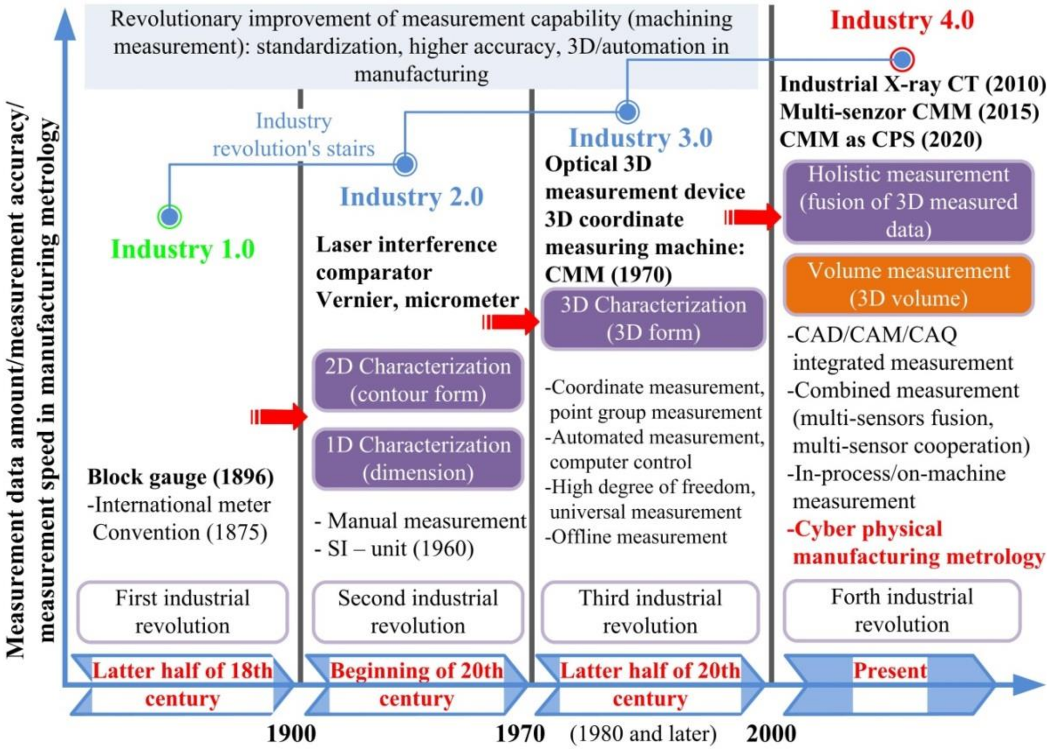

Figure 1. Correlation between era industry models and manufacturing measurement (adopted according [4]).

We can define the following facts: (i) holistic measurement model applied as a smart system (workshop, machine and part (3D measured data)), and (ii) coordinate measuring machine (CMM) as multi sensor and cyber physical system (CPS), make up today the basic framework smart metrology model for Industry 4.0.

In concept of smart manufacturing, model for CP2M is integral part, figure 2 [4]. This model has two parts: virtual and physical. They are connected by the infrastructure of the Industrial Internet of Things (IIoT). In this concept, the basic element that connects of those worlds is the CMM agent, and its function is to control CMM as a CPS. The specific units that are particularly important for the application of this model are: measuring part as a smart product, big data of metrological analysis and cloud metrology model.

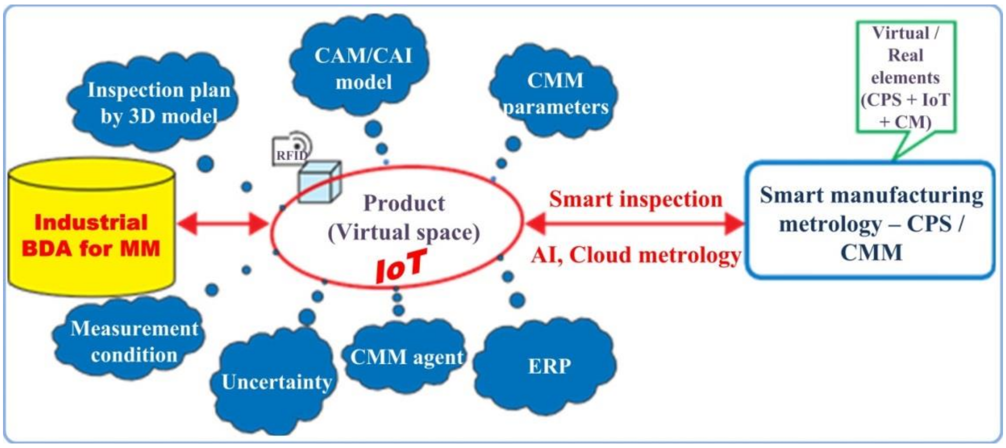

Figure 2. Model of cyber physical manufacturing metrology (CMM) (adopted according [4]).

This paper has several sections: (i) the definitions of concept Industry 4.0 and CP2M is initially given, (ii) then the CP2M model from four corner is explained in detail: metrology processes, devices for metrology, software and engineering approach, (iii) some results of the research and development of our CP2M are shown as a next, and (iv) conclusions and future research.

2. Manufacturing metrology and Industry 4.0

According [5] manufacturing metrology consist following wholes: (i) shape (size, position, form and surface texture), (ii) material (fissure, texture, hardness, and E/G modulus), (iii) function (force, moment, speed, noise), and (iv) electricity (current, voltage, resistor and magnetic size). If we look at the Industry 4.0 model framework, we can conclude that it has all types of measurements, with the first component being the most represented. From Industry 4.0 perspective, the CP2M concept can be defined through four wholes: metrology processes, devices for metrology, software for information exchange and modeling for engineering approach, which is given below.

2.1. Metrology Processes

They are issues related to the manufacturing process, would be mapped and recorded as in the virtual information system with real time in smart workshop. On figure 3 is given a link between metrological processes and elements of Industry 4.0 that support it: big data analytics (BDA, AI) and industrial internet of things (IIoT).

