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Automated Microassembly of Tissue Engineering Scaffold

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***Abstract*— This video presents a fully automated desktop workstation for fabricating tissue engineering (TE) scaffolds by assembling microscopic building blocks of dimension $0.5 \times 0.5 \times 0.2mm^3$ and $60\mu m$ thickness. A TE scaffold is a porous supporting structure made of biodegradable material for cells to attach to and proliferate. TE scaffolds fabricated this way enable 3D control of the cells and agents to promote optimal tissue growth. This video outlines the architecture and control strategies of the workstation, and demonstrates its efficiency. Visual and force feedbacks, as well as a haptic exploration, make the assembly robust to large relative errors in the microparts.**

I. Introduction

A tissue engineering (TE) scaffold is a porous 3D structure made from biodegradable material and coated with nutrients and growth factors to form a biomimetic surface. Scaffolds assembled with microscopic parts enable 3D control of the cells and agents distributions to promote optimal tissue growth [1]. The feasibility of (manually) assembling such scaffolds was demonstrated in [2], in which assembly as shown in Fig. 1 took several hours. Considering the large number of microparts for even a small piece of scaffold, i.e., about 10,000 parts for a cubic centimeter scaffold, illustrates the need for an automatic robotic microassembly.

However, there is a list of challenges to automate a microassembly process, thus most of the present microassembly tasks are performed manually or semi-automatically [3]. The first group of challenges lies in the positioning and alignment. An accuracy of $100\mu m$ can be achieved by conventional accurate robots, but this is not sufficient for microassembly tasks. Moreover, precision in microassembly systems is often deteriorated by factors such as tolerance stack up due to thermal effects, errors and approximations in the modeling of sensors and manipulators, internal and external vibrations and parts machining errors [4].

Forces involved in the microworld pose another challenge. Surface-related forces, such as electrostatic, van der Waals and surface tension forces then dominate gravitational forces, hence manipulation in the micro world is completely different from that in the macro world [5]. Finally, microparts made of polymer or silicon are fragile and easily broken by improperly applied forces and the forces in the range of *mN* are hard to be measured and controlled.

This video presents an automatic 4-DoF microassembly workstation to assemble TE scaffolds automatically [6]. Vision feedback is used during alignment to achieve a positioning accuracy of less than $10\mu m$. To implement closed-loop force control, a beam-like gripper with integrated force sensing with a 3*mN* resolution and 500*mN* measuring range was designed and fabricated. When the system detects problems with the assembly, a haptic exploration strategy is used to find a successful grasp configuration. Fully automated microassembly experiments demonstrate the efficiency of the system and control strategies robust to large relative fabrication error in the microparts.

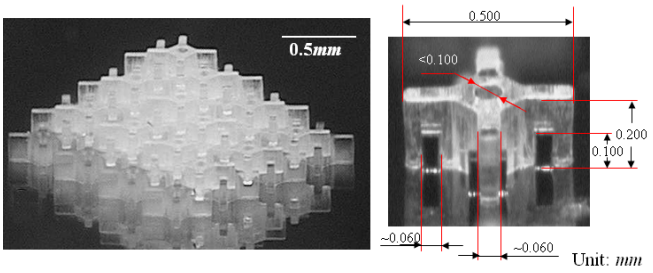

Fig. 1. A piece of automatically assembled tissue engineering scaffold made of 50 microparts, and the dimensions of one micropart.

II. Experiment Setup

The workstation is composed of four linear translation stages (Fig. 2). Two long-travel-range stages are mounted together to form a cross for conveying and alignment, and a vertical stage is fixed on the top of them functioning as the working platform. A gripper with force sensor is mounted to another vertical stage to accomplish grasping and assembly. Three sets of microscopes with CCD camera are used to provide front, side and top views.

In order to perform alignment based on visual information, a gripper had to be designed that does not occlude the visual field. Our gripper is a simple pin fixed on a cantilever beam, which uses friction to pick up a micropart when it is inserted into the hole of the micropart (Fig. 1, right). The main body of the gripper is made from a Tungsten rod using electrolyte-etching. A girdle is fixed on the tip to function as pushing shoulder. The cantilever beam works as a mechanical amplifier to produce a relatively large moment at the support end when a force is applied on the gripper tip. Force is obtained by measuring the strain of the support end through strain gauges.

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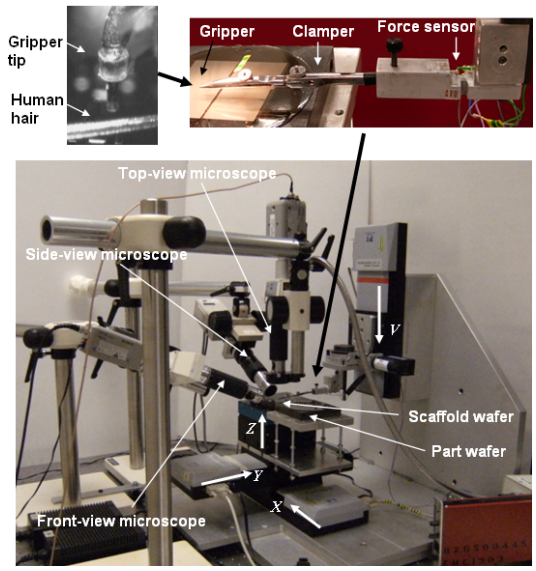

Fig. 2. Scaffold microassembly worstation, force sensor and microgripper compared with a human hair.

A VC++ program coordinates all the hardware and supervises the whole assembly process.

III. Control Strategy

The strategy we developed to perform our microassembly is similar to that used in a common life pin-into-hole task, for example to insert a key into a lock. One first approaches the key from the lock using vision, then inserts it by controlling the force. If one misses the hole, one tries to adjust the key in the hole using haptic feedback. Similarly, our 3D microassembly of tissue engineering scaffold uses a visually guided approach, force controlled insertion and haptic exploration to find the hole when necessary.

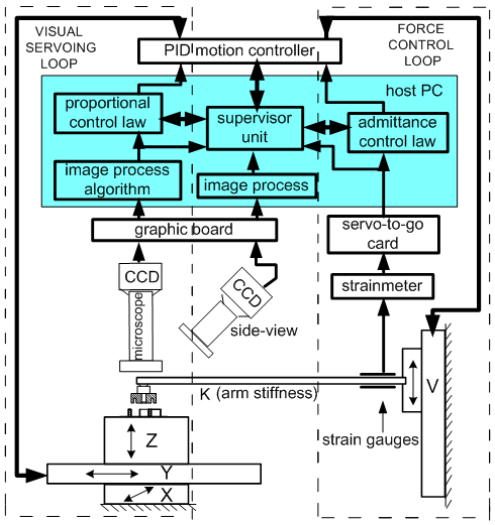

Fig. 3. Schematic of automated microassembly with visual servoing and force control loops.

Once a micropart is picked, it will be conveyed to the scaffold location, aligned with the help of visual feedback, and then assembly is performