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# A next generation IoT based approach for collaborative manufacturing

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## Abstract

In this paper, a next generation Internet of Things (IoT) based approach is proposed, which is deployed on the Next Generation Internet called GENI. The IoT based approach can enable globally distributed software and manufacturing resources to be accessed from different locations and accomplish a complex set of mini life cycle activities including design analysis, assembly planning, and simulation. The focus is on the emerging domain of micro devices assembly, which involves the assembly of micron sized parts using automated micro assembly work cells. A case study regarding micro assembly is conducted and demonstrates the feasibility of the next generation IoT based approach.

**Keywords:** Micro Assembly, collaborative manufacturing, Next Generation Internet, IoT

## 1. Introduction

Micro Devices Assembly (MDA) [1] refers to the assembly of tiny, micron-sized parts (in the order of $10^{-6}$m). When a micro part design is complex in shape and requires the use of materials of varying properties, they cannot be manufactured using Micro-electrical Mechanical Systems (MEMS) technology [2]. It is generally accepted that manual micro assembly is tiresome, time-consuming, unreliable, and costly [3]. Thus, the use of computer-aided micro assembly becomes critical and essential. IoT is becoming popular in the context of the on-going IT revolution and it refers to the network of physical objects or "things" which are embedded with electronics, software, sensors. In this network, everyday physical objects are able to be connected to the internet and enable themselves to exchange data with the manufacturer, operator and/or other connected devices [4]. With the emergence of cloud computing and IoT technology, MDA is gradually undergoing unprecedented development opportunities.

This paper focuses on the design of a next generation IoT based approach for Micro Assembly which is deployed on a Cloud platform involving the next generation Internet initiative called Global Environment for Network Innovations (GENI). GENI provides a virtual laboratory for networking and distributed systems research and education, which allows engineers to access and obtain cyber resources from different locations for collaborative manufacturing [5]. The Next Generation Internet (GENI) provides an opportunity to exchange high gigabit data exchange which is required for planning, analysis and simulation of assembly plans in domains such as micro assembly (the current Internet has limitations which leads to network latency when distributed engineers interact as part of concurrent engineering based product and process design activities). The remainder of this paper is organized as follows. The section 2 investigates the literature review with regard to the techniques and technologies of micro assembly. A next generation IoT based approach for Micro Assembly is detailed in section 3. A case study is illustrated in section 4 and finally section 5 concludes the paper.

## 2. Literature Review

To date, a large number of papers have been published in the area of MDA; a cross section of these papers can be found in [6-10]. Some of the research thrusts in the field of MDA include (a) studying and modeling adhesive forces coming into play during part manipulation [14-16, 27, 33] (b) designing automated gripping mechanisms and work cells for rapid assembly [11-13, 28-32] (c) exploring the use of Virtual Reality based interfaces and simulators to facilitate rapid assembly as well as cross functional analysis [17-20, 26, 34, 35]. To assist the assembly of micron sized parts with high efficiency and accuracy, some of the researchers have explored the use of Virtual Reality based tools and environments to study process design issues related to MDA. Gobinath et al [17] discussed the design and development of an integrated physical and virtual environment to facilitate the assembly of micron-sized parts. Tan et al [18] outlined a virtual environment based on modeling of micromanipulation robot, in which a general framework was presented for micromanipulation. In [19], Li et al presented a simulated environment in virtual reality for robot task teaching, which avoided the high cost and risk on a real work cell. In [20], Bolopion et al presented a comprehensive review of haptic feedback teleoperation systems for micromanipulation, which took advantage of virtual reality to greatly benefit teleoperation systems and micro assembly systems.

