Micro-Factory: A Small Factory to Manufacture Even Smaller Parts

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Abstract

A micro-factory is best described as a small factory to manufacture even smaller parts. The precision of the control mechanism and the required accuracy by each of its tools has made micro-factory an interesting topic for research and development. The introduction of automatic control, the use of visual feedback, the development of novel control algorithms for motion control are a few fields which gives a lot of scope for researchers to explore.

Keywords: Micro-factory, Desktop Micro-factory.

Introduction

The current approach for micro-manufacturing and micro-assembly using high precision pick-and-place robots equipped with micro grippers has eventually become defect prone and time consuming. The task was highly skill based and not easily repeatable. The cost of the assembly is reasonably high as it requires constant human intervention. The need of an automatic micro-factory specific to material types, component geometries, and types of mechanical motions that can be realized at a lesser cost with lesser human intervention has increased enormously in the past few years. [2]

A Personal Computer has more than once been seen to manage a desktop micro-factory system at various levels. However we now have processors in the market with processing speed ranging up to 120 MHz .It only seems fit to use an embedded platform dedicated solely to the control of the micro-factory and its components. It reduces the size of the micro-factory, increases its portability and reduces its power consumption considerably. [6]

Figure 1 shows the major components that make up a microfactory system.

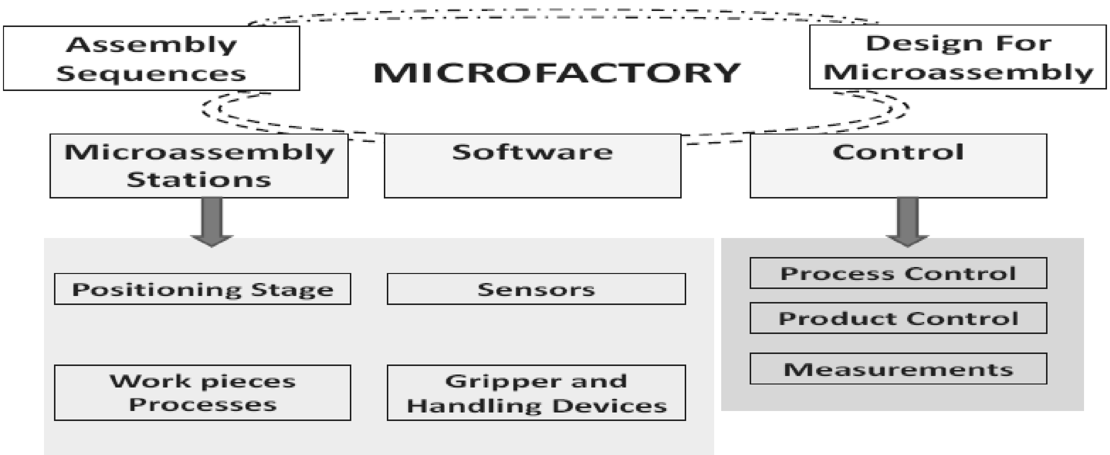

Figure 1.Component of Microfactory

History and Current Advances in the Micro-Factory

The MEL micro-factory as shown in Fig. 2 is the first prototype of desktop machining micro-factory, developed by the Mechanical Engineering Laboratory in Japan in the nineties. It consists of machine tools namely a microlathe, a milling machine, a press machine, and assembly machines such as a transfer arm and a Two-fingered hand. Production of small sized machine parts and their assembly was made possible due to this prototype. The key features of the first micro-factory were the reduction in size and weight, reduction in the driving energy of facilities and energy required to control the ambient environment, reduction in inertial force and hence increase in speed, and positioning precision. There was also enhancement in terms of flexibility of the manufacturing system as the layout of the production system could be easily changed. It was envisioned that due to the above features a few ambitious prospects such as mobile manufacturing or manufacturing system for extreme environments such as vacuum or micro-gravity would be within reach after adequate enhancements in the micro-factory. [3]