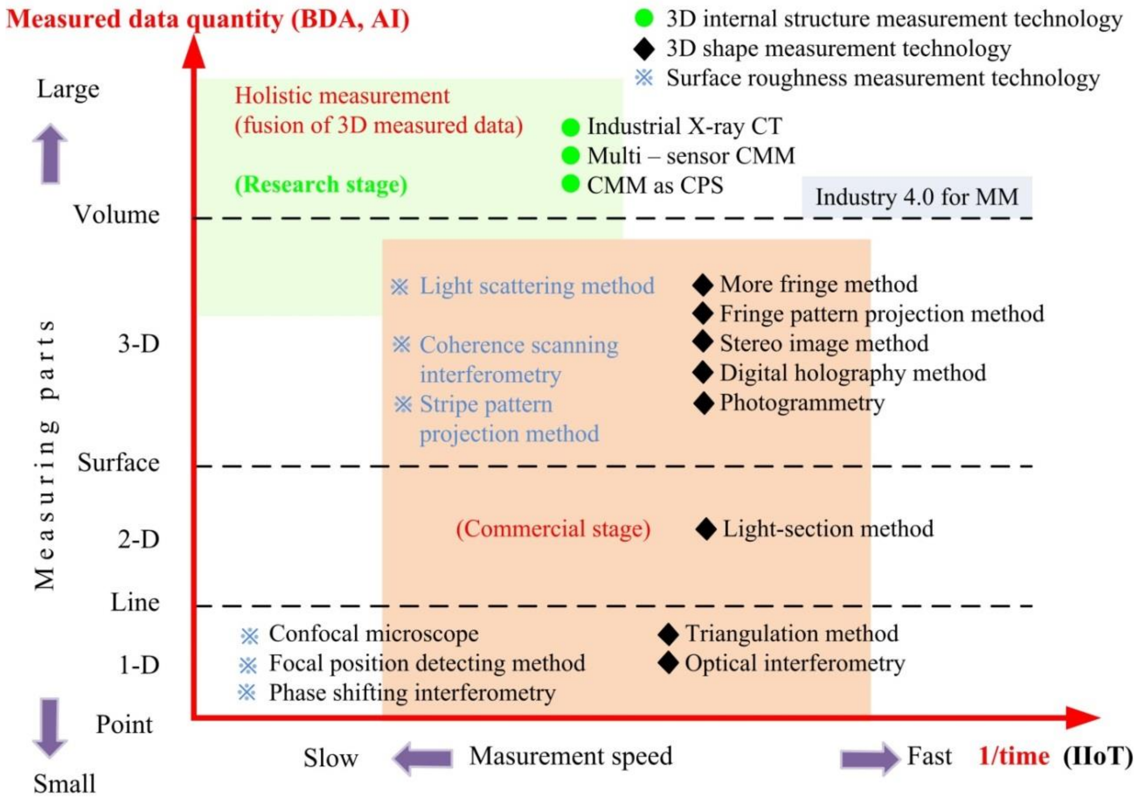

Figure 3. Map of manufacturing metrological processes and link to Industry 4.0 model (adopted according [4]).

The holistic concept of measurement generates large data sets, which are analyzed by BDA using AI techniques, and key metrological characteristics are generated on the intelligent product itself. The mapping of this information is done using IIoT, and its elements make up the infrastructure of the overall CP2M model.

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2.2. Devices for Metrology
Metrological devices within the manufacturing system in Industry 4.0 model would be considered as "Things" or "objects". These include (smart) automation devices (like as CMM), field devices (measuring robot), operating devices, mobile devices, field - buses, programmable logic controllers, servers, web access devices, etc. Relative embedded technologies will also be used to merge these physical devices with virtual systems, and also the conditions of the physical devices would be recorded automatically to the information system of smart manufacturing, figure 4.

