

# A Versatile and Reconfigurable Microassembly Workstation

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**Abstract** – In this paper, a versatile and reconfigurable microassembly workstation designed and realized as a research tool for investigation of the problems in microassembly and micromanipulation processes and recent developments on mechanical and control structure of the system with respect to the previous workstation are presented. These developments include: (i) addition of a manipulator system to realize more complicated assembly and manipulation tasks, (ii) addition of extra DOF for the vision system and sample holder stages in order to make the system more versatile (iii) a new optical microscope as the vision system in order to visualize the microworld and determine the position and orientation of micro components to be assembled or manipulated, (iv) a modular control system hardware which allows handling more DOF. In addition several experiments using the workstation are presented in different modes of operation like tele-operated, semi-automated and fully automated by means of visual based schemes.

**Index Terms** – *microassembly, micromanipulation, microassembly workstation.*

## I. INTRODUCTION

With the miniaturization of products to the levels of micrometers and the recent developments in microsystem fabrication technologies, there is a great need for an assembly process for the formation of complex hybrid microsystems. Integration of microcomponents made up of different materials and manufactured using different micro fabrication techniques is still a primary challenge since some of the fundamental problems originating from the small size of parts to be manipulated, high precision necessity and specific problems of the microworld in that field are still not fully investigated. The necessity of the assembly process requires flexible, modular, accurate mechanisms, which can finely pick, orientate, move and release different types of objects at the right place. In the presence of microparts, assembly is a key issue in the formation of a product since different functions require different materials within a product.

Several groups have conducted research to develop microassembly systems. In that context, flexible microrobot-based microassembly desktop stations (MMS) in which microassembly processes are carried out by automatically controlled micro robots are proposed in [1] [2] [3]. Design and

development of a 6 degree of freedom robotic manipulator used in the assembly of three-dimensional MEMS microstructures is presented in [4] as the further development of the 5 DOF manipulator presented in [5][6]. A vision based feedback control system used in the automation of microassembly of MEMS devices using that 6 DOF robotic manipulator is presented in [7]. A microassembly system consisting of a 4 DOF base unit, a 2 DOF top unit equipped with an illumination dome and 3 microscopes with CCD cameras located on a ring structure above the whole system for the automated assembly of bio-micro robots is presented in [8]. In [9] multi-manipulator cooperation for the execution of microassembly tasks by using different kinds of micro endeffectors under stereo microscopic vision system is introduced.

In this paper, we propose a versatile and reconfigurable inspection and handling system for mini/micro products and components manipulation and assembly. Previously, a single manipulator system [10] has been developed for microassembly and manipulation operations. Experiments realized on the previous system brought the necessity for additional features to the system like an extra manipulator for coordinated execution of tasks, a rotational DOF for the sample plate, a more modular control system hardware eligible for handling more DOF and a new optical microscope as vision system configured to allow automated control of magnification and focusing. The vision system also provides narrowscope view with adjustable magnification and wide-scope view for the global picture of the environment. With the enhancements on the previous system the system became more suitable to realize more complicated assembly and manipulation tasks.

## II. MICROASSEMBLY WORKSTATION

The overall functional structure of the workstation is depicted in Fig 1. The developed workstation is providing environment (positioning and vision systems) allowing wide range of the tasks to be performed by changing the endeffector tools attached to the end of each manipulator system. The overall mechanical motion has 9 DOF in manipulation and 3 DOF in vision systems. According to the endeffectors to be used, the number of DOF is subject to change in the system.

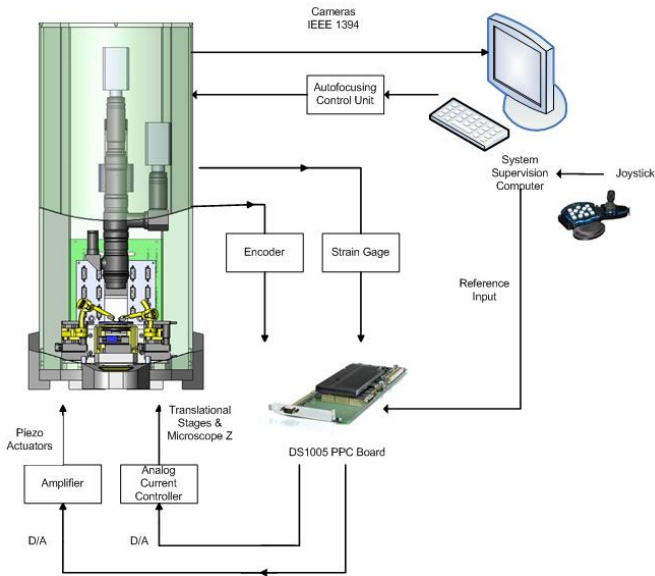


Fig. 1 System Configuration

### A. Manipulation System

Manipulation system consists of two 3 DOF tool holder micromanipulator stages. Each manipulator consists of three linear stages configured as a Cartesian xyz system with 7 nanometers design resolution. The system presented in [10] which was the first prototype of the microassembly workstation has only one manipulator stage configured as a coarse and fine positioning stage. This configuration is changed in that workstation since the desired precision and travel range can be provided by using the linear stages. A second manipulator system with the same configuration is added to the system in order to perform more complex manipulation and assembly tasks with coordinated motion. For example; a cell can be manipulated by a probe while it is being held or supported by means of a suitable end effector.

The system also has a 3 DOF sample precision positioning system (x,y,θ) which provides the usage of the substrate surface more effectively by moving the different regions of the substrate into the field of view of the microscope. Rotational stage is designed over a xy Cartesian positioning system with the resolution of 45 nano degrees. The design of the stage also allows backlighting with a gap opening of 20mm.

End effectors and necessary fixtures are used interchangeably in the system. Microgrippers, probes and other manipulation tools can be the matter of choice and necessary fixtures are designed to be easily integrated to the system. The whole system is placed onto an actively controlled damping table in order to get rid of environmental vibrations. Actual system is shown in Fig. 2

### B. Vision System

Vision system is designed to provide the system and the operator clear visualization of the microworld, position and orientation of the parts to be manipulated. Integrated with the hardware system, user interface designed for the vision system utilizes coarse and fine views of the workspace, enables

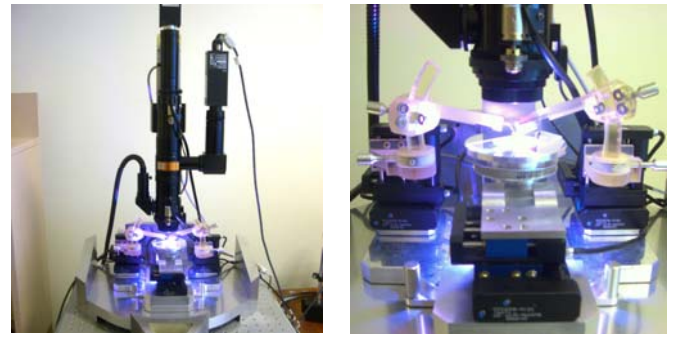


Fig. 2 Actual System.

adjusting necessary magnification values for the task to be performed, autofocusing to provide clear images and determine the depth information. It also allows the realization of automated tasks with the utilization of visual feedback by determining the relative distances between the regions of interest and supplying the necessary information to the motion stages. An optical microscope with visual resolution of 0.7 micrometers and the visual magnification of 4x-800x is equipped with two CCD cameras to obtain coarse and fine images of the environment. (See Figure 3)

The optical microscope used in the workstation as the visual system is selected and configured according to the needs of a microassembly and manipulation system. It is configured in such a way that with two different optical paths, one with constant magnification to provide global view of the workspace and the other with extra magnification for the detailed view of the workspace. By enabling such a feature, positions of microparts scattered all over the sample plate can be determined and transferred to the assembly point of interest. On the other hand, by means of magnified view, assembly or manipulation of parts can be realized precisely with more accurate handling of the parts to be manipulated. Focus and magnification adjustment are controlled with stepper motors in order to fully automate the operations performed in the system.

Illumination is the key issue for the vision system. As the assembly tasks require image processing algorithms for the detection of the parts to be manipulated and information about the geometries of these parts, the illumination techniques should be considered carefully. For example, shadows can cause problems for extracting the exact shape of the parts which may cause the assembly or manipulation tasks to fail. In that context, system is equipped with two light sources, one providing backlight illumination by means of a RGB Led Illuminator and an upper illuminator from the microscope's vision path. Both illumination systems can be controlled from the system computer.

### C. System Supervision

The control system consists of two parts; a Vision computer and a Real-time dSPACE 1005. The Real-time computer has a sampling rate of 10 KHz, and performs all real-time operations. On every sampling period the positions of all the stages are acquired, filters are used to calculate velocity, references are obtained from the vision computer

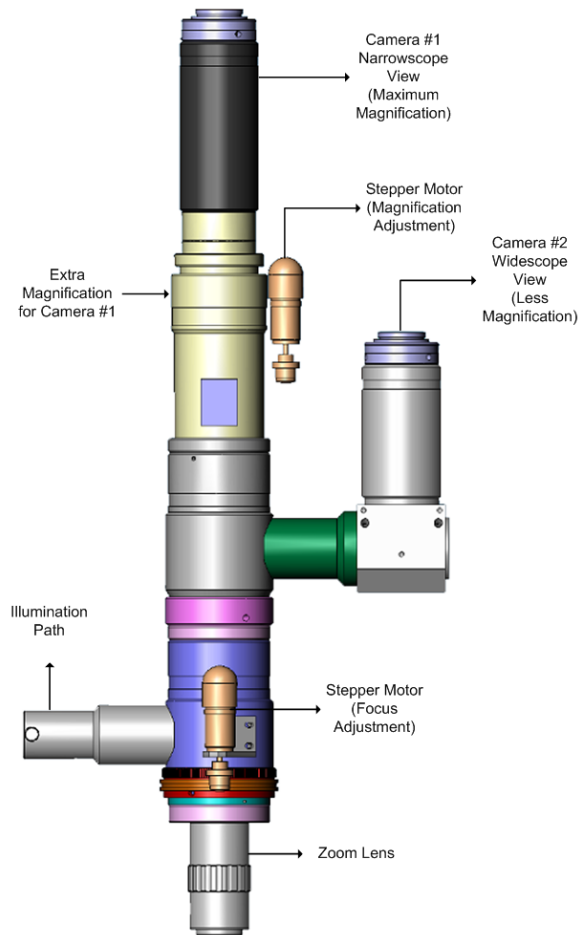


Fig. 3 Optical Microscope Structure.

then the system outputs are calculated using SMC controllers and the current references are output to the stages.

Above this architecture there is a trajectory generation algorithm that runs over a duration of several sampling periods (depending on the distance and minimum speed of the stages) that ensures each manipulator group's stages perform a linear motion by scaling the control outputs given to the grouped stages and setting the travel time according to the slowest member. All the functions of the above system are written in functional manner, new stages or motors can be defined as new modules of the system, grouped with other parts where synchronized motion is desired, then real-time binaries are compiled and loaded into the Real-time computer. The Real-time computer can operate without the need for a sophisticated GUI, and references from different sources can be used to drive it, much like the controller of an industrial robot, it can be commanded by any other platform. The depicted GUI was written in C# and uses Halcon image processing library. However the modularity and reconfigurability permitted experiments by other groups to be performed on the same setup using C++ and OpenCV. Control structure is shown in Fig. 4.

The vision computer has the task of capturing images

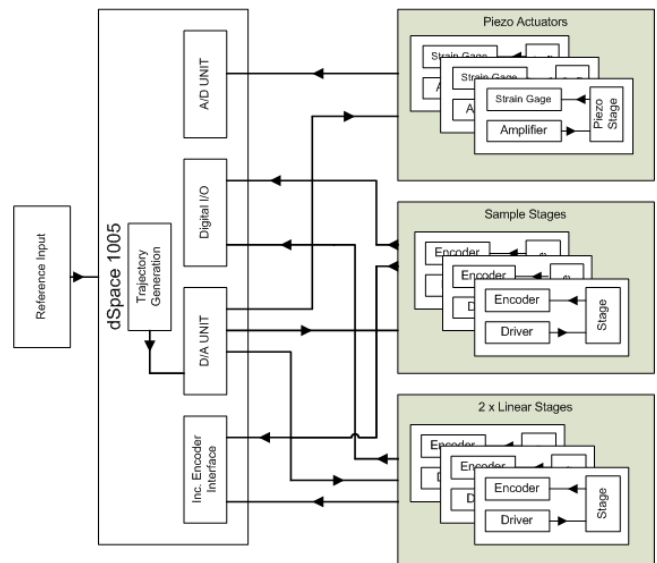


Fig. 4 Control Structure.

from the camera's, calculating the relative positions on the screen and getting the desired inputs from the user by means of direct destination position coordinates for any of the manipulators or platforms or more sophisticated high level functions like "push item to position" types of commands, converting the image coordinates to world coordinates according to the mapping values and sending them to the Real-time computer. The vision system runs between 22 to 30 Hz depending on the Camera's performance.