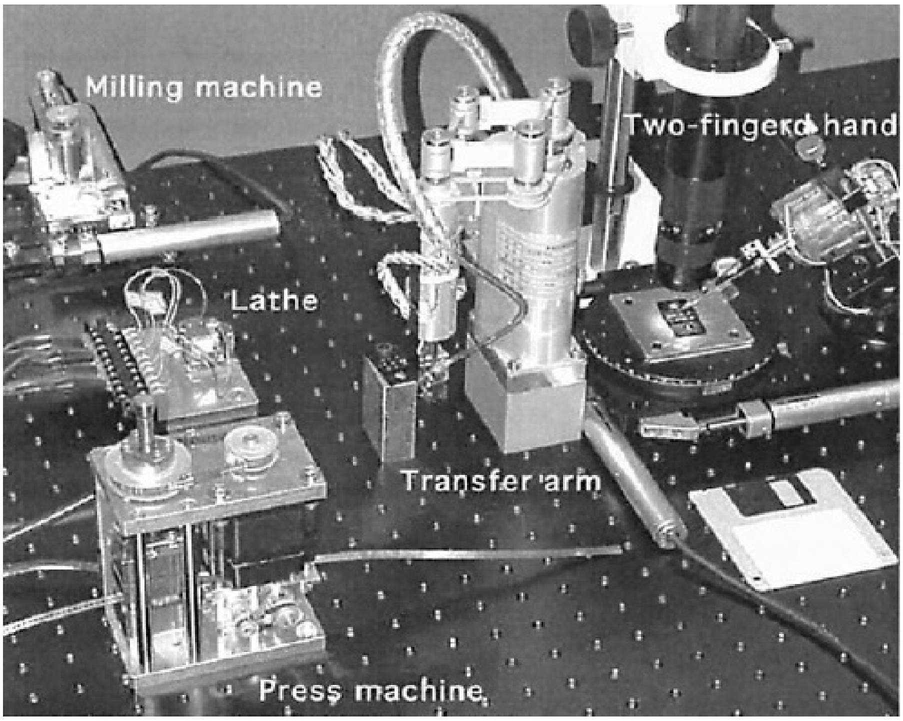

Figure 2.MEL micro-factory

This was followed by the development of:

- A second Japanese micro-factory by Hirano and Furuta [2002].
- Carnegie Mellon University which introduces a flexible agent-based automated control of a miniature assembly factory [Hollis and Gowdy, 1998].
- Fraunhofer IPA [Gaugel et al., 2002] which focused on the development of a marketable micro-factory, "MiniProd", using a "plug and produce" principle.

A flexible micro-factory that supported automated operation for multi-operation manufacturing of micro/ meso-scale components was developed by Andrew E. Honegger et.al. In 2004-05, they discuss the architecture of an improved micro-factory and the development of its hardware and software for factory level integration and control. [5]

The authors deem their work to emphasize on increased structural stiffness, machining accuracy, calibration methodologies, portability and automation including part transfer and tool placement systems for machining operations. Online micro-factory metrology systems have also been developed by them to allow pre-, in- and post-process work-piece measurements.

The architecture of the improvised micro-factory included a three-axis micro/ meso-scale machine tool (mMT), a five-axis mMT and a metrology station. The characteristics and specifications of each of these components and their advantages when compared to the previous micro-factory prototypes include flexibility to be easily converted for other processes, machine convertibility, high acceleration, stiffness, and accuracy capabilities. The problem of moment loading of bearing and the possible solutions for this have been offered by the authors.

The improved configuration of five axis mMT is said to have eliminated the need for compensating linear travel and reduced the overall machine size. The metrology station uses multiple sensors, including laser distance sensors, tactile probes and vision systems. The motion stages in the station use DC motors driving ball-screw actuators with linear ball bearings and linear optical encoders.

A major achievement by the authors is the automated part transfer. Transfer of raw materials, processed parts and sensors from machine to machine is shown to be handled by a four-axis gantry system. A servo-actuated wrist with a two-fingered pneumatic gripper is attached to the end of the gantry arm and is used to grasp and hold work-pieces and sensors during transport. The authors have developed a sensor rich environment for their proposed micro-factory which includes sensors for process monitoring, part measurement, and tool-tip detection. These sensors along with CCD cameras allow simultaneous observation of processes and real time adaptive control.