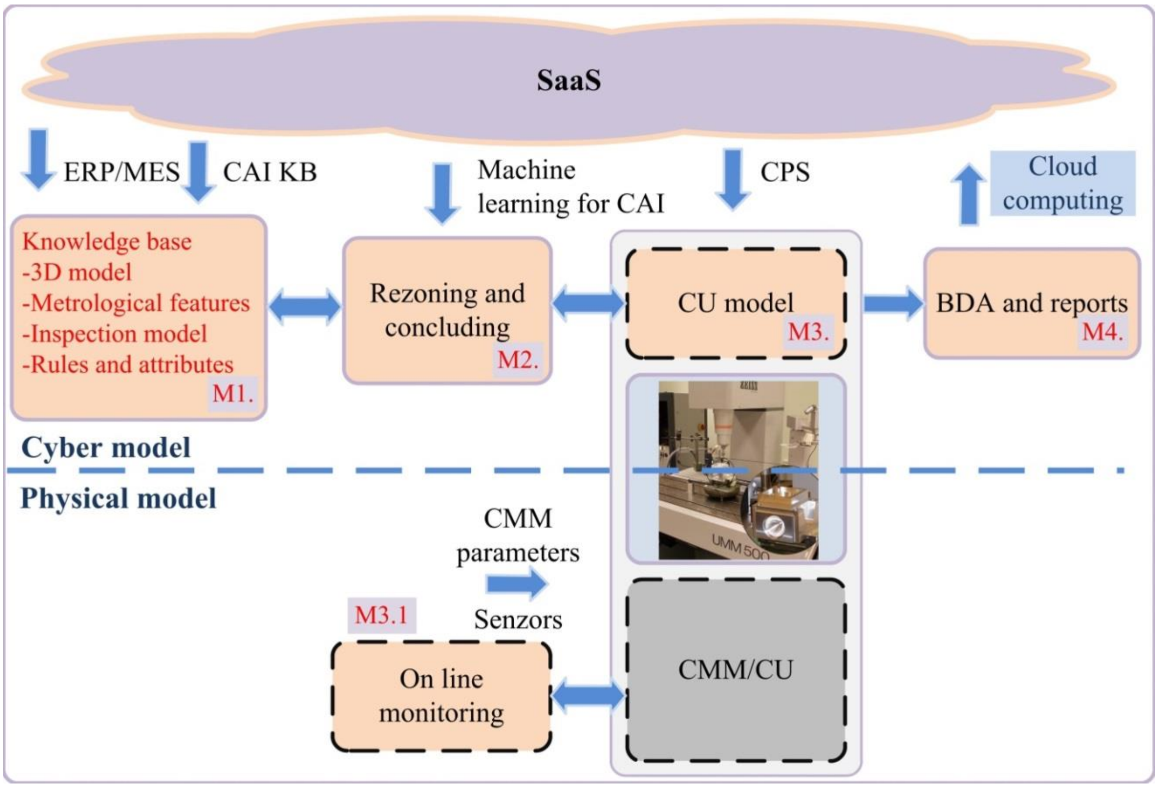

Figure 4. Cyber physical model CP2M.

On virtual enterprise level the CP2M model is connected to smart workshop (manufacturing) via ERP (enterprise resource planning) and MES (manufacturing execution system), as a rule using SaaS cloud computing model, and by IIoT this connection is realized at the physical level.

2.3. Software for information exchange
The software perspective emphasizes on the software realization for the interfaces and integration among items (IoT) from the physical-, cyber- and automation-levels in Industry 4.0. Feature-based technology and STEP standard could be considered as a main integrator in terms of linking the engineering and manufacturing domain within various CAx systems, including Industry 4.0 model. To specify the part data representation for a specific application, STEP (ISO 10303) uses Application Protocols (AP). Beside STEP APs, the following standards and interfaces are important for CAI. A vendor-independent Dimensional Measuring Interface Standard (DMIS) provides the bidirectional communication of inspection data between systems and inspection equipment, and is frequently used with CMMs. It is intermediate format between a CAD system and a CMM's native proprietary language. Dimensional Markup Language (DML) translates the measurement data from CMMs into a standardized file that could be used for data analysis and reporting. I++ DME-Interface provides communications protocol, syntax and semantics for command and response across the interface, providing low level inspection instructions for driving CMMs, figure 6 [6].

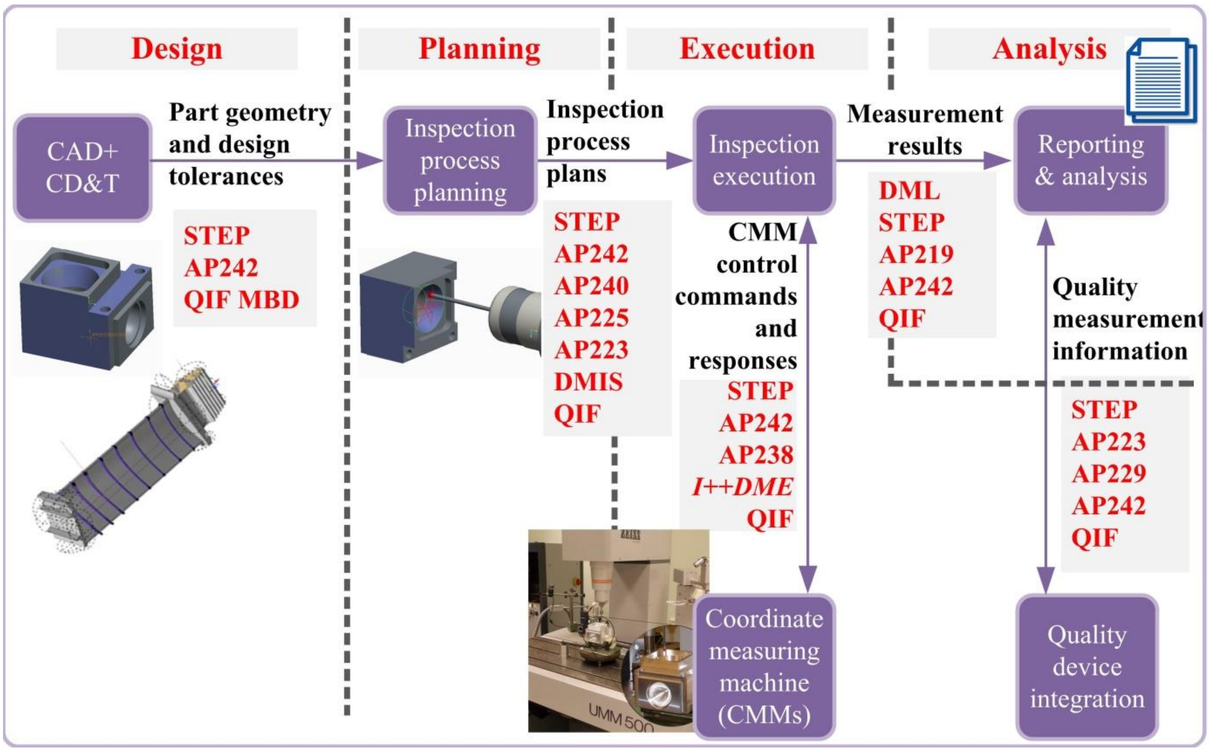

Figure 5. CMM interoperability model for Industry 4.0 / CP2M model.

The inspection planning is the most important step in the development of CAI framework a freeform surface, for CP2M model as a part of Industry 4.0 concept. In a context of the research presented in this paper (section 3) [3,12,13,14], the most important approach is STEP and STEPNC enabled inspection. Starting from STEP AP219, AP224, AP238 and AP242, CMM generates an inspection plan in DMIS (Dimensional Measuring Interface Standard - ISO 22093) format [6]. The Quality Information Framework (QIF) is an ANSI (the American National Standards Institute) standard that defines an integrated set of XML information models to enable the productive exchange of metrology data throughout the entire manufacturing quality measurement process [7]. OPC UA is next open standard for information exchange on industrial communication: devices within machines, between machines and from machines to systems. OPC UA was the recommended industrial communication standard in the Reference Architecture Model Industry 4.0 (RAMI 4.0) [8]. It provides both communication protocol and information modeling method (IIoT), allowing easy modeling and development of digital twins of manufacturing equipment in the cyberspace for Industry 4.0 model.

2.4. Modeling for engineering approaches

Industry 4.0 is building smart factories in deployment that have four dimensions, figure 6 [9,10,11].

Elements of manufacturing metrology include all part on smart factory: (i) smart manufacturing (smart metrology) based on advanced digital-oriented technologies (additive manufacturing, cloud computing and internet of things). It has automated flexible lines that adapt production processes with changed conditions to the type of product, while sometime maintaining high quality, high productivity and flexibility, as well as production volume, with optimal consumption of resources; (ii) smart products (advanced production mode and new characteristics, including also of metrological parameters). They generate and send to the manufacturer exploitation feedback information, which is used primarily in the field of customer service. On this way increases the value added of the product, and the manufacturer develops a new business model (product + service); (iii) new ways workers perform their activities, based on advanced digital-oriented technologies (smart working), and (iv) smart supply-chain (procurement of raw materials and delivery of finished products). Bidirectional exchange of information in collaborative production, using it exchange also for digital platforms of design of the innovative products.

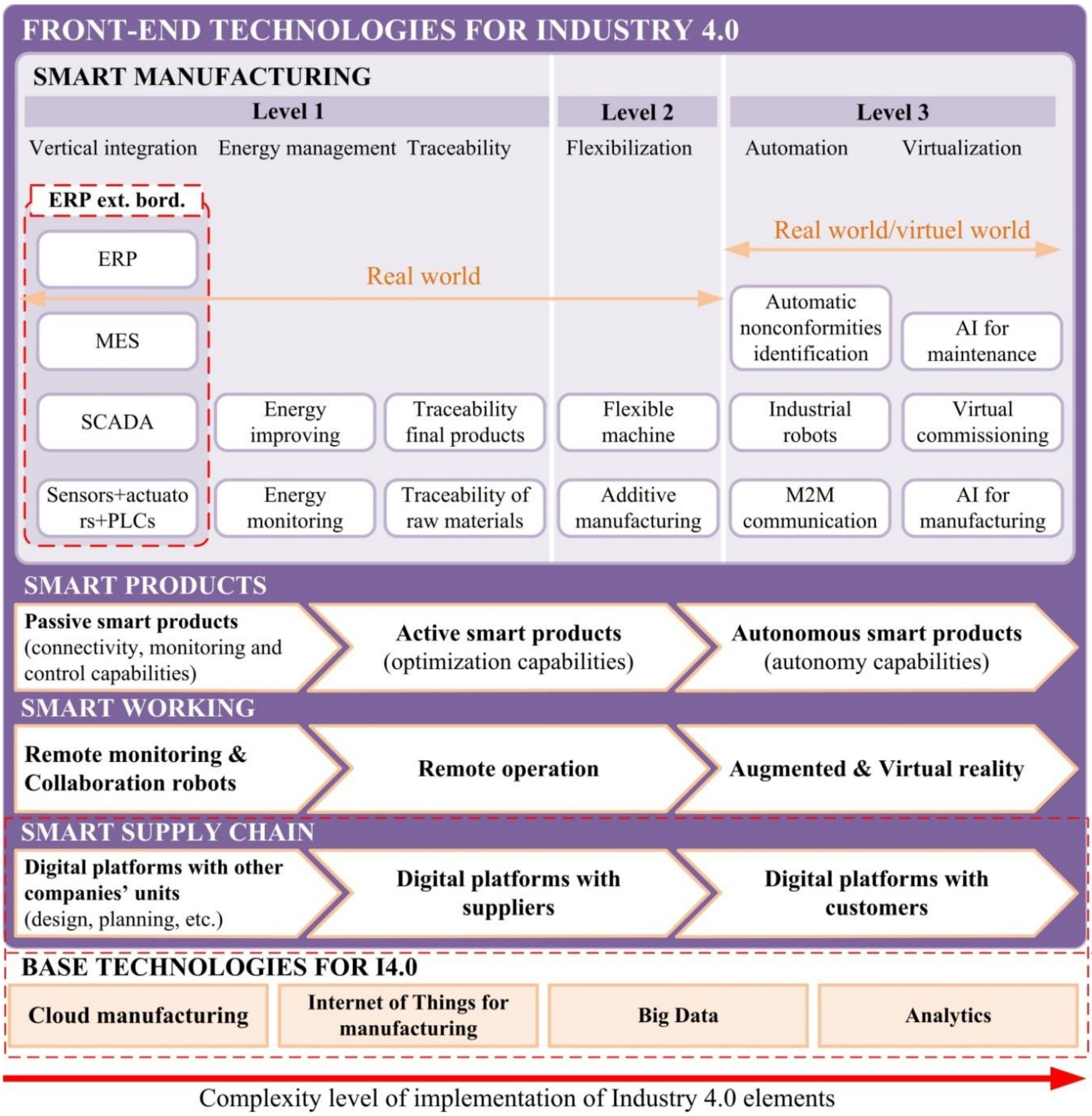

Figure 6. Framework of Industry 4.0 model for smart factory (adopted according [9]).

3. Cyber-physical manufacturing metrology model (CP3M) – some research results

The framework of CP3M model consists of the following sub – modules [3,12,13,14]: (a) module for definition and recognition of geometrical features (GF) from CAD/GD&T model of the measurement part, where we used them for definition of metrological feature (MF) (b) module for building of intelligent inspection process planning (IIPP), that contains methods for prismatic parts presented, and method for freeform surfaces application, (c) CMM – generation of control data list for CMM that is transferred to CMM using cloud technology, and (d) module for analysis of results and generation of the final measuring reports. Cloud services within the organization provide the necessary information for integration of knowledge and data from various phases in product design and manufacturing/metrology into inspection planning, and make available information about inspection results to all interested parties in product lifecycle.

