A Virtual Factory Environment to support Process Design in Micro Assembly Domains

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ABSTRACT

In this paper, the creation of a virtual factory environment to support the assembly of micro devices is discussed. While most of the research has focused on micro assembly processes using dedicated work cells, there is a need to develop advanced Virtual Reality based simulation environments which can support the study of factory and work cell level assembly alternatives. Such virtual environments will enable comparison of 'what if' assembly alternatives that can enable reduction of overall assembly time as well as support assembly level re-design of individual work cells.

Keywords: virtual assembly, micro assembly, virtual reality.
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1 INTRODUCTION

The use of Virtual Prototypes in product and process design activities has become widespread in engineering. In general, a virtual prototype (VP) can be described as a 3 Dimensional Virtual Reality (VR) based object, system or environment, that seeks to 'mimic' the appearance and behavior of a target (or 'real world') object, system or environment. Engineering organizations have adopted use of VPs to lower costs as well as reduce the overall life cycle development cycle [2, 10-12]. In this paper, the focus of discussion is on the creation of virtual factory environments to support process design activities in the domain of micro assembly.

Micro Devices Assembly (MDA) refers to the assembly of micron sized devices; a micron is 10^{-6} meters. MEMS techniques common in the integrated circuit industry today cannot be used when the target product designs have complex shapes, and heterogeneous material properties. Assembly of micro devices, parts or structures are required to handle such complex micro designs. In such contexts, there is a need to investigate innovative micro assembly methods and techniques [1-3]. Due to the extremely small size of the parts involved, it is very difficult and tedious to manually assembly micro parts; there is a need to develop automated or semi automated approaches to support the rapid assembly of micron sized parts. This paper outlines the creation of an information based manufacturing framework to support the assembly of micro devices.

In recent years, there have been various research efforts that have explored important techniques related to the manipulation, assembly and control of micro devices. Microassembly work cells (MAWC) are currently being developed to assist in this activity. VR has been in various robotic and other engineering contexts for process design and control. Monferrer and Bonyuet [4] proposed a system to control robots in difficult or dangerous tasks using a VR-based framework. A set of guidelines is proposed to define an ideal user interface that would use VR to help an operator control an underwater robot. User interfaces are provided with video images and data such as depth and distance. A major drawback of the system is that the operator is expected to undergo extensive training. The authors identify three major categories of issues to developing a VR-based control system. These include (a) user interface issues, (b) technical issues, and (c) VR issues. The authors conclude that building an environment to control a physical system is an iterative process that can be improved with each new application task. Monferrer et al. highlighted the role of the human user in the design of VR-based collaborative environments. Hamdi et al [8] outlined the use of prototyping of bio-nano robots using VR.

Several researchers have explored the use of VR in microassembly to help in assembly planning and comparison of gripping and assembly alternatives. Further, as it is difficult to work directly with parts in the scale of a few microns, a Virtual Environment (VE) enables engineers to consider and study "what if" scenarios virtually before interacting directly with physical microassembly resources. In the remaining sections of this chapter, a review of a limited number of research efforts in microassembly is discussed.

Probst et al. [6] outlined the use of a VR-based environment to control the assembly tasks using a microassembly system called the IRIS microassembly system V2. The physical workstation consists of a 6-DOF microassembly system including several micro grippers, a base unit, a top unit, cameras, and an illumination dome. The microassembly workstation has a graphical user interface (GUI) to enable users to assemble a microrobot for medical applications. The GUI contains a VR module that provides visual feedback of the real hardware. The VE is implemented using OpenSceneGraph. Before completing the physical assembly, a user can plan the various assembly tasks and then study them in a VE. Once the assembly task is studied to ensure feasibility, the instructions to complete the physical assembly are transmitted to the workstation controller. A collision-detection module is used to detect potential collisions during the assembly process.

Alex et al. [1] described an approach involving the integration of a VR Modeling Language (VRML)-based virtual micro world with visual servoing-micromanipulation strategies. The limitation of Micro Electro Mechanical Systems (MEMS) technologies in dealing with the complexities involved in the shape and properties of complicated parts created the need for teleoperated micromanipulation and assembly. Such an integrated technique provides a vision-based feedback (using cameras), which helps in resolving the difficulties involved in the micro domain area. A user interacts with the virtual micro world that is represented by VRML. The manipulation of parts in this virtual world results in messages sent to the visual servoing agent in the form of a vector. The whole interaction between the virtual micro world, the user, and the servoing agent is enabled by the JAVA programming language. Other researchers have also explored the use of VR to assist in microassembly tasks. These include Ferreira and Hamdi [3], Bradley et al. [1], Sulzmann et al. [9] and Cassier et al. [8].

