A Perspective on Advances in Cloud-based Additive Manufacturing

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Abstract: With advances in technology coupled with Industry 4.0, it has become a reality to provide real time information along with monitoring 3D printing process remotely. The unique benefits associated with additive manufacturing (AM) is its potential to produce complex-shaped personalized products with reduced material waste, fewer cost of manufacture, lesser consumption of energy during manufacturing, while allowing in producing the products on-demand. This paper covers the features of cloud-based Additive Manufacturing (AM) by describing about Sustainable Distributed Manufacturing, Automated Order-Processing, Smart resource efficiency improvement, Big data-driven, smart and sustainable manufacturing, resource sharing between different stakeholders, rapid product development with cloud-based AM Platform (CAMP) and cloud-based manufacturing process monitoring. The paper aims to study the recent advances that took place in cloud-based AM and enlist its salient features to help researchers and manufacturing industry adopt the same and get the basic information. Big data-driven, smart and sustainable manufacturing is the present need of manufacturing at its full potential with secure, real-time communication and intelligent process monitoring and diagnostics.

Keywords: Additive Manufacturing (AM), Cloud-based Additive Manufacturing, 3D Printing

1. Introduction

Connecting 3D printers to the cloud is a fundamental step that allows customers to configure printing processes based on their requirements. Further, the hardware can provide real-time information to the cloud so that printing processes can be monitored remotely. As 3D printing processes usually take hours to finish, it is important to understand AM material characteristics with 3D printing principle[1)] and identify failures as early as possible to save both time and cost. In this way, customers are able to control the printing strategies. This is one of the main influencers of printed part quality. In this era of the fourth industrial revolution, there are several enabling technologies to attain a networked environment such as the Internet of Things (IoT) and Cyber-Physical Systems (CPS). Meanwhile, the rapid development of Artificial Intelligence (AI) technologies has the potential to increase the smartness of the cloud platform so that it is able to understand what is occurring in the connected machines. However, current research on this is still at an early stage and there is limited knowledge on how to integrate these advanced technologies to realize a more autonomous and intelligent cloud environment. Therefore, the second challenge is to enable a real-time, secure, and standard communication in the cloud environment and improve its smartness.

With the recent technological advancement, making use of resources ad-hoc in place of conventional resources in setting up the manufacturing processes is becoming a reality through AM. In order to offer better solution to the manufacturing problems in conformity to the cloud manufacturing (CM) paradigm for clarity and the accountability of AM processes, AM resources must conform to the principle of transparency[2-4)]. Managing the manufacturing resources systematically and correctly in order to launch cloud-based 3D printing services is a challenging problem. In order to handle such problems, cloud-based collaboration architecture with peer self-managing node can be one solution. The collaboration architecture can facilitate in bridging between self-managing nodes to share among them available manufacturing resources in building a scalable and dynamic AM cloud [5-7)]. As the essential requirement in context of Industry 4.0, it is highly recommended to adopt AM for end-part manufacture on integrating cloud-based AM technology with cyber-physical schemes[8-10)].

Unique features of AM technology assure entirely a new path to rapid product-development. Products of varying material characteristics can be obtained by controlling some significant process parameters during their 3D printing. With its integration with CM paradigm, AM technology offers ease in accessing manufacturing resources and efficient utilization of distributed recourses, allowing minimum expense. The cloud-based AM technology that is available at present targets mainly on offering services for mere 3D printing and does not focus on supporting customers throughout the process of product development. It is therefore required to think of a modern CM platform to bridge together and manage all the hard and soft resources, perform the tests, affirm its support from end-part manufacture alongside designing and process-planning[11-13]. CM platform can also support the researchers keen to determine mechanical characteristics of additive materials[14-16]. This platform can allow the user to obtain data to study functional behaviour of additively printed parts under varying conditions[17-19]. The CM platform can enable effective AM process diagnostics and process health monitoring as well, allowing intelligent effort to put by the local servers based on the processing of related real-time data collected from sensors during manufacture.

2. Features of Cloud-based AM technology

2.1 Sustainable Distributed Manufacturing

Sustainable manufacturing is usually described by manufacture or printing of parts when the entire process of product development affirms a strong relation to three independent essential pillars; environmental (biotic and abiotic surroundings) responsibility, social welfare and economic evolution[20-23].

The usual drift in opting sustainable distributed manufacturing is servicification through distributed cloud-based manufacturing systems (DCMS) resulting into a paradigm shift of manufacturing technology due to growing embedment of tools of information technology in manufacturing[24-26]. DCMS offers significant advantages assuring mass customization for the product in a shorter overall lead time under competitive costs with greater flexibility in product's supply-chain. Through DCMS industries can outperform to lean the product's supply-chain with almost no dependence to the machine, material, location and inventory enabling just-in-time manufacture with build-to-order scheme. The DCMS can led a responsive supply-chain through dynamic control across product planning and development[27-30].