A graphical user interface, as the main interaction block with the operator, is developed for the user to control the system with all its features. It consists of blocks handling:

- Visual information acquired by the microscope;
- The presentation of the state of the overall workstation
- Presentation of the current position for all DOF of the motion system
- Entering commands from operator to execute desired tasks
- Certain level of the system diagnostics.

In order to allow operator handling of all of these information the GUI is designed as a set of screens each allowing interaction to the specific tasks of the system. The operator can observe and intervene almost every aspect of the workstation via GUI. Desired motion commands can be given by simply clicking on the live image captured from the CCD cameras or using the joystick controlling every axis by selecting the axis of interest. Features related to the vision system like focusing, magnification, etc. can also be adjusted from the GUI.

#### D. Motion Control

Motion control is the basis for the microassembly workstation since the precision and accuracy of the assembly tasks mostly depend on the control performance. All the elements of the motion control system either the linear stages or the rotational stage or Piezo suffers from high disturbance

in the system due to friction, hysteresis etc. In order to have robust control system, the disturbance present in the system needs to be rejected. To remove the disturbance in the system disturbance observer is used. The output of the disturbance observer is feed to the control input in order to counter effect the disturbance present in the system.

The structure shown in Fig. 5 had been applied for all DOF in the workstation and achieved results are satisfactory.

The control algorithms employed in motion control are based on Sliding Mode Control (SMC) methods. The most salient feature of the Sliding Mode Control (SMC) is the possibility to constrain a system motion in a selected manifold in the state space. Such motion in general results in a system performance that includes disturbance rejection and insensitivity to parameter variations. The resulting step responses of the translational stages are shown in Fig. 6 and Fig 7. Details about the algorithm used and the results obtained can be found in [10] and [11].

### III. EXPERIMENTS AND RESULTS

For testing of the reliability of the system several experiments are implemented in different modes of operation; tele-operated, semi-automated and fully automated by means of visual based schemes. Experiments are realized using polystyrene microspheres with diameters of approximately 50  $\mu\text{m}$  and using various manipulation tools. Tele-operated microassembly is realized in two different ways; by giving commands on the screen with mouse clicks or by means of a

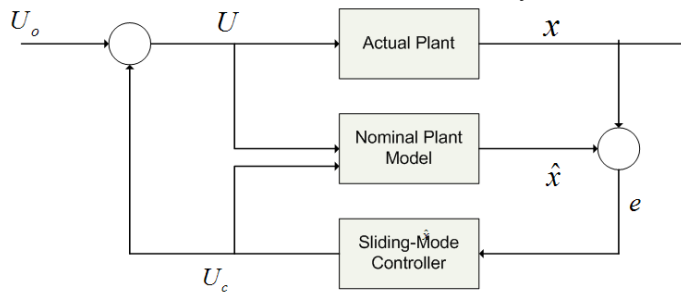


Fig. 5 Functional Diagram of the plant.

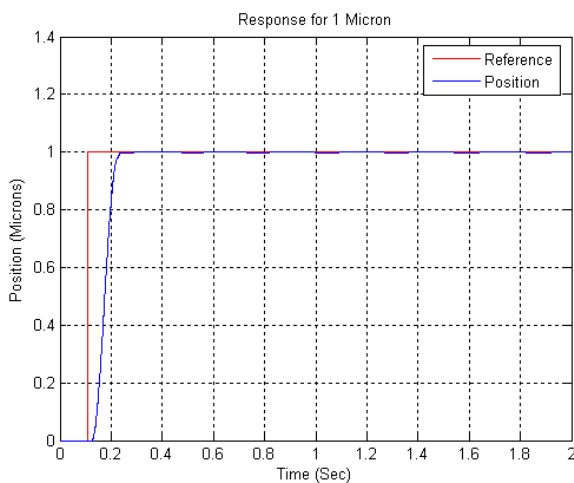


Fig. 6 Step Response of Stages for 1 $\mu\text{m}$ .

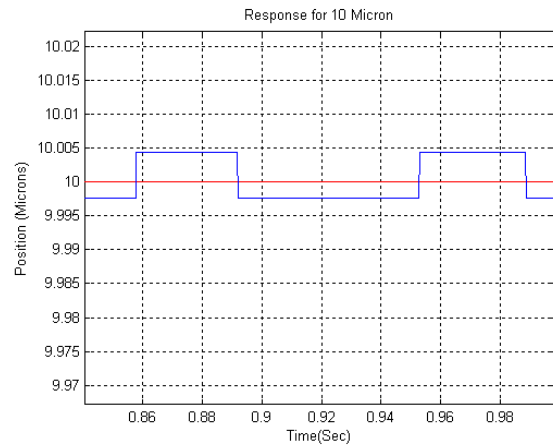


Fig. 7 Design Resolution (One Encoder Pulse).

joystick. Semi-automated micro assembly involves the intervention of the operator to some extent. The operator only chooses the particle to be manipulated and the destination point where the particle is to be moved, the rest is executed automatically.