Hollis et al have addressed the need of a platform technology in microassembly [13]. One of their conclusions is the need to develop a way to integrate promising parallel or sequential assembly techniques into an automated system without high costs. The authors have proposed the Agile Assembly Architecture (AAA) to provide a base technology for rapid design, programming, and deployment of precision automated assembly systems. In their design, there are 2 components:
a) A distributed system of tightly integrated mechanical/computational agents

b) A unified Interface Tool to allow a user to select and to assemble, program, and monitor them both in a virtual factory environment and in the real factory.

As indicated by the review of papers in this section, use of VR in micro assembly is not new. The work outlined in this paper is an extension of our previous work discussed in [10]. The main contribution of this paper is the design of an information based manufacturing framework and the development of a virtual factory for micro assembly applications. Other work including our own [1, 3, 5-6, 8, 9 and 10] have focused primarily on using VR to support assembly planning and assembly design issues at the work cell level. Only our previously reported work [10] involves support of an immersive interface to the user. The other previously reported research have supported only non immersive levels of interaction with the user.

2 THE DESIGN OF AN INBM FRAMEWORK AND VIRTUAL ENVIRONMENT

As research in MDA progresses, it is important to realize that a robust framework is needed to facilitate the realization of rapid and flexible assembly of micro devices. This framework should not only focus on the mechanical issues of manipulation, assembly and control but should also seek to capitalize on the distributed access to information as well as explore the use of distributed collaborative resources (encompassing physical resources such as assembly equipment, etc to software resources such as path planning modules, analysis components, etc). It is important to also recognize that (in a limited context) there is no need for all the required resources to be co-located. The various collaborators or partners (involved as part of a virtual team) responding to a customer's need can possess a diverse set of resources and expertise; the partners in this virtual team (or virtual enterprise) can change depending on the changing customer requirements. For such an approach to become reality, the role of information (and relevant information technology) needs to be recognized. Information and information models will become key drivers that propel the accomplishment of a target set of tasks.

The 4 main components in this Information based Manufacturing (INBM) framework will include:
(i) Information models which will propel the various collaborative distributed activities (or life cycle activities which will result in a target micro assembly product)
(ii) A suite of planning, analysis and simulation tools to accomplish the various life cycle activities
(iii) Physical resources to assemble the various micro designs
(iv) Advanced Cyberinfrastructure (such as Internet based technologies) to help link the distributed resources

In the context of the above INBM framework, the creation of virtual environments to help distributed partners to work together to analyze both work cell level and factory level assembly alternatives become crucial. The design of these environments is described in the remaining sections of this paper.

3.1 The Design of the Virtual Factory Environment (VFE)

The VFE's design includes the ability to interact with users through a user interface, perform a range of analysis and compare the assembly alternatives. While the literature review indicates that innovative methods addressing specific problems within MDA are being explored, it also reiterates the need for the development of an integrated framework to support the rapid and flexible assembly of micro devices at high volumes of production.

A typical micro factory can be comprised of several work cells which can assemble a range of micro devices, conveyors to transport work in progress and components as well as other material handling robots and sensors. A work cell can be described as a collection of re-programmable assembly equipment including micro positioning stages, assembly platens, cameras (with microscopes) and grippers. Each work cell may have a diverse set of capabilities including assembly degrees of freedom and gripper designs. The Virtual Factory Environment (VFE)'s design should address 2 major capabilities:

(a) Compare the factory level alternatives virtually in response to a given micro design to be assembled (using a range of work cells and tools in a given assembly context)
(b) Compare the assembly steps and design process level details within a given work cell.

The design of the virtual factory environment architecture includes several modules. The User Interface is the interface between the user and the VFD. A number of different interfaces need to be supported including Mouse, Keyboard and Haptic devices. Users can select the options they desire or use a combination of interfaces.