In CP3M is a feature-based model for probe path planning for sculptured surfaces using an example of turbine blades [12, 13,14]. The probe path planning model represents a part of CP3M for free form surfaces. In this model the geometrical information for feature description is taken from CAD model of the part in IGES format, figure 7.

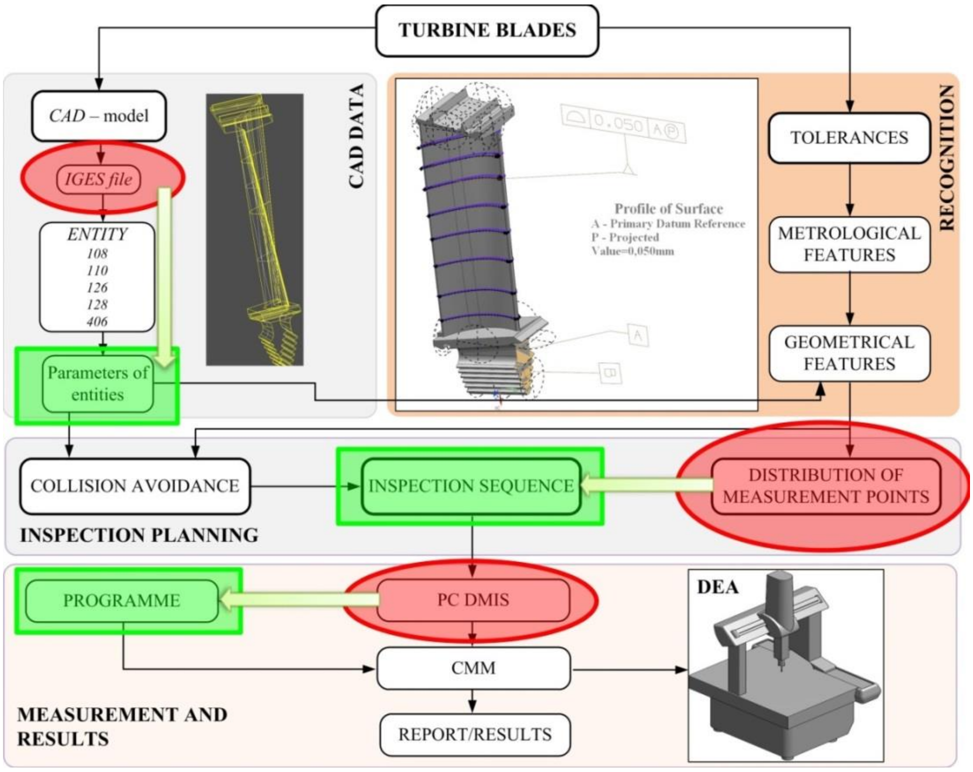

Figure 7. Inspection planning of turbine blades CP3M model.

The inspection plan consists of input CAD data, recognition of metrological and geometrical primitives, definition of inspection sequences, distribution of measuring points, collision avoidance principle, and measurement and analysis of the results. Realization of the CPM3 model in practice is being investigated for the DEA CMM, which is based on the IoT Cloud technology. Connection of the physical and the virtual world is provided using an IIoT device - Raspberry Pi3, which, via industrial router, has access to the Internet and realizes direct communication with the CMM control unit, using Ethernet or Wi-Fi connection. After each measurement, report is generated and automatically sent to the Cloud where it is stored. The system sends the report to a user or a predefined group of users, via email or SMS service: start/end of measurement, various alarms, environment sensor readings and other important information.

4. Conclusions

Cyber-physical manufacturing metrology play very important role in Industry 4.0 model for manufacturing. Already today, manufacturers of metrology equipment, in particular CMM, produce them as CPS, which can be used in Industry 4.0 concept in industry. On the other hand, researchers around of the world have already presented their results from the field research of CP2M. Some of them have already been presented in this paper. In the coming period, rapid diffusion of these models (Industry 4.0 and CP2M) into industrial applications should be expected, as soon as possible.

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