The control unit includes a UMAC 80MHz processor which interprets the standard G-code. It was programmed to offer closed loop PID control .The software routine also included a GUI developed in VB and .Net that enables the deployment of developed programs. The GUI is also made to train the micro-factory for new work-pieces. This shows the amount of intelligence rendered to the system.[5]

Architecture for a reconfigurable micro manufacturing system is presented by C. Makatsoris et al. in their article. The proposed architecture comprises a micro manufacturing cell a hexagonal-base on which three tool heads performing a different manufacturing process can be attached. These tool heads are interchangeable. Hence flexibility has been provided in terms of the different materials used, dimensions of the job, and the tolerances. The manufacturing cell also includes manipulation robots and an automated buffer unit. A modular conveyor belt is used for part transfer. Specific emphasis has been again given to the control system of this system which in consideration with the architecture has to be modular, flexible and easy to reconfigure. A new issue brought to light by these authors is the issue of co-ordination between the tasks performed by the manufacturing cell.

The authors have also specified intricate details of design including the design for work piece holding when it is being processed. The author performs an evaluation of individual operations and builds a simulation model of his improvised micro-factory cell. The concept of his improvised micro-manufacturing cell was verified with the preliminary results of the dynamic FEA analysis of the processing module. Their aim is to build a control system supporting the ”plug and play” approach which will accommodate the variety of processes demanded in the production area.[6]

M. Gauthier et al. give a very interesting twist to the concept of a micro-factory. They observed that the working of micro-manipulators is restricted by adhesion and the surface forces. In order to reduce these constraints they propose that the micro assembly tasks be performed in a liquid medium where the restricting forces in question have much less effect. This idea gave birth to a whole architecture of a micro-factory which was designed in consideration with the liquid medium environment. It includes the definition of submerged conveyance systems and workstations. Several approaches for part transfer were analyzed by the authors before they finalized the architecture for the submerged micro-factory. They contrast the effects of contact forces in air and water and discuss the impact of hydrodynamic forces on micro-objects. The minimum dimensions of the work piece when to be used in this type of architecture is mentioned. Thus a constraint in the form of size has been imposed. However when we shift our domain from the micro to the nano scale the reduction of surface and adhesion forces will prove to be extremely important. [8]

A Few Examples of Micro-Factories

The Experimental Microfactory System, Seiko Instruments Inc

This system as shown in Fig. 3 consists of a processing unit, an assembling unit and conveyance unit. An electrochemical machining device, micropumps and a recognition device make up the processing unit. The assembly unit comprises of two 7 DoF arms where each axis driven by ultrasonic micromotors. A precise positioning stage is used for the assembly of microparts along with several tools such as vacuum and electromagnetic chucks. The conveyance unit is made up of an electromagnetic microactuator array. This assembly is mostly used to make gear trains.[9]

Specifications

- Accuracy of the 2 arms-20 micrometer
- Positioning stage resolution-.5 micrometer
- Machining resolution-20 micrometer
- Depth of processing-300 micrometer
- Processing area-5x5 mm^2
- Micro actuator size-1 mm^2

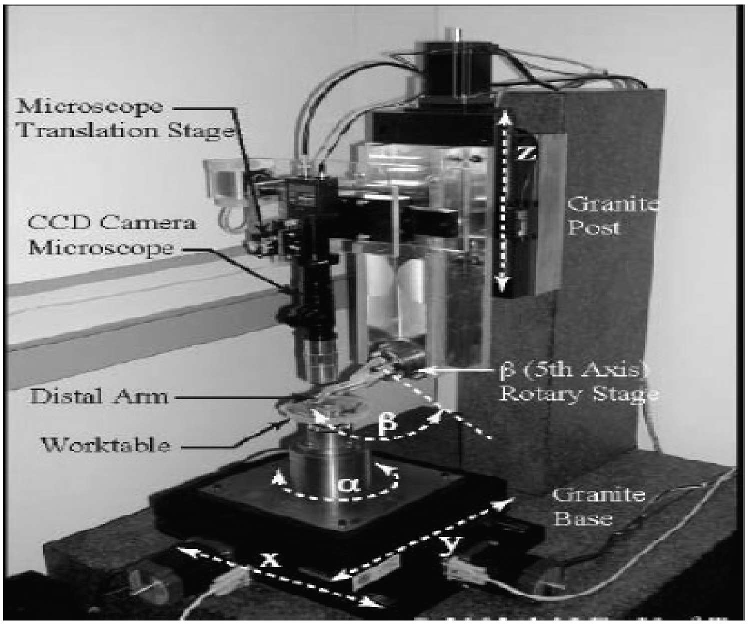

Figure 3.Experimental Microfactory System

OLYMPUS, Japan

This micro-factory as shown in Fig. 4 included a video microscope with a bifocal optical system, an ultrasonic motor driven manipulator which was parallel linked , an elastic hinge with bending deformation, and a positioning stage having 6 DoF.