The Advanced Virtual Reality (VR) based Visualization module is the main virtual environment which allows users and other software tools to visualize and study the impact of various analysis activities. It provides the platform for the simulation activities. This module can be implemented on Coin 3D or other graphical tools using C++ tools. The VR Interaction module enables the user interface options to link with the visualization module. It will be responsible for virtually picking up components, re-arranging layouts as well as navigate in the virtual environment. The Virtual Factory Module is the top level module which divides each micro assembly problem into 2 sub-problems. The first focuses on determining a feasible way to assemble a given part design by deciding which of the work cells can satisfy customer requirements; it also determines the route taken within the virtual factory (it can compare several alternatives as well). The Factory Analysis Module is the lower level module which can be used to determine the detailed assembly plan and path plan within any of the work cells in the virtual factory. The Navigational module is needed for visually examining or analyzing the process design alternatives (assembly plan, factory route, etc). This allows user to move around, fly through, zoom in and zoom out in the VFE. The Collision detection module provides a lower level collision detection capability which is important for comparing and validating process level details such as assembly path, gripper interaction, etc. Figure 3 shows the sequence diagram of the VFE (based on the Unified Modeling Language constructs) which provides an overview of the key interactions among these various modules.

3.2 The Design of the Factory Analysis Module

The VFE was designed and implemented using Coin 3D and C++ tools. The Factory Analysis module is capable of generating an assembly sequence plan as well as detailed path plans to complete the needed assembly using the work cells in a target Factory. The two work cells implemented in the VFE currently are designed after two types of existing physical cells at the Center for Information based Bioengineering and Manufacturing (CINBM).

The first type of virtual cell (figure 1) seeks to mimic the functioning of a physical microassembly work cell that is comprised of micropositioners, a part handling gripper (from Zyvex Corporation), cameras, and a work piece supporting platen (WSP). The WSP is supported by a three-degree-of-freedom (3-DOF) micro translation stage constructed from three 1-DOF translation-stage. The other components in the work cell are an InfiniVar video microscope, a video monitor, and a computer.

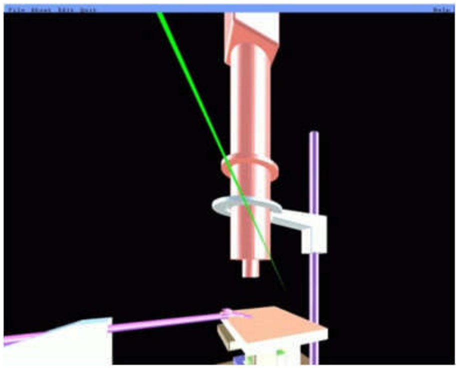

Fig. 1: A view of the virtual work cell level planning module for microassembly.

The second virtual work cell (figure 2) reflects the capabilities of an advanced work cell to support microassembly tasks. In this advanced work cell, the physical assembly and positioning of micro components is achieved through an automated worktable, gripping unit, and camera and monitoring components. The worktable has two linear DOF in the *x*- and *y*-axis and one rotational DOF. The gripping system includes an innovative gripper that is capable of moving along the *z*-axis and has an angular DOF. The monitoring/visualization resources consist of two microscopes, two color video cameras, and illumination units. The micro gripping unit is an innovative mechanism that allows an assortment of tweezer-shaped grippers to be used. This allows a comparison of various gripping surfaces and materials to be studied. This gripping mechanism is designed to be adapted to many different tweezer-like grippers. Many different types of tweezers may be used interchangeably to achieve a high level of adaptability, thus allowing different configurations to be assembled.

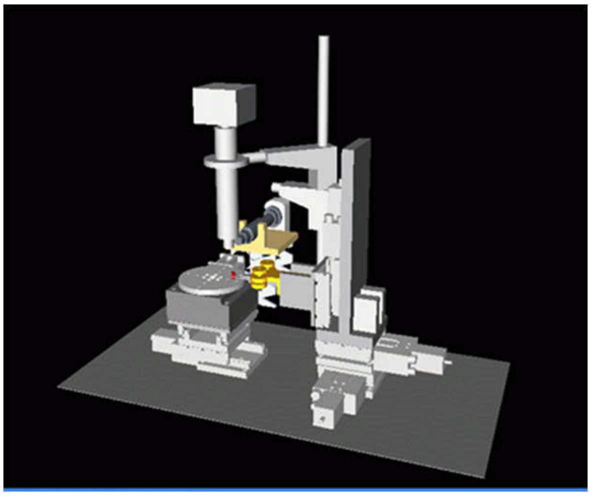

Fig. 2: A closer view of one of the advanced virtual microassembly cell.