There has also been recent interest in the area of IoT and related approaches. Chen et al [36] outlined a framework with a four-layer model for enterprise IT departments to design logistic systems based on IoT and SaaS cloud computing technology. In this framework, certain logistic processes including RFID-based pallet inventory, pallet monitoring and location-based logistic transportation were investigated in order to deploy IoT technologies. In [37], Abu-Elkheir et al proposed a data management framework for IoT, which adapted a federated, data-centric approach to link sensors and data. The IoT-based data management system had the capability of supporting both offline and real-time data cycles to accommodate the diverse data and processing needs of potential IoT users. Li et al [38] conducted a survey about the IoT and reviewed related technologies such as wireless sensor networks, barcodes, intelligent sensing, RFID, NFC and cloud computing. There are many benefits to embracing IoT based approach [21, 22]. The benefits lie in being able to form collaborative partnerships to respond in a more agile manner to changing customer preferences while being able to seamless exchange data, information and knowledge at various levels of abstraction. Such an emphasis on adoption of IoT principles can also set in motion the realization of advanced next generation Cyber Physical relationships and frameworks which can enable software tools to control and accomplish various mundane as well as advanced physical activities [23]. In the manufacturing context, engineers can access a cloud of resources using various IoT devices and sensors which can exchange and share data/information from remote locations including interacting with physical manufacturing resources [24].

## 3. The Next Generation IoT based approach for Micro Assembly

The process context for the next generation IoT based approach in terms of Micro Assembly involves a 'mini' micro assembly life cycle. A cloud based approach support the sharing of resources and modules used in this life cycle. The components of Cyber Physical modules of the approach for Micro Assembly are illustrated in figure 1. The cyber activities involve Design Analysis, Assembly Planning, Path Planning, Virtual Reality (VR) Simulation/ Analysis of Assembly Alternatives. Assembly planning module is used to figure out the assembly sequence to be completed by the micro gripper using various cyber physical resources. A Greedy Algorithm (GRA) approach is proposed and

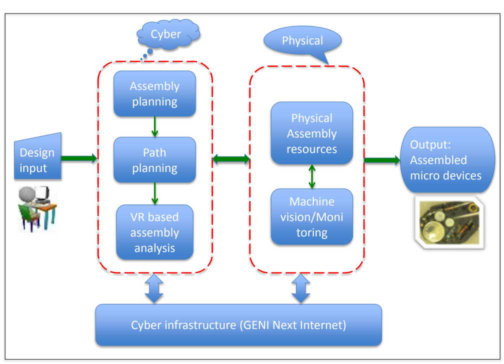


Figure 1: The Next Generation IoT based Architecture for micro assembly

additional information can be found in section 3.1. VR based Simulation module has been developed to support allows engineers to design the assembly plan and perform the assembly simulation (additional details can be found in section 3.2). Physical activities include micromanipulation, micro assembly, and assembly monitoring. The physical assembly resources typically consist of work table, micro gripper, micro positioner, feeders, camera and microscope (additional details can be found in section 3.3). The cyber (software) modules and physical resources for this framework are linked using the next generation (GENI) network using a cloud computing approach. A part of this demonstration was accomplished as a US Ignite initiative [25]. A brief discussion of the benefits of adopting a cloud based approach followed by an overview of the GENI and US Ignite initiatives is provided later in this section 3.4.

### 3.1 GRA based Assembly Generator Module

In our approach, there are multiple assembly generating resources from various life cycle partners involved in a Virtual Enterprise (VE) oriented collaborative context. In such a VE, various VE partner organizations may have their own assembly planning, path planning, image processing and camera based monitoring modules. Depending on the process and product context, an appropriate set of tools and resources (cyber and physical) may be used using the shared cloud based framework. Virtual analysis of assembly alternatives will enable VE partners to collaborate and use specific collaborative resources for a given design. This provides flexibility in responding to various customer designs. The assembly planning module aims at determining the optimal assembly sequence to be completed by the micro gripper using various cyber physical resources for the assembly of micro devices. In the assembly plan module, a GRA based approach is used to determine the near optimal assembly sequences of target micro objects (the objective is to reduce the assembly time and distances of robot tasks). Typically, a GRA seeks to make a locally optimal choice that looks best (at that current state) which help identify a nearly optimal global solution; this is the origin of the term 'greedy' in the context of a GRA. The user provides the detailed information regarding the layout of the physical work cells, the part feeders and destination locations of the micro devices. The key steps of this approach are summarized below: (1) Initialize the distance $\mathbf{d_{ij}}$ between any point (i) and point (j) where i, j ∈ {0, 1, 2...n}. The set $\mathbf{S} \leftarrow \{\mathbf{P_0}\}$ and the default travelling sequences are the set $\mathbf{A} \leftarrow \{\mathbf{P_1, P_2, P_3 ... P_n}\}$. (2) Find the point (j) which is the shortest distance to Home $\mathbf{P_0}$ and add the $\mathbf{P_j}$ into the **S,** then the set $S \leftarrow S \cup \{\mathbf{P_j}\}$. Also the point $\mathbf{P_j}$ should be removed from set **A**, then $\mathbf{A} \leftarrow \mathbf{A} - \{\mathbf{P_j}\}$. (3) Next, we need to find the solution of sub problem **A**. Find the point (k) which is the shortest distance to Point (j). So, the set $\mathbf{S} \leftarrow \mathbf{S} \cup \{\mathbf{P_k}\}$, the set $\mathbf{A} \leftarrow \mathbf{A} - \{\mathbf{P_k}\}$. (4) Using the while loop algorithm, the set ***S*** records all the points and the best travelling sequence is the set ***S***. One example with 9 parts and 2 feeders is tested using the above algorithm and the figure 2 shows the MDA part design and its layout. The composite part design (see fig 2) was created to test the capabilities of the cyber physical approach including physical micro assembly manipulation and assembly capabilities. This part design has a number of intricate micron and meso scale components including gears, pins, hollow cylinders, stepped shafts, etc. According to the GRA approach, the result of the assembly plan sequence for this part design is shown in figure 3.

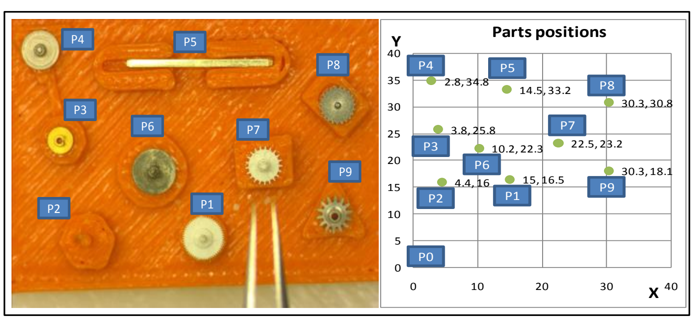


Figure 2: A MDA part design and its layout

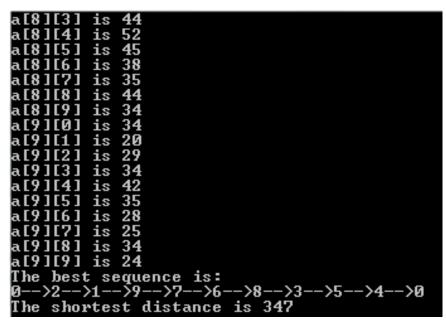


Figure 3: A screen shot of GRA result

### 3.2The Virtual Reality based Simulation Environment for Micro Assembly

The Virtual Reality (VR) based simulation environments was built using Unity3D platform to assist the analysis of the assembly/ path plans interactively by engineers from different locations. The distributed engineers used the Next Internet (being developed under GENI) to propose, compare, and modify assembly/path plans rapidly. The high-gigabit data relating to these VR images were transmitted using this next generation Internet technology.

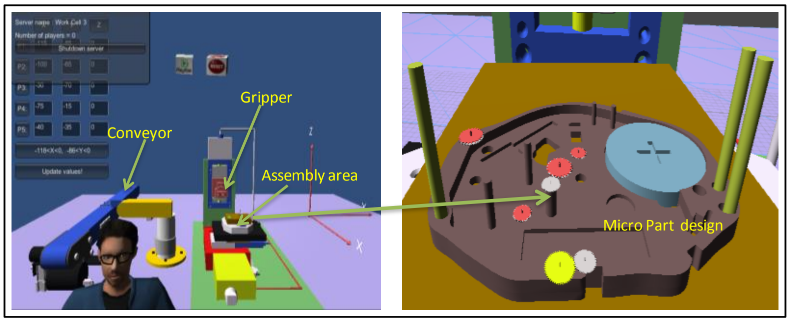


Figure 4: A view of virtual environment for MDA

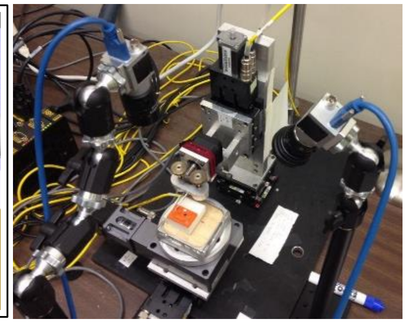

Figure 5: One of the Physical work cells used for MDA

Inputs to this environment are assembly plans generated by the Assembly Planning module discussed in section 3.2. The CAD models of the various entities in the virtual environments were first created using Solidworks and then imported to create the virtual assembly environments. Figure 4 provides a view of these Virtual Environments which is used to 'virtually' propose, compare and analyze assembly alternatives. An avatar is also available to help users interact with these virtual environments. Users can also input their candidate assembly plans through a web based interface. The assembly simulations enable the users to assess the feasibility of the generated (or manually input) assembly plans, which are also shared among the distributed users (and teams) through the cloud. The primary benefit of using such simulation environments is to allow users to study assembly alternatives, validate /modify or identify problems (such as collisions, infeasibility of a path plan, etc) as well as make changes to the assembly layout to improve the overall assembly process.

### 3.3 Physical Micro Assembly Resources

Various physical work cells were used in this test bed. They are designed to assemble different micron sized parts. For instance, work cell 1 has been designed to assemble components ranging from 30-70 microns. This work cell has 5 degree of freedom (DOF) (X, Y, Z, Rotation and Gripper Movements) and has piezoelectric, shape memory alloy and mechanical grippers. Another work cell has an assembly work area with a rotational degree of freedom and is mounted on an assembly plate. The gripper in this work cell is mounted on a tool holding support which is attached to a linear micro positioner. The third work cell uses a shape memory alloy gripper to assemble components in the scale of 500 microns to 1 millimeter. Figure 5 shows one of the Physical Work Cells at the Center for Information Centric Engineering. This work cell has 4 degrees of freedom with different types of gripper and actuation mechanisms. The work area is supported on a fixture which has a rotational degree of freedom and two linear degrees of freedom (in the x and y axis). The gripper has a linear DOF in the Z-axis. Two cameras are available for assisting in the assembly activities as well as for monitoring progress of the assembly tasks.

### 3.4 The Adoption of GENI based Cloud Technology

The cloud based approach linked users in different locations who could collaboratively plan, analyze and assemble micro devices. The physical assembly resources to be linked using cloud computing technologies were in a manufacturing lab at Oklahoma State University. The cyber resources interacted with these physical resources to accomplish various micro assembly tasks. The cloud-based approach was accomplished in the context of the GENI and US Ignite initiatives. Since the collaboration for MDA among distributed organizations involves high definition graphics and visualization data exchange in the virtual prototyping and assembly monitoring activities, it is not supported well by current Internet networks with high latency network. In the context of collaborative micro assembly, such networks especially facilitate exchange and sharing of high bandwidth graphics (such as virtual reality based 3D data as in our micro assembly context, camera monitoring of a manufacturing process, etc.).

## 4. Discussion

In our implementation, a test bed based on GENI was created to support and validate the next generation IoT based approach for Micro Assembly. In this test bed, users among geographically distributed locations were able to perform collaborate and accomplish cyber and physical micro assembly tasks. On the cyber aspect, it involves the assembly planning, path planning, virtual reality based simulation environment and robotic assembly command generation. The physical assembly resources include micro assembly work cells comprising of micro grippers, positioners, micro scopes, cameras and controllers. The cyber modules interacted with each other and updated the status of their activities to ensure the overall accomplishment of the life cycle; on the physical side, the cameras, robots and grippers which are part of the physical resources functioned as physical and cyber sensors and exchanged

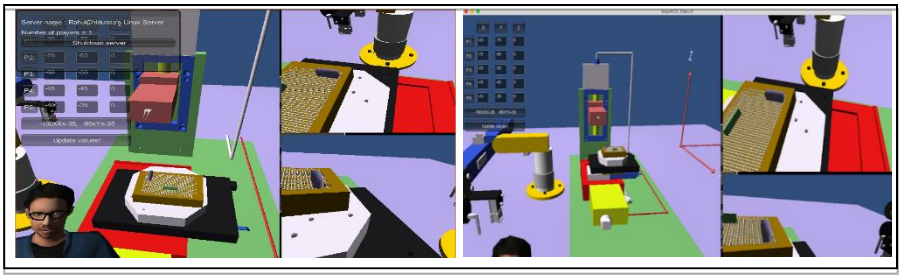

Figure 6: Assembly Analysis using Virtual Environments linked on GENI (Tulsa and Stillwater, Oklahoma)

data on the status of various activities as the micro assembly life cycle progressed. The physical feedback was posted by intermediary interfaces which communicated with an overall task monitoring module that updated the distributed partners at various locations about the overall activities progress. This enabled effective communication and interaction among distributed teams.

Figure 6 shows the demonstration linked 2 users in Tulsa and Stillwater, Oklahoma who worked on assembly analysis using Virtual Environments deployed on GENI. In this demonstration, if the user in Tulsa modified assembly plans, the updated assmbly plans can be reflected simutaneously in Stillwater and vice versa. After the candidate assembly sequence is anaylsed and validated, the physical assembly command generator module would generate the assembly code and send it to the physical micro work cell. It is used to carry out the movements, rotation and micro manipulation by the micro robotics. The following program shown in table 1 is one example that the gripper picks up one part from the feeder and moves it to the target area.

Table 1: Part of a complete program to perform micro assembly tasks using work cell

| **Command** | **Comments** |
|---|---|
| X4.94112 Y5.99308 Z/0 ROT/0 M/0 | Move along X axis towards x coordinate 4.94112 and y coordinate 5.99308 |
| X/0 Y/0 Z(-8.3402) ROT/0 M/0 | Move along Z axis towards z coordinate -8.3402 |
| X/0 Y/0 Z/0 ROT/0 M/(6.32012) | The gripper closes 6.32012 units |
| X/0 Y/0 Z(-3) ROT/0 M/0 | Move along Z axis towards z coordinate -3 |
| X/0 Y/0 Z(-5.76) ROT/0 M/0 | Move along Z axis towards z coordinate -5.76 |
| X/0 Y/0 Z/0 ROT/0 M/(-6.32012) | The gripper opens 6.32012 units |

Our demonstration highlighted the fact that the life cycle of micro assembly based product designs would be decreased using such a cyber physical approach and that the VE partners or companies will be able to response to their customers' requirements in an agile manner.

## 5. Conclusion

In this paper, a next generation IoT based approach for collaborative manufacturing was discussed. The approach enables globally distributed software and manufacturing resources to be accessed from different locations and accomplish a complex set of mini life cycle activities including design analysis, assembly planning, and simulation. The cyber and physical resources in this approach are illustrated in detail. Also, a test bed based was created to support and validate the next generation IoT based approach for Micro Assembly. In this test bed, users among geographically distributed locations are able to perform cyber and physical resources linked on GENI based Cloud collaboratively. On the cyber aspect, it involves the assembly planning, path planning, virtual reality based simulation environment and robotic assembly command generation. The physical assembly resources include micro assembly work cells comprising of micro grippers, positioners, micro scopes, cameras and controllers. The result demonstrates the feasibility of the next generation IoT based approach for collaborative Micro Assembly.

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