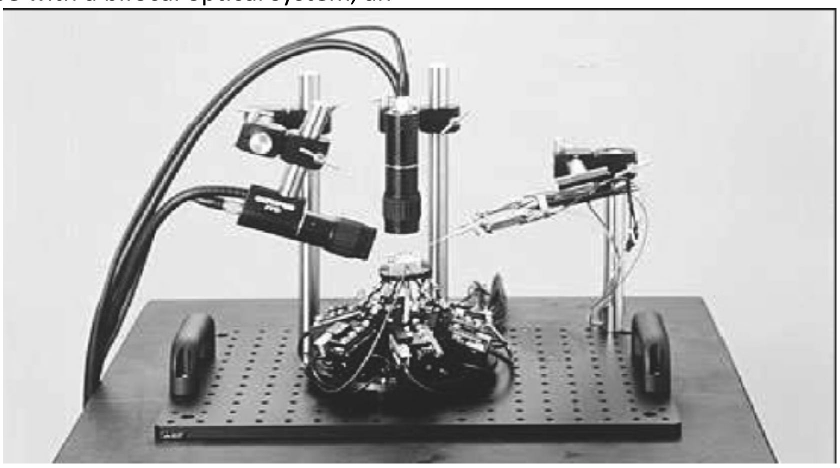
Figure 4.OLYMPUS

This system uses a magnified image provided by the camera to go about operations like micro-welding and inspection. It is the first of the tele-operated kind.[9]

Zyvex A100

Zyvex A100 Assembly system as shown in Fig. 5 has 2 positioning robots which can grasp, move, test and correctly place the micro-scale workpiece.

One of them has a 3 DoF, whereas the other is enhanced with a 4 DoF. It also offers re-configurable micro-grippers for manipulating micro-scale objects. It is used mostly in the process of MEMS manufacturing. Its use is coupled with an electron or optical microscope for micro-assembly.[9]

Specifications

A. 3 DoF positioner
- Resolution of positioner in x y axes- 100 nanometers
- Resolution of positioner in Ø axis-3.5 micrometers

B. 4 DoF positioner
- Resolution of positioner in x y axes- 100 nanometers
- Resolution of positioner in Ø axis-3 micrometers

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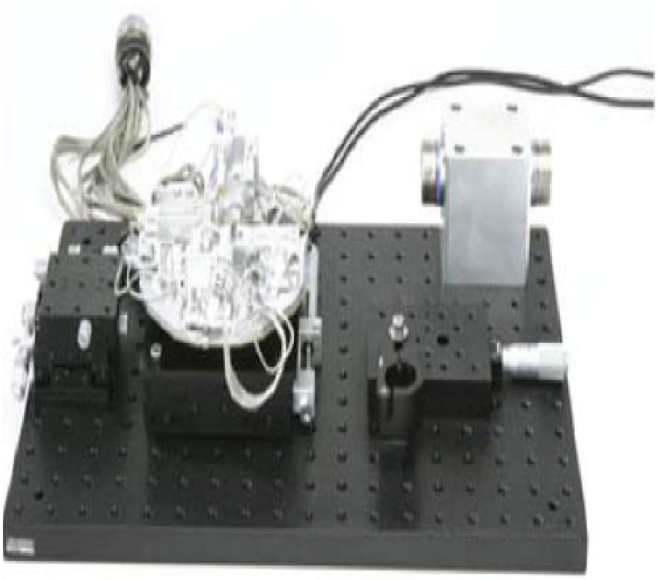

Figure 5.Zyvex A100 Assembly System

The Robotic Workstation (MJMP)-University of Toronto

This workstation as shown in Fig. 6 possesses the unique characteristics of being generic as opposed to application specific. It consists of a five axis robot manipulator driven by 5 phase stepper motors. A 3 axis translational stage for the movement of the micro-scope has also been enabled.

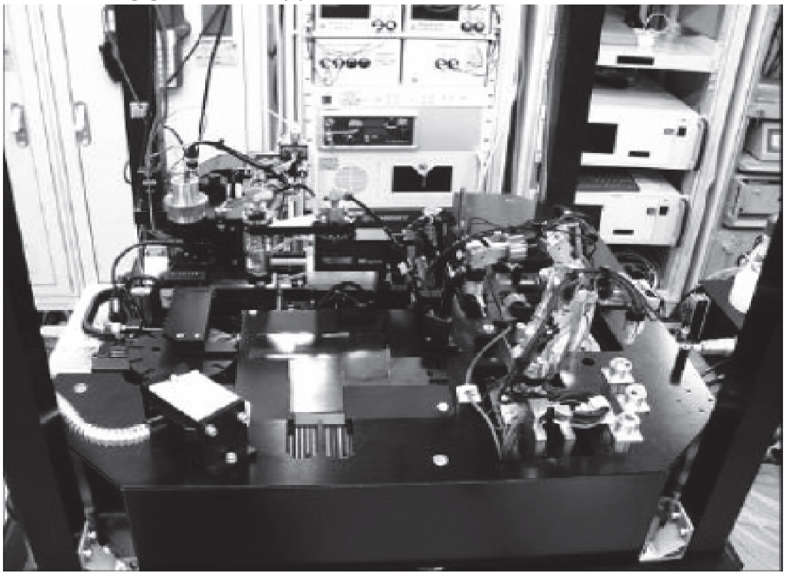

Figure 6.Robotic Workstation (MJMP)-University of Toronto

Specifications

- Resolution of the stepper motor- 0.5 micrometer
- Maximum number of steps by the stepper motor-4000 steps
- Rotational resolution-0.36 degrees
- Travel range in the x y axis-200 millimeter
- Travel range in the z axis-150 millimeter
- Rotation range in the beta axis- 50 degrees to -50 degrees[9]

Evaluation of Micro-Factory in the Market

The first micro-factory proved capable of assembling the test product within an enclosed space of approximately 50 by 70cm. Its size, configurability, flexibility renders it useful for the manufacturing of micro-nano scale components. A good travelling range and resolution both in the linear and the rotational axes of the manipulator increase the workspace covered by one element of the micro-factory. Plug and play approach in the processing unit provides scope for increasing the versatility of the micro-factory. The automation of the nano-robots and positioning stages enabled by electronic feedback or visual feedback make the job of the micro-factory more accurate and repeatable. Control strategies developed for transporting the raw work-pieces from stage to stage in the manufacturing process help to make the system independent of human intervention, robust and self-correcting. Thus it has been proved that the micro-factories developed to date are adequate to meet the required production rate, system efficiency and cost.

To further maximize the system efficiency, the product design, the processes and systems must be changed concurrently. Only systems like micro-factory which are compact, safe and flexible can be thought by adopting concurrent design strategy. Therefore, the micro-factory has a great scope as a future manufacturing system for micro mechanical fabrication of many varieties of products. [10]

Role of Nano-Robots in the Desktop Micro-Factory

The robot is a programmable electro-mechanical system with more than 3 degrees of freedom at the very least. A certain amount of intelligence is also provided to a robot. Which is derived as a feedback from a sensor rich environment? According to their size and the size of the objects the robot is designed to handle the robots can be classified as macro-scale, micro-scale and nano-scale robots. The interactions of a nano-robot with the environment are mechanical, electromagnetic and chemical in nature. The application of nano robots can be seen in the assembly and handling of micro-parts in a desktop micro-factory. What makes nano-robots different is that it works in an environment where surface forces such as van der Waals are dominant over gravitational forces, which play a huge role when it comes to macro-scale robots. Also the final accuracy needed by these robots is in the order of micro to nano-meters and hence the motors used to move are highly precise and devoid of vibration errors. Mainly electro-magnetic and piezo-electric motors are used for this purpose. The sensors used to enhance the robots in a desktop micro-factory are obstacle avoidance, collision avoidance, velocity measurement, displacement measurement, orientation sensing etc. The nano-robots are therefore inevitable in a desktop micro-factory. They fulfill the functionalities of part handling, part assembly and part transfer. [2-11]

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