By interacting with the virtual and physical work cells (and using a range of micropositioners, micro grippers, cameras, and controllers), users can study microassembly issues related to gripper-path planning and assembly. A range of pick and place tasks have been completed involving micron-sized pins and cams in the size range of 50 to 800 η.

The work cell analysis modules have an assembly-planning sub-module which provides two options to either generate an assembly plan manually or through a Genetic Algorithm (GA) approach. A user can manually enter an assembly sequence and 3-D path into a text file, which is read by the visualization module. If a user chooses to use a GA-based approach, then the GA-based sequence generator determines a near-optimal assembly sequence based on the position of the various bins containing the micro devices as well as the final destination of the micro pins on the target part. Candidate assembly sequences, as well as path plans, can be compared using the VFE (Figure 2). Alternately, the layout of the bins (where the micro devices, such as pins, are held for a given assembly task) can be modified and resulting assembly times associated with various layout options can also be compared. Subsequently, after a final plan is determined, the assembly instructions can be transmitted to the physical cell where the assembly tasks are completed. Feedback from cameras ensures satisfactory completion of the target microassembly tasks. The four other key modules involved in this process include the assembly-planning (or sequence-generating) module, the collision-detection module, the visualization manager, and the motion-generation module. The collision-detection module (mentioned earlier) validates the assembly plan to ensure that no undesired collisions occur when the assembly resources (such as the gripper and micropositioners) are in operation. The visualization, or VR world manager, renders all the data for user visualization. The motion-generation module receives candidate assembly sequences (generated within the GA-based module) as input and generates a collision-free 3-D path around possible obstacles in the assembly environment. The 3-D path is used to calculate the travel distance of the gripper when evaluating candidate assembly-sequencing alternatives.

