Information Centric Engineering (ICE) Frameworks for Advanced Manufacturing Enterprises

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Abstract. As revolutionary advances in Next Generation Internet technologies continue to emerge, the impact on industrial manufacturing practices globally is expected to be substantial. Collaboration among enterprises is becoming more commonplace. The design of next generation frameworks based on Information Centric Engineering (ICE) principles holds the potential to facilitate rapid and flexible collaboration among global industrial partners. This paper outlines the key components of such a framework in the context of an emerging industrial domain related to micro devices assembly. Discussions of pilot demonstrations using Next Generation and Future Internet frameworks related to the GENI and US Ignite initiatives are also provided.

1 Introduction

The recent advances in Information Technology (IT) especially the development of next generation Internet frameworks including cloud computing technologies holds the potential of catalyzing the next revolution in advanced global manufacturing that relies heavily on information centric engineering (ICE) principles. The adoption of ICE principles in manufacturing lays the foundation for industrial manufacturing and other organizations to form virtual partnerships to collaborate in response to fast changing customer requirements. The 3 core facets of an Information Centric Engineering (ICE) framework include functions, principles and technologies related to:

(i) Modeling of Information
(ii) Simulation and Visualization of Information
(iii) Exchange of Information

A brief discussion of these 3 facets follows.

Modeling of Information (the role of information models): The role of information models assumes significance in any industrial engineering collaboration. Creating such 'information models' (or information intensive process models) at various levels of abstraction within an enterprise is key to understanding an existing or new process. The modeling abstraction can be at the process, factory or enterprise levels (or a combination of them). Such models provide a foundation for designing software

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systems to support manufacturing or other engineering activities as well as can be used to propel a large cross section of engineering activities in a product development life cycle (from product conceptualization to assembly, shipping, etc.). Such information models can be created by a variety of existing languages. For example, Activity diagrams can be built using the Unified Modeling Language UML; enterprise models can be created using engineering Enterprise Modeling Language (eEML). These models can capture a range of attributes such as critical information or physical inputs, constraints, performing mechanisms and physical or information outcomes. The major benefit of using such information models is that they provide a detailed understanding of the functional relationships between the various activities and sub-activities. While some of them (such as UML based activity) provide only functional dependencies, other models (such as those built using eEML, for example) capture both the functional relationships and the temporal precedence constraints among the modeled entities. When a virtual enterprise needs to be created, in response to an existing or emerging need, the creation of such information models for a given collaborative context becomes essential to designing, modifying and implementing such collaborations.

Simulation and Visualization of Information: The second major facet of ICE relates to simulation and visualization of information. Such information can be both in the product and process design contexts within a product development life cycle. The motivating force behind adopting such principles is the benefit accrued from simulating product and process design attributes. In today's global environment, when cross-functional engineering teams are distributed, the need for advanced 3D virtual reality based simulation techniques becomes as essential part of any collaborative effort. While CAD/CAM tools are widely used in industry, the next generation of simulation techniques rely substantially on Virtual Reality based simulation tools. The adoption of such Virtual Reality based prototypes (sometimes referred to as Virtual Prototypes) in design, manufacturing, assembly, testing, service and other life cycle activities enables engineers involved in downstream activities (even though they are in a different location) to be involved in upstream 'conceptual' design activities. The primary benefit to a collaborative enterprise lies in being able to identify design problems early in the design, discarding infeasible designs from downstream perspectives (such as assembly, testing, etc.) and providing a powerful collaborative medium (through Virtual Reality technology) for engineers to communicate effectively. Such virtual prototypes can be physics or non physics based depending on the process or product design context. For example, a virtual assembly based analysis approach can be adopted by a team of distributed manufacturing engineers collaborating on studying assembly alternatives.

Exchange of Information**:** The third major facet of ICE deals with the exchange of information which is essential to collaboration at any level. In general, the 'exchange' facet underscores the importance of exchanging information seamlessly across heterogeneous platforms among distributed partners. Such an information exchange can be accomplished by using Cyber networks which can be our existing Internet, the more advanced Internet2 (which is available to a limited number of universities and hospitals) and the emerging GENI network (which is the next generation of Internets under development by various countries as part of the next generation Global Environment for Network Innovation GENI initiative).This information exchange can be between physical resources, or software (cyber) resources or between cyber physical resources involved in a product development life cycle (including design, planning, simulation based analysis and physical assembly tasks, service, etc.). Under exchange, enterprises will also need to address semantic interoperability issues to ensure seamless exchange of information between software and other resources belonging to various engineering partners or enterprises.

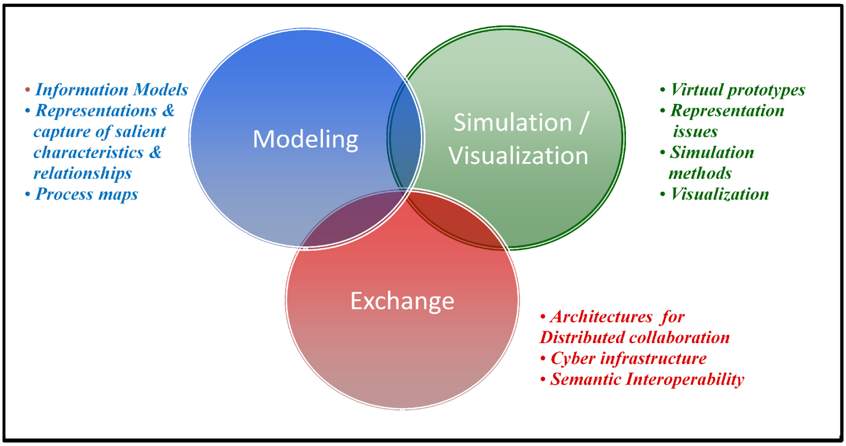

Fig. 1. The 3 core facets of an Information Centric Engineering (ICE) Framework

2 ICE Framework for Micro Devices Assembly

For emerging industrial domains such as the field of micro devices assembly, the adoption of an ICE framework will facilitate collaboration among distributed partners. A brief note about the domain of micro assembly is relevant. Micro Devices Assembly (MDA) refers to the assembly of micron sized devices for various engineering and other application contexts. When a micro sized part design has complex shapes and varying material properties, then the existing MEMS technologies will not be able to produce such a design. In such contexts, the individual micro parts need to be assembled using micro devices assembly techniques and technology. MDA is an emerging domain with a significant economic potential in various fields such as biomedicine (sensors and monitors), semiconductor and electronics manufacturing and surveillance/imaging devices (micro cameras, monitors), and safety products (to detect leak of contaminants).

Most of the existing MDA approaches are cumbersome, time consuming and costly. In most scenarios MDA resources are not available at a single organization; resources are very expensive and distributed among different organizations across different locations. This underscores the necessity for engineering collaborations among enterprises with expertise in micro design, planning, simulation and assembly. The adoption of an ICE based framework linking distributed teams, their software and physical resources assumes significance. The role of information models (to propose and formulate collaborative approaches between teams as well as to understand existing micro assembly processes and systems), virtual prototypes (to conduct simulation and analysis of proposed assembly approaches prior to physical assembly) as well as next generation Internet based exchange strategies (to exchange information between collaborating partner enterprises) become an intrinsic aspect of any collaborative framework developed to respond to changing customer requirements. Figure 2 illustrates such an ICE framework for the domain of micro devices assembly.