Such services from DCMS often find it difficult to measure the sustainability performance of a particular selection made for the supply-chain due to its dynamic behaviour letting in the variability and uncertainty in source material and manufacturing processes[31]. The DCMS attributes such as location independency and customer controlled dynamic planning- optimization schemes may allow relative comparison of possible supply chains though the impact of delivery services may offer complexity[32-34].

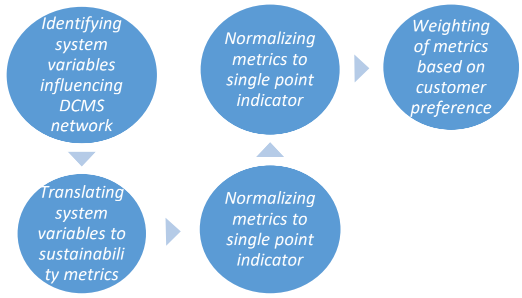

Fig.1: Sustainability Assessment Framework of DCMS

2.2 Automated Order-Processing

Although AM technology is in close accordance with Industry 4.0, researchers believe that processing of order needs to be given attention and should be designed based on consumer's preferences. Therefore, automation of order-processing has to be made on cloud-based platform where consumers will be offered options like quotation coting, customer-request register and 3D visualization apart from selection of required features, this platform needs to show concepts involved and the process-flow. According to the manufacturing constraints and the guidelines to conform to, part's geometry required to be checked automatically by a part-screening service on this platform as an important stage during order-processing[35-37].

The material and process specific design-guidelines for the parts to conform to are important to consider in order to allow for the tolerances on the part to get printed in a fault-free automated CM platform. Based on these guidelines, an algorithm on the platform will inspect the submitted STL (Standard Triangle Language) file of the parts for allowable dimensions/thicknesses and gaps/holes.

The entire process of generating a successful order, that conventionally requires high user input and manual effort, can employ on the CM platform a decision support methodology building a communication interface between manufacturing service and the customer. Fig. 1 represents a scheme for the features offered by a cloud-based automated order-processing platform[38-40].

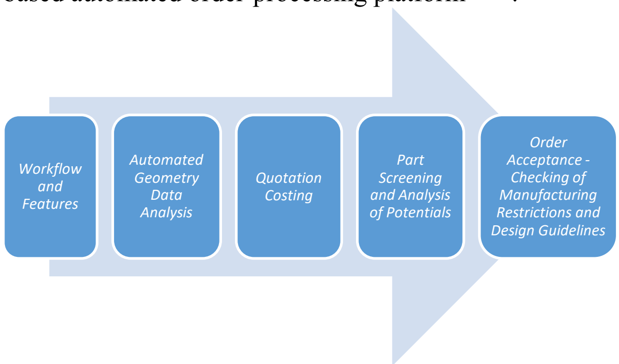

Fig.2: A cloud-based automated order-processing platform

2.3 Smart resource efficiency improvement

Cloud-based AM technologies forming a key feature for Industry 4.0 have a potential making improvement on resource efficiency for a network a reality.

In context to the higher degree of freedom, out of available popular AM techniques, Laser Powder-Bed Fusion technique (LPBF) is gaining tremendous attention on being advantageous in many ways compared to other freeform fabrication processes. Having typical field of application as rapid prototyping, LPBF has expanded its domain and is now popularly employed in aerospace and medical. LPBF works on a process that employ laser irradiation of pre-laid powdered-metal bed to perform selective laser sintering (SLS) or selective laser melting (SLM) based on the process parameters. The common practice of opting for AM technology is to print single entities or small units which negatively affect to a large the process efficiency. It is highly recommended to employ AM to print assemblies comprising of several parts under the same building volume in order to improve the resource efficiency[41-43].

Since the time consumed in laser screening completely depends on the area of surface to be scanned, the time efficiency can significantly be improved on printing a number of parts simultaneously on the network platform. In printing the parts simultaneously, the overall processing-time can significantly be reduced which, in turn, can lower the machine power consumption leading to improved energy efficiency. In order to improve the material efficiency, the quantity of metal powder, left unused on the bed after part manufacture through laser melting of metal powder, required to be reduced and recycled[44-46].

For resource-efficiency to get improved, it is essential for the AM framework to offer smart CM platform for AM services. Advanced information technology support to Industry 4.0 enables the CM platform to dynamically share the AM services at maximum potential with high resource-efficiency[47-49].

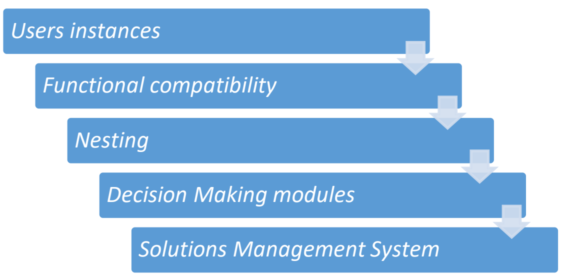

Fig.3: Smart resource-efficient Framework

2.4 Big data-driven, smart and sustainable manufacturing

Smart manufacturing is now gaining more attention of researchers from academia and industry with the growing trend in employing information technology tools in manufacturing technology. The term sustainable and smart AM (SSAM) can be used in this context to represent a technology that combines key techniques of AM, sustainable manufacturing and smart manufacturing. An AM framework is therefore needs to work based on big-data analytics. The big-data driven sustainable and smart additive manufacturing (BD-SSAM) can support in making better decisions in view of sustainability, productivity and profitability[50-52]. Selecting the right suggested options in real-time offered in smart manufacturing based on the choices made by the customer will lead to better resource handling and the work flow which further leads to rapid product development.

Smart manufacturing integrates together the basic conventional manufacturing and the modern big-data based technologies, for example industrial internet of things (IIoT), Big Data Analytics (BDA) and Artificial intelligence (AI), for improved process control and making smart real-time decisions. These modern technologies also help in reducing power consumption, impact on environment and the wastage of materials during manufacturing leading to better resource-efficiency and green supply-chain. Real-time data generation and analysis is the demand for a smart manufacturing technology that is applied from raw-material handling to manicuring to product-packaging [53-55].

SSAM offers:

- Market demand prediction
- Improved product design
- Improved product quality
- Reduced power consumption
- Smart process control

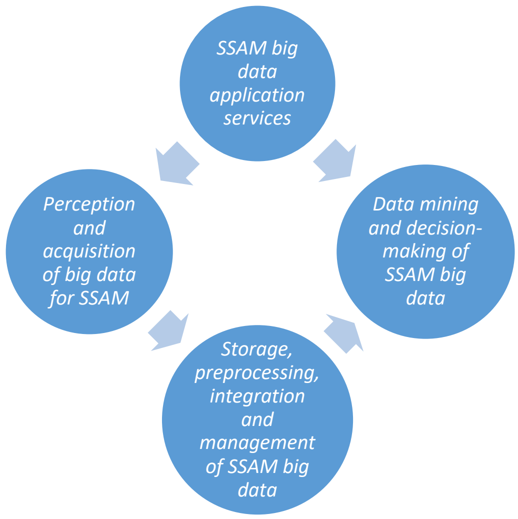

Fig.4: Big-data based architecture in SSAM

2.5 Sharing of AM resources and capabilities between different stakeholders

People from manufacturing industries always wish to predict the dynamic changes in the demand to survive with the competitors. Collaborative business-ecosystem with the stakeholders can make their predictions at ease where new approaches, improved methods, latest technological tools can be suggested and implemented. Use of cloud computing in AM industry helps in sharing among stakeholders the manufacturing resources and technological tools. The business-ecosystem for CM platform helps business partners to connect, collaborate and be able to adapt for the dynamic business changes. This digital infrastructure can also facilitate against varying manufacturing trends and modern technology adaption, thus comply with Industry 4.0. The use of modern technology in manufacturing helps improving the productivity, ensures better performance of processes involved, and the improves profits. With the integration of modern technology, manufacturing-ecosystem can offer smart features to connect, collaborate and compete. Decentralized services can be controlled and managed effectively on CAMP. Such CM platform can process manufacturing resources and services amongst the stakeholders. The modern manufacturing-ecosystem, with smart decision making capabilities to have better control on the processes, demands manufacturers to have adequate knowledge of when and how to collaborate across the business boundaries. In order to address the challenges of dynamically varying manufacturing demands, companies present on CM platform can share their resources and services to give out the best possible manufacture. The CM ecosystem, therefore, ensures achieving a flexible distributed platform to give support in tackling the varying manufacturing demands, to set up between the stakeholders effective collaboration of resources/services and to give room to adapt for the new technology for betterment.

It is highly required to have a measure of impact of manufacturing-ecosystem on biological-ecosystem in order to rate the performance of the manufacturing companies depending on their impact on the bionics. Manufacturing-ecosystem is a metaphor that present companies in a strong business relational environment. Manufacturing companies and stakeholders need to collaborate on CM ecosystem to develop among them an innovative environment. A greater level of collaboration between company-company, producer-consumer and human-machines can be achieved with digitization and modern information technology tools.

Collaborative CM ecosystem provides benefit to each stakeholder, such as material suppliers, logistics providers, technology partners and policy-makers. Each contributes significantly to the produce the final product with improved functionalities to match the customer's needs. Product's digital representation on popular digital marketplace can make the consumer understand the product details with 'rotating view' mode. Customer can be asked for material choices and can offer customization for the product. Once the order is placed, the product can be additively printed in-house through an ad-hocor contractual AM service. Digital marketplaces help in reducing the cost and time while product's customization helps in producing suitable and custom-built product.

The ecosystem-driven CM is the future of product-manufacture. To seize the profit, stakeholders will tend to opt for more value added-services, creative technology collaboration with flexible workforce[56-58].

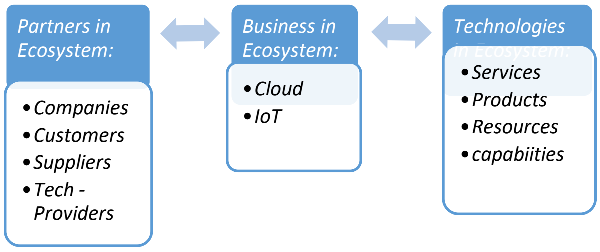

Fig.5: Ecosystem driven AM industry

2.6 Collaborative rapid product development with CAMP

In AM technology, complete design information is digitized in the form of product's STL file and the same can be shared among the stakeholders on a cloud-based platform. Companies across the globe are now offering cloud-based 3D part printing, from where information and services can be accessed and availed, enabling sustainable utilization of available manufacturing resources. Regular improvement should always be considered to enhance the services from CAMP keeping in mind:

- Interaction of machines with the cloud.
- Simple service definitions.
- Limited AM support.

Intelligent integration of technologies is now possible with the aid of IoT (Internet of Things) services resulting in to a manufacturing environment to smartly achieve sustainable manufacturing, can be produced[22].

In order to make the CAMP-services customer-centric research has to be conducted to find the ways of making services available through CAMP helpful for the customers to choose them efficiently[59-61]. In this regard, architecture of an IoT enabled CAMP can be designed based on the Bayesian Networks[62] (BNs) where decision making can be linked to hybrid Multi Criteria Decision-Making (MCDM) method to build an informative environment for product development supporting design and process planning[63-66]. A Cyber-Physical 3D-Printer (CP3DP) is required for 3D printing. Issues resulting to printing-failures must be identified and addressed to fail-safe the entire process[67-69].

2.7 A cloud-based manufacturing process monitoring

In order to have manufacturing environment allow for process monitoring, cloud-based platform needs to have intelligent diagnosis services[70-72]. The diagnosis services work based on distributed resources over the network and help in monitoring printer condition, leading to better control on the process. The manufacturing environment integrates a cyber-physical system with sensors and communication networks[73-75]. Intelligent diagnosis can be made for set-up life consumed through knowledge based algorithm processing the data collected from sensors[76-79]. The diagnosis system must activate the local server to take corrective measures against the situation met and should interact with machine tool-control unit[80-84].

3.0 Conclusion

With rise in technology advancement, cloud-based AM is gaining importance and the same has been studied in this paper via existing literature review. It has been seen that the current research on this is still at a very nascent stage along with lack of knowledge on how to utilize advanced technologies at their full potential. It is clear that the technology integration at CM platform is highly required to setup and allow for fine-tune between various stakeholders collaboration of resources/services. It has been seen that in order to efficiently use cloud-based AM, there is a need for real-time, secure, and standard communication in the cloud environment. This paper has also looked at the features of cloud-based AM like Sustainable Distributed Manufacturing, Automated Order Processing, Smart resource efficiency improvement, Big data-driven, smart and sustainable manufacturing, resource sharing between different stakeholders, rapid product development with cloud-based AM Platform (CAMP) and cloud-based manufacturing process monitoring. AM has all the potential to support manufacture of customized products with the adapt of modern technologies to facilitate the manufacturing processes on cloud right from order processing with the choices for materials and features where stakeholders can also easily contribute with their expert services securely, to finally dispatching the product to the customer. The AM process can easily be integrated with IIoT, BDA and AI to further improve the sustainability and the customer experience. Thus, it is coming out clearly that there is a lot of scope for future research in this area by looking at one feature at a time.

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