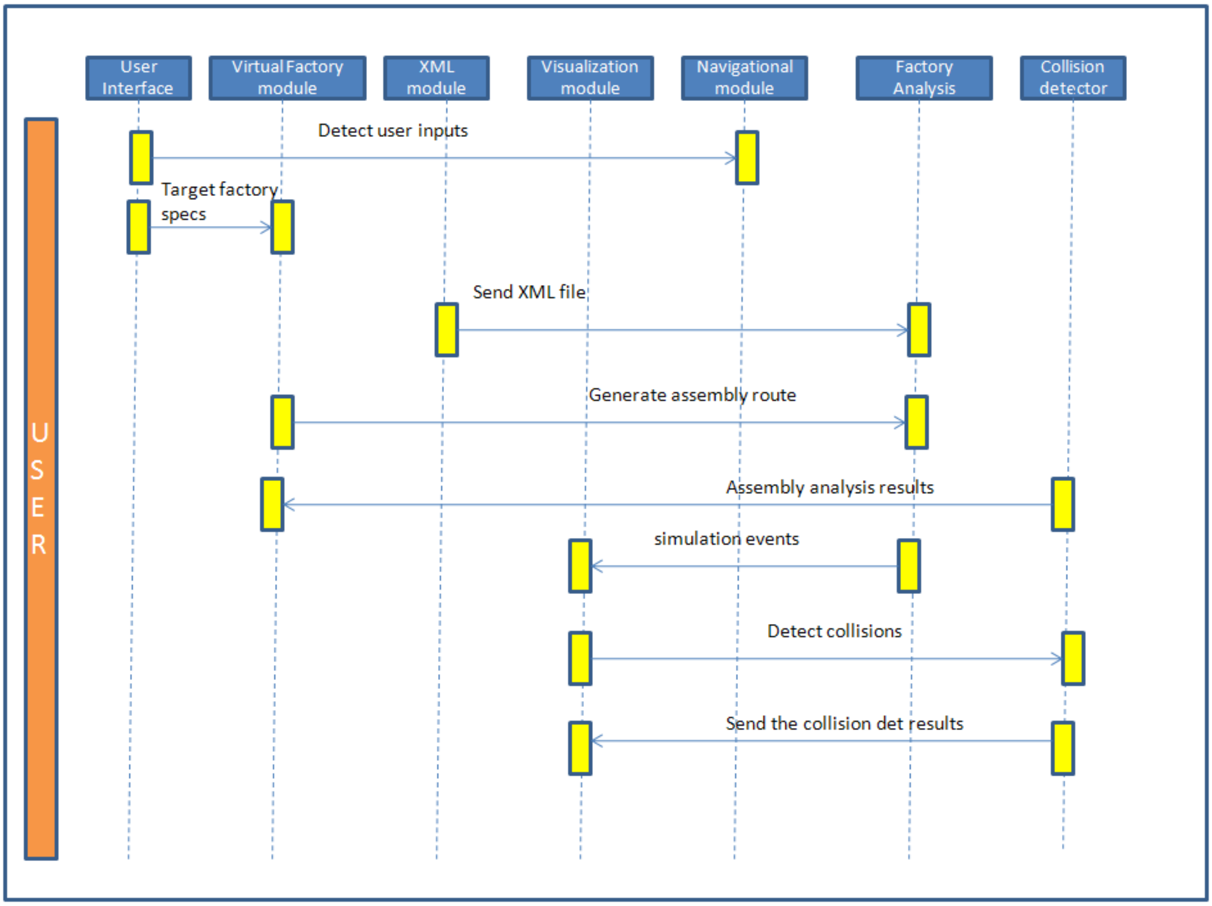

Fig. 3: A sequence diagram showing the main interactions in the VFE.

The genetic operator works by randomly generating parent sequences (corresponding to assembly sequences), generating new child assembly sequences, determining the best child sequences, and subsequently generating the next generation of sequences from their respective parents. This process is continued until the new sequences do not show any appreciable difference in the travelling distance of the gripper.

3 DISCUSSION

The Virtual Factory Module focuses on the top level factory routing in between the various work cells in the VFE. It is comprised of (a) a constraint matching procedure (b) factory route generator (c) interface with the factory analysis module discussed earlier. The Virtual Factory Module allows users to also manually interact and specify a target factory route. The constraint matching procedure is a sub-module which compares the assembly requirements for a given micro design with the capabilities of the various micro assembly resources and generates candidate routing plans. A given assembly process is divided into a set of sub-assembly activities which can simultaneously or sequentially completed an identified set of activities. Various options can be compared with respect to the overall assembly time. For example, work cell 4, 5 and 6 can together assemble a specific sub-assembly AS2 while work cells 1 and 2 can work together to complete the assembly of sub-assembly AS3. Subsequently, these two items can be assembled using another work cell 7. User can be presented the various alternatives which can be compared interactively. The emphasis on reducing the overall assembly travel time in between various work stations. The users can also in a similar manner interact with the lower level process assembly issues by selecting a given work cell operation and studying the various alternatives within that specific work cell. Apart from also manually inputting a specific factory route and/or work cell level assembly plan, users can also create an XML file which specifies the assembly sequence at both levels of detail.

Two views of the factory level environments are shown in figures 4 and 5. They correspond to two different micro factory designs whose capabilities can be evaluated in the context of given micro part designs. In figure 4, three work cells are considered to respond to the assembly requirements with a specific set of part handling capabilities. In figure 5, an alternative layout is considered with different part handling capabilities. The main outcomes from the evaluation include a factory level route plan, detailed assembly plans for the work cells involved as well as associated process times.