By using the GUI developed for the workstation, in the tele-operation mode, using a sharp tungsten manipulator to push the micro spheres with a diameter of 50  $\mu\text{m}$ , initial letters of Sabanci University is formed. (Fig. 8)

Several conventional visual servoing schemes are also implemented for various microsystem applications. An image based visual servoing algorithm using optimal control penalizing the pixel error and the control signal magnitude is implemented to form a line pattern by pushing 50  $\mu\text{m}$  diameter polystyrene spheres. (Fig. 9) In order to locate the microspheres precisely, a feature extraction algorithm to detect the tip of the probe and the spheres is developed. Moreover the trajectory planning is designed to avoid the obstacles and determine the priorities of the particles to be located.

The workstation is designed in such a way that various types of end effectors can easily be adapted to the system and used as the handling tools. Different types of microgrippers are used in order to implement pick place experiments in the

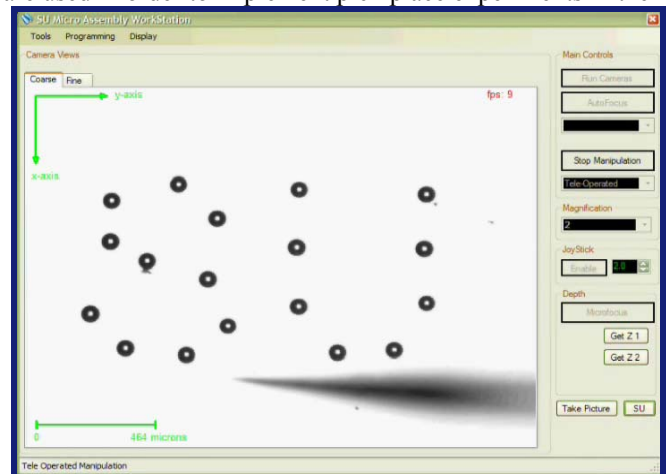


Fig. 8 SU Pattern Formation.

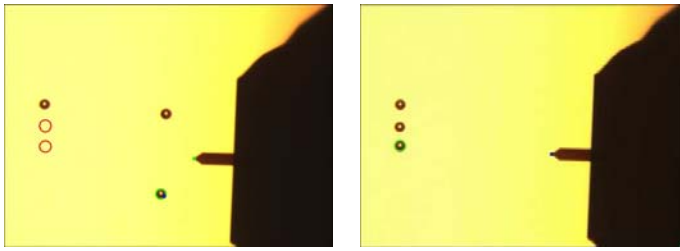


Fig. 9 Line Pattern Formation Using Visual Based Schemes.[12]

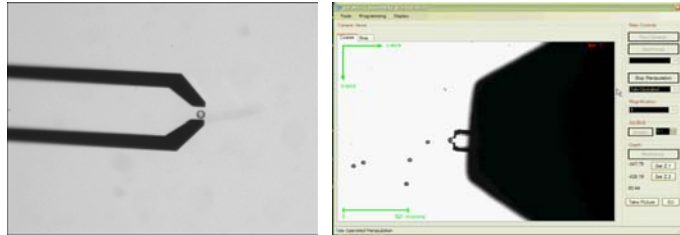


Fig. 10 Microgripper Experiments.

system as shown in Fig. 10. The workstation is also used for cell manipulation experiments using micropipettes, probes, etc.

#### IV. CONCLUSION

In this paper, a versatile and reconfigurable microassembly workstation designed and realized as a research tool for investigation of the problems in microassembly and micromanipulation processes is presented. Additional features for the realization of more complicated assembly and manipulation tasks are presented as improvements to the previous workstation presented in [10]. Details are given about the structure of the mechanical and control structure of the workstation.

In addition several experiments demonstrating the functionality of the workstation are presented. Experiments are realized using different modes of operation like tele-operated, semi-automated and fully automated by means of visual based schemes. The results of the experiments are promising in the sense of precision, accuracy and reliability.

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