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The Critical Assessment of Cloud Manufacturing Technology and Future Trends

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Abstract— Cloud Manufacturing (CM) has created huge stir in manufacturing world recently. Combining beneficial aspects of Cloud computing with those of traditional manufacturing methods resulted into emergence of new paradigm of Cloud manufacturing. In this paper, thorough review is presented regarding the same, so as to understand the concept behind it. Identified advantages and limitations are assessed and listed down in later part. Some of the new technologies carrying great future scope, like 'Cloud Robotics', 'Cloud Based Design and Manufacturing', 'Internet of things', are also explored in this paper. Paper concludes on the note that Cloud manufacturing is indeed responsible for huge progress in manufacturing sector, though overall development is still in earlier phases and more research work is yet required.

Index Terms— Cloud Computing, Cloud Based Design and Manufacturing, Cloud Manufacturing, Cloud Robotics, Internet of Things (IoT).

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I. Introduction

Cloud Manufacturing (CM) has been gaining a lot of attention in last decade of so. It is probably one of the best crossfield applications of Cloud computing technology. Widespread reach of internet and development of smart phones, portable gears etc. are some of the main reasons behind its success. Especially with Cloud technology, we can now consider computing as utility like water, energy etc. [1]. The most striking feature of Cloud computing technology is Everything-as-a-Service (XaaS). Cloud manufacturing takes advantage of same feature. Decentralization and distributive nature of manufacturing processes can be achieved by integration of Cloud computing technology with it [2].

Manufacturing world is itself going through lot of revolutionary transformations. With emergence of concepts like 'Design Anywhere, Manufacture Anywhere', Rapid Prototyping' etc., entire manufacturing sector has become more service oriented and customer centered. Thus there is need of flexible, reliable and secured system which will give feasible and sustainable solutions to all these issues of modern manufacturing world. Cloud manufacturing proves to be ideal solution for it because of properties like utility pricing, interoperability, remote access and control of data, multi-tenancy, resource sharing etc. Some of the definitions of Cloud manufacturing are given ahead:

1. A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction [3];

2. Cloud manufacturing is an integrated cyber-physical system that can provide on-demand manufacturing services, digitally and physically, at the best utilization of manufacturing resources [4];

3. Cloud Manufacturing is a networked manufacturing model in which locally and globally distributed manufacturing resources for complete product life-cycle are made available by providers for satisfying consumer demands, and are centrally organized and controlled as manufacturing Cloud services. The model supports unified interaction between service providers and consumers, for trading and usage of configurable resources/ services, as well as dynamic and flexible cooperation and collaboration in multi-partner manufacturing missions. Distinct characteristics for use of services are that they are scalable, sold on demand, and fully managed by the provider [5].

In simple words, Cloud manufacturing is a system by which you can manage the entire manufacturing process with the help of Cloud technology, independent of the constraints like time, position or infrastructure etc.

The purpose of this paper is to study and assess the Cloud manufacturing paradigm with respect to ongoing research and future scope. Also to determine crucial factors affecting Cloud manufacturing system. For this work, no. of papers from reviewed journals were referred so as get keen insights of this topic. For simplification purpose and confining to the scope of topic, selected few only are mentioned here.

The remainder of the paper is arranged as follows: section 2 provides literature survey of Cloud manufacturing system technologies from research-development and implementation point of view; section 3 describes current and future trends of CM systems; in section 4 a detail discussion is given based on study done so far with conclusion and future scope; and references are given at the end of the paper.

II. Literature Survey

Emergence of internet proved to be milestone in technological development. Internetworking became far easier because of internet. In last two decades or so, many new techniques came into existence for the very same purpose such as grid computing, cluster computing, peer-to-peer (P2P) computing, service computing etc. Though all of them had shown great promises at start, many limitations came into light in later times. For example, in grid computing, we get good

scalability and decentralized user management ability but potential of creating third party solutions is very limited; in cluster computing, low latency-high bandwidth interconnection network can easily be created but it lacks capabilities such as utility pricing or distributed resource and service management etc. [1]. The latest technology, known as Cloud computing, has given active solutions to most of those shortcomings of other computing techniques. Cloud technology has made computing more service oriented and has affected other related fields too, where information and communication technology plays crucial role like design and manufacturing sector.

Area of Cloud based manufacturing or simply Cloud manufacturing (CM) has initially been explored in order to overcome limitations of networked manufacturing. Such as networked manufacturing lacks strong and rigid structure, which often leads to quality concerns. Also it isn't adaptive or flexible in nature. Scalability and interoperability are major issues in networked manufacturing [6]. But with passing time Cloud manufacturing proved to be more promising than speculations. Since last 5-6 years, a lot of research work has been going on, dedicated specifically towards development of Cloud manufacturing system. This work includes development of CM system architecture, platforms, frameworks model or small scaled applications.

Brant and Sundaram proposed Cloud based system for micro-additive manufacturing of metal structures, focusing on on-demand control and feedback [7]. In [8], implementation of broker system for Cloud additive manufacturing was proposed using ranking method. Valilai and Houshmand proposed XMLAYMOD platform based on Cloud manufacturing system [9], [10]. In this, standard STEP data format and XML has been used for development of Cloud system structure. Effective use of Stochastic Petri Net (SPN) model was done for creation of Cloud based additive manufacturing system in [6]. In [11], [12] Cloud manufacturing solution described focusing on distributive nature of manufacturing processes.

Now considering subtractive manufacturing, Cloud technology proved to be useful. Complex part machining [14], Effective process planning [15], optimization of overall equipment selection and overall machining [16] can be done using Cloud manufacturing techniques [13], [17]. Xu proposed four layered architecture for Cloud manufacturing system. A computing and service oriented model was described in [18].

A fundamental layered framework of Cloud manufacturing is given in Fig 1 below,

Fig 1 Fundamental CM layered framework

Apart from these, there were no. of Cloud manufacturing platforms, architectures or system designs have been proposed so far by researchers. And all of them can be considered as stepping stones towards development of a Cloud manufacturing system, ideal for tackling real world manufacturing problems. In next section of paper, a detail description is given on current research scenario and future trends in the field of Cloud manufacturing.

III. Current and Future Trends in CM

Although there has been tremendous research going on in Cloud manufacturing system development, we are still in earlier stages of it. Since last few years, researchers and developers have started amalgamation of technologies with Cloud manufacturing systems for better outcomes. Some of the most promising among them are given ahead.

A. Cloud Based Design and Manufacturing (CBDM):

Cloud Based Design and manufacturing is concept which goes one step ahead of the CM. In this, not only manufacturing but designing is also made available as a service via Cloud platform. There are Cloud based design platforms available already, such as AutoCAD360 which allows designers to edit, view their CAD file virtually in smart phones, tabs etc. CBDM combines the features of Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) and Computer Aided Engineering (CAE) on virtual level itself. It allows cross disciplinary designing and manufacturing team to work on same product model simultaneously [19]. The prototype system of CBDM theory called MENTOR (Manufacturing Experimentation and Outreach) was developed at Georgia Tech. It combines the features of CAD software and additive manufacturing technology [20]. CBDM concept has great future scope as it has the capacity to give the solution on interoperability. Since designing is provided as a service, there will be need of standard format for CAD files, which will solve the problem for interoperability.

Also in SMEs, where infrastructure and money are major concerns, CBDM would be beneficiary as it inherently possesses 'utility pricing' property.

B. Cloud Manufacturing and Internet of Things (IoT):

Cloud manufacturing supported with Internet of things technology turns out to be highly efficient and productive combination. IoT consists of technologies like sensors, actuators, RFIDs etc. Combination of IoT and CM has been major topic of discussion because it gives capability of automation. Real time data collection, feedback and performance analysis, remote operation monitoring and process control are some of the features of automation. Those can be achieved easily with CM-IoT. 'Factories of future' are being developed using this technological paradigm only. Wang et al. [21] discussed assembly automation with Cloud-IoT technique using Object oriented product model template concept.

Huge research and development is going on now in the fields of Cloud manufacturing and Internet of Things (IoT) technologies. Its contribution to future manufacturing sector is

only going increase and will be of high importance in the field of automation.

C. Cloud Robotics:

Cloud robotics is a branch in which resources in the field of robotics are controlled, maintained and shared with the help of Cloud technology. With respect to Cloud manufacturing, Cloud robotics proves to be major aspect as it acts as a bridge between virtual world and physical world. Overall effectiveness of Cloud manufacturing system can be increased using robotics. It is also possible to provide this as a service (Robot-as-a-Service) because of Cloud technology [22]. Owing the discussion from previous topic, Cloud robotics will have invaluable importance in automation process. It not only gives scalability option in manufacturing firms but also can be used in environment unsuitable for human intervention. Some of the ongoing research works in the field of Cloud robotics are RoboEarth program, Rapyuta framework, RoboBrain, MyRobots, COALAS, etc. As research and development in the area of artificial intelligence is gaining momentum, it will surely increase use of Cloud assisted robotics in upcoming time. Wang et.al [23] proposed Cloud-based robotic application layout in which, robotics were used as service attribute on virtualized level.

There are other manufacturing fields too, which are benefiting from Cloud manufacturing technology. Cloud manufacturing can be utilized to increase overall performance and efficiency of semiconductor manufacturing. Bottlenecks in wafer fabrication in such processes can be minimized up to great extent by optimal resource allocation using CM [24]. Use of 'Digital Eco Factories' has gained attention lately for sustainable manufacturing. Cloud technology proves to be essential part of it because of feature like Software-as-a-Service (SaaS) [25].

'Manufacturing operations management' (MOM) and 'Enterprise resource planning' fields are already on the path of revolution because of Cloud manufacturing technology. In Cloud manufacturing field, great amount of work is still needed as it has tremendous scope in future. Beside these, many possibilities are yet to come into light and it is only going to increase impact of Cloud manufacturing in our day to day life.

IV. Discussion and Conclusion

Cloud technology carries inherent characteristics like ubiquitous access, big data management, pay-per-use, resource pooling, virtualization, multi-tenancy etc. while considering Cloud based manufacturing, all of these features directly or indirectly benefit the overall manufacturing processes. That why Cloud manufacturing has been so successful so far.

A. Some of the distinct advantages of Cloud manufacturing are as follows:

1. Ability of reducing idle period in manufacturing unit, by minimizing bottlenecks and optimal resource utilization;
2. Reduction of cost included in overall product development, be it starting investments, infrastructure cost or maintenance cost. Since Cloud manufacturing has service centric perspective and utility pricing approach. Thus manufacturer can acquire resources from service providers as per needs. It is very important factor considering small and medium scaled enterprises (SMEs);
3. Elasticity and Scalability are important advantages of CM, especially concerning supply chain management [26];
4. Mass customization is possible by means of CM;
5. Distributed manufacturing is easily achievable with CM. Corporate collaboration is promoted because of it for mutual benefits. For knowledge or resource sharing, and efficient workflow between partners, integration of services has to be smooth. Cloud manufacturing does all work for this on virtual level itself [27];

B. Although Cloud manufacturing can definitely be considered as path-breaking technology, but still there are some issues which need to consider and study before large scale implementation of it. Some of most critical issues are given below:

1. Safety and Security are biggest concerns for Cloud technology. Information or knowledge base crucial to any organization cannot be advisable to simply put on internet. In manufacturing field, especially in subtractive manufacturing, service know-hows, patent technologies are important and considered as core competencies [14]. At such times, safety protocols, for Cloud manufacturing systems and service providers, are of highest priorities. Therefore major research work is still required in this area.
2. Interoperability is another issue in Cloud manufacturing. Universal standards are necessary for this, specifically for computer aided application technologies (CAx) [28].
3. Virtualization is key part of Cloud manufacturing technology, but it brings certain challenges along with it. Different quality of services, varying load-balancing techniques, lack of standard resource provisioning model, varying availability of computational facility and performances are some of the most prolific topics to look at in this area [26];
4. Cloud technology adoption is another limitation in wide scaled spread of Cloud manufacturing applications. Most of the development in CM system application has been done in field of additive manufacturing. That contrasts the market scenario, where CNC machining still remains priority choice for majority of manufacturers worldwide. Lack of availability of infrastructure, economical limitations are also responsible factors in inhibition of Cloud technology adoption on larger scales.
5. Human factor is important consideration in Cloud manufacturing implementation. As manufacturing processes are going to be automated, unemployment will increase. Also training existing workforce, making human-computer interaction easier, workstation environment safety are some of noteworthy challenges for Cloud manufacturing adoption and implementation [29].

So to conclude this discussion, it would not be difficult to assume that Cloud manufacturing is indeed has great impact on manufacturing world. Since limitations are still of great consideration, huge scope is available in research and development in this paradigm. For now, we can say that, with emerging new technologies and combining those with Cloud manufacturing systems, new doors will surely open to faster, cleaner and safer manufacturing world.

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