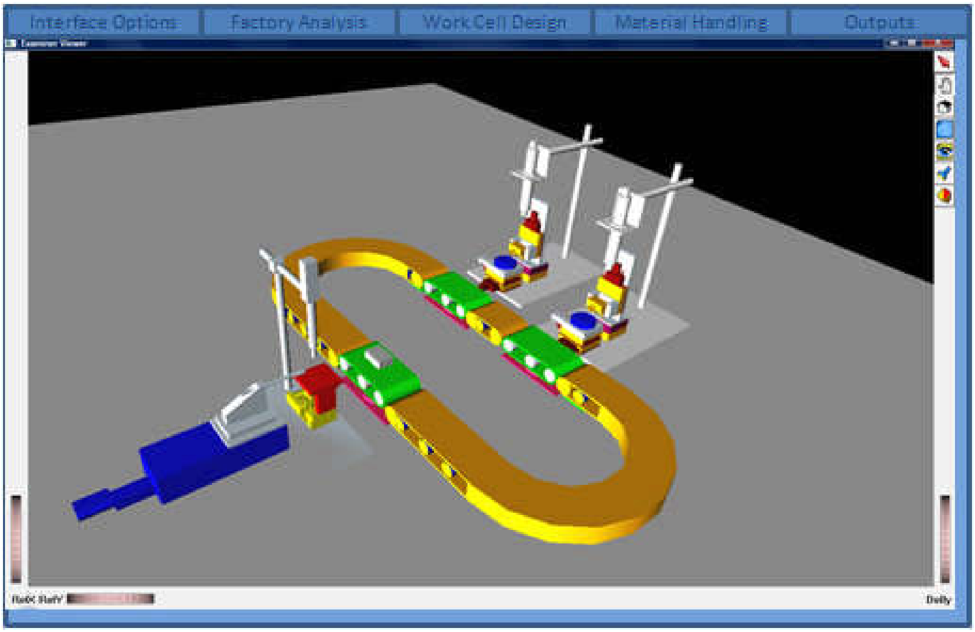

Fig. 4: A view of a virtual factory design.

4 CONCLUSION

This paper discussed the design of a Virtual Factory Environment (VFE) for micro assembly contexts. The VFE comprises of various modules to enable comparison of factory and work cell level assembly alternatives. The VFE can be comprised of given number of work cells (depending on the customer requirements or potential partners); the virtual environment enables engineers to rapidly assess and determine process level options when responding to a diverse range of micro level product designs. The VFE enables engineers to model a range of micro assembly resources including micro positioners, grippers, conveyors to transport work in progress as well as other material handling robots and sensors. A work cell can be described as a collection of re-programmable assembly equipment including micro positioning stages, assembly platens, cameras (with microscopes) and grippers. Each work cell may have a diverse set of capabilities including assembly degrees of freedom and gripper designs.

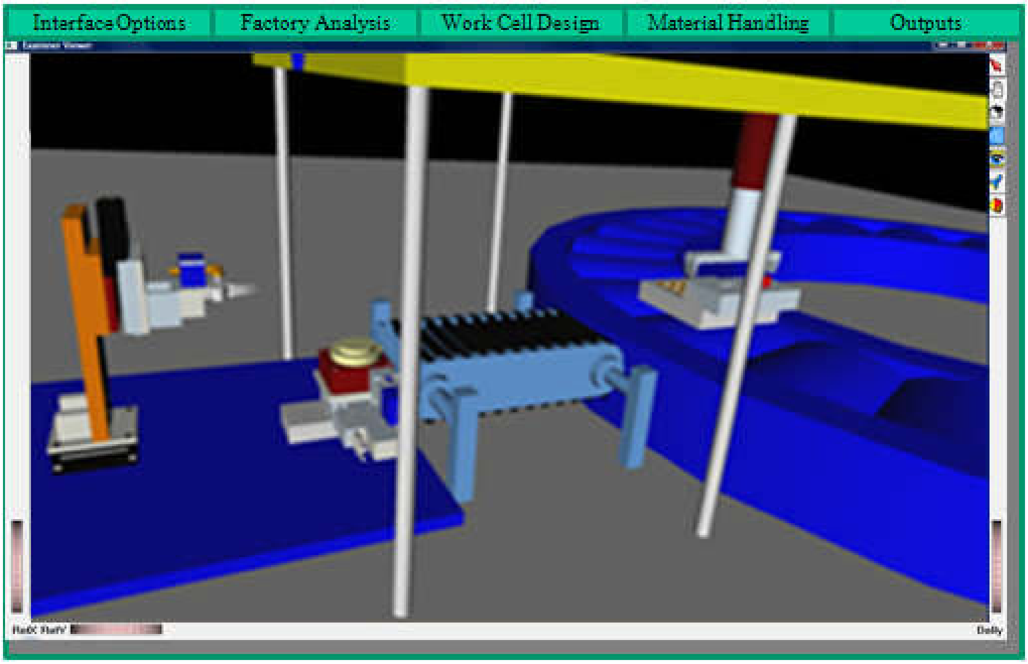

Fig. 5: A view of an alternative virtual factory design.

5 ACKNOWLEDGEMENT

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