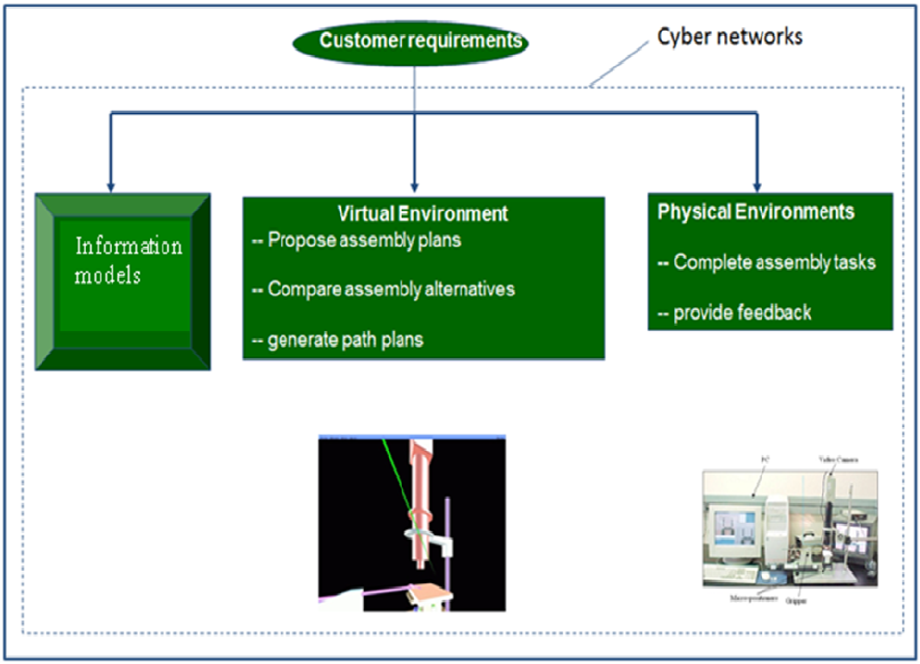

Fig. 2. An Information Centric Engineering (ICE) Framework for micro devices assembly

A discussion of the ICE framework for advanced manufacturing follows. This framework (outlined in figure 2) emphasizes 4 key components: (i) *role of information models, (ii) virtual environments and (iii) physical assembly resources which are linked through (iv) information exchange frameworks and cyber infrastructure.* Together, these components in this ICE framework facilitate distributed enterprise partners operating as a Virtual Enterprise (VE) to respond to emerging micro assembly needs. When a set of requirements to assemble a set of micro devices is provided by a customer (through the Internet), the ICE framework seeks to facilitate this accomplishment using these collaborative resources (figure 2). An overview of these components follows. In our framework, users (through a user interface), provide the information about a target micro device to be assembled.

Information Models: An array of information models (for various process contexts and needs) can capture the functional dependencies and temporal precedence constraints (for various needs such as formulating the collaboration among partners, for mapping the process steps within micro assembly, etc.). These models can also be used to propel manufacturing level simulations as they capture the sequence of events as well as identify driving inputs (from collaborators or partners), enterprise or process constraints, performing mechanisms (responsible for assigned tasks) and WIP or final outcomes. These models were built for the domain of micro assembly using the engineering Enterprise Modeling Language (eEML); they were used to design the collaborative environments (the virtual environments) as well as lay the foundation for the information exchange approaches among the distributed partners and resources.

Virtual Reality Based Simulation Environments: These virtual reality based simulation environments were designed and developed to enable distributed teams of engineers to rapidly study assembly alternatives for varying part designs; they can be used to generate (propose), compare and evaluate assembly plans to assemble a target set of micro devices (figure 3). Subsequently, assembly path plans including micro gripping approaches for assembly were proposed and validated using virtual environments (figure 3). Semi immersive and fully immersive VR environments allow teams of users to collaborate cross-functionally through Internet or other cyber infrastructure (eg. Extranets). The simulation of the assembly activities were linked using cloud computing technologies as part of a Future Internet / Next Generation Initiatives involving the GENI test bed and the US Ignite initiative.

Physical MDA Resources: To be able to respond to diverse micro designs, a diverse range of physical micro assembly resources are needed to complete a target assembly. These resources include micro assembly grippers, sensors, fixtures and work cells, which will be needed to complete various target assembly tasks (as an implementation of selected assembly alternatives studied using the VR environment). In a virtual enterprise context, these resources are distributed but linked through cyber infrastructure. In our demonstration, we used two different work cells to assemble a variety of millimeter and micron sized parts (figure 3 a and 3 b provide views of the virtual work cell and the physical work cell for micro assembly activities).

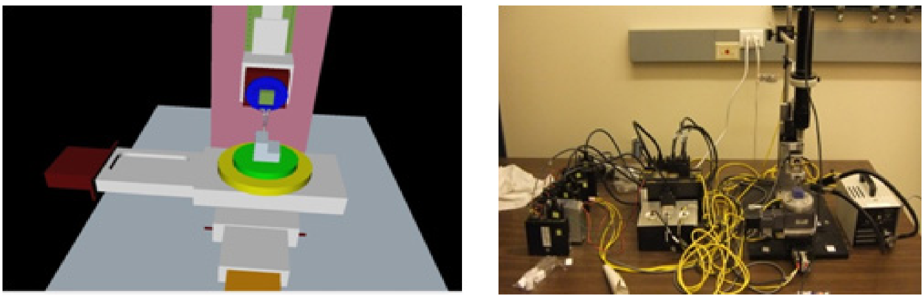

Fig. 3. (a) A Virtual Assembly environment (b) A Physical micro assembly work cell

Advanced Cyber Infrastructure: This is needed to support the information exchange (or the "exchange of information" identified in figure 2 in the ICE framework) among the cyber physical resources to accomplish various planning, simulation based analysis and physical assembly tasks using the distributed resources. Recently, the use of cloud based technologies is becoming widespread.

In our pilot demonstration aimed at demonstrating the feasibility of such an ICE framework, we used distributed resources and modules for generating the assembly plan, 3D path plan, conducting the simulation of target assembly/path plans, and finally completing physical assembly of target parts. These resources were linked using the next generation (GENI) network using a cloud computing approach. An array of micro devices were assembled using this ICE framework (one of them is shown in figure 5). A part of this demonstration was accomplished as part of the US Ignite initiative. A brief discussion of both these initiatives follows.

The GENI (www.geni.net) initiative is an NSF initiative in the US which focuses on the design of the next generation of Internets including the deployment of software designed networks (SDN) and cloud based technologies (as part of a long term Future Internet initiative). In the context of advanced manufacturing (such as micro assembly), such networks will enable distributed VE partners to exchange high bandwidth graphic rich data (such as the simulation of assembly alternatives, design of process layouts, analysis of potential assembly problems as well as monitoring the physical accomplishment of target assembly plans). In the European Union (EU) and Japan (as well as other countries), similar initiatives have also been initiated; in the EU, the Future Internet Research and Experimentation Initative (FIRE) is investigating and experimentally validating highly innovative ideas for new networking and service paradigms (http://cordis.europa.eu/fp7/ict/fire/).

Another important initiative is the US Ignite (http://us-ignite.org/) which seeks to foster the creation of next-generation Internet applications that provide transformative public benefit using ultrafast high gigabit networks. Advanced Manufacturing is one of the six national priority areas (the other five are Health, Public Safety, Education & Workforce, Energy, and Transportation). Both these initiatives herald the emergence of the next generation computing frameworks which in turn have set in motion the next Information Centric revolution in Advanced Manufacturing (and Engineering) that is expected to impact global practises in a phenomenal manner.

The simulation of target micro devices using Virtual Assembly environments (figure 6) has also been posted at this Youtube site: https://www.youtube.com/watch?v=pwxXZqn7R34. The related physical assembly activities can be found at this web location (https://www.youtube.com/watch?v=OC0WpoeA7Ck). The general approach to exchange information and sharing of resources from the advanced manufacturing domain discussed in this paper was also used to demonstrate feasibility of linking educational resources and learning modules among K-12 and engineering students. One of these demonstrations involved children with autism interacting with their teacher at another location using haptic device (which enabled them to "feel" the objects they touched virtually inside a computer); this collaborative framework was used to teach science and math concepts to autistic students in grades 1 and 2 from a local school (Sangre Ridge Elementary) in Stillwater, Oklahoma; this was part of a project aimed at supporting learning activities for children with autism; a part of these activities have been recorded and can be found at https://www.youtube.com/watch?v=BAfd2ax6tk4. Another recording of interactions among middle school students (from Stillwater Middle School) can be found at http://youtu.be/EIlNqpCAIu4. The important conclusion from the latter demonstrations involves recognizing the potential of using such next generation frameworks for supporting educational activities when it involves sharing of distributed resources as well as supporting interaction between teachers and children at different locations.

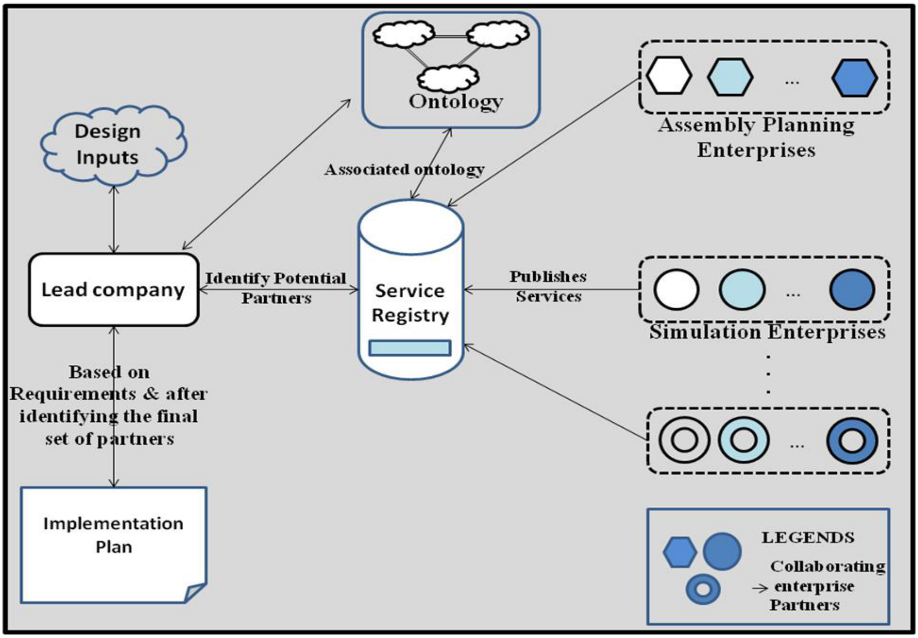

Fig. 4. A Semantic Test Bed to demonstrate collaboration among distributed VE partners

In a different demonstration, a Semantic Test Bed was created to demonstrate an approach aimed at addressing semantic interoperability. In this Test Bed, our emphasis was to highlight an innovative approach which would allow VE partners to collaborate based on the user requirements. This approach can be described using figure 4, which outlines the main interactions among the distributed VE partners and their resources. There are 3 phases:

(i) Understanding user design requirements: Based on this understanding, an enterprise level plan is developed which identifies the main engineering tasks to be completed to assemble the target micro design (this can range from assembly planning path planning, analysis of assembly alternatives, simulation of assembly alternatives and finally physical assembly)

(ii) Identification of VE partners: This phase involves selecting enterprise partners based on capabilities of VE partners and enterprise level plan. If there are more than one enterprise who can perform a given task in the enterprise plan, then based on their performance capabilities, cost of involvement and history of prior activities, the most feasible partner is identified. Each enterprise interested in being of a VE needs to publish their services in a services directory (see figure 4).

Ontology of micro assembly activities were created using the OWL (Web Ontology Language); the services of each potential enterprise partner were described using OWL-S (where S is for services)

(iii) Implementation of enterprise plan: In this last phase, the enterprise manager module initiates completion of enterprise level plan including assembly plan development, simulation and finally physical assembly. This is executed by interacting with the distributed modules and tools at the partner enterprises.

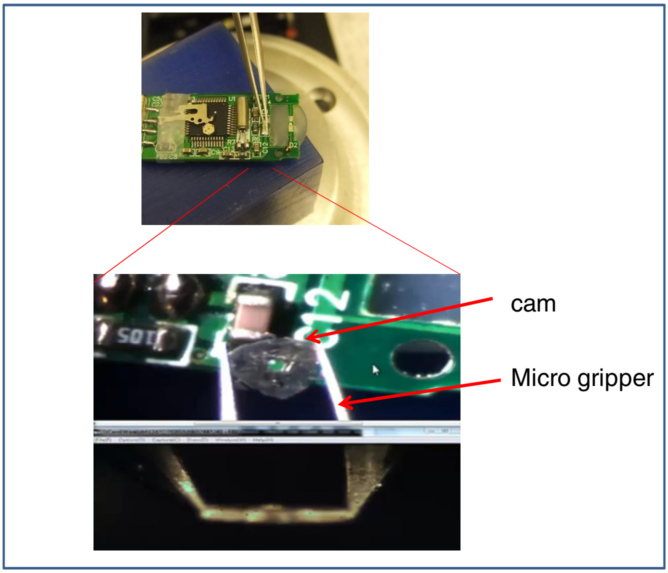

Fig. 5. Two views of a micro assembly process in progress

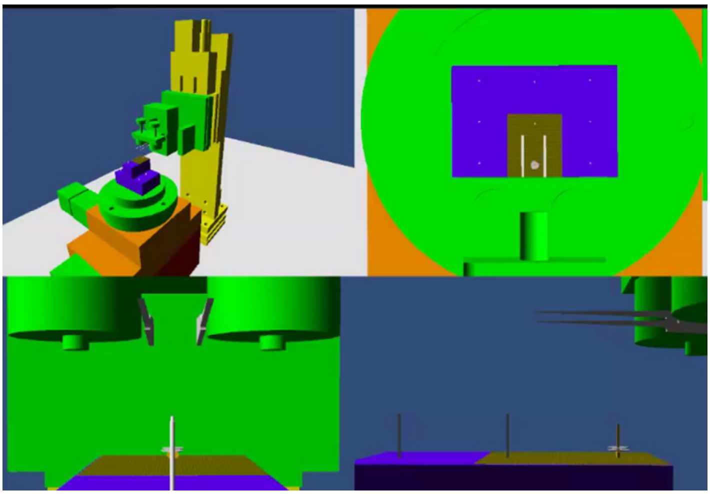

Fig. 6. Views of a virtual environment to study micro assembly alternatives

3 Conclusion

This paper outlined an Information Centric Engineering (ICE) to support collaborations among distributed partners in manufacturing contexts. An overview of the 3 core facets of ICE (which emphasized the role of information models, virtual prototyping frameworks and information exchange approaches) was provided. This ICE framework was used as basis to develop a more comprehensive framework for the emerging domain of micro assembly. The collaborative framework emphasized the 3 facets of ICE which was used to support collaboration among enterprise partners (and their software and physical resources) using advanced cyber infrastructure (to support the information exchange necessary for collaboration). In most situations, micro devices assembly (MDA) resources are not located at a single organization; resources will be distributed among different organizations across different locations. For this reason, an ICE framework is needed to support the collaborative and rapid assembly of micro devices.

Our ICE framework enabled the sharing of engineering resources using next generation Internet technologies (as part of pilot demonstrations involving use of GENI frameworks and as part of the US Ignite initiative); a discussion of an innovative semantic framework to support collaboration among potential partner enterprises was also provided; this demonstration focused also on the domain of micro assembly and included enterprise planning, resources discovery, selection of identified partner for relevant services and finally execution of the enterprise plan which ended in the assembly of target micro part designs. Such ICE frameworks facilitate the realization of global virtual enterprises where collaboration between with distributed partners is possible especially when responding quickly to changing customer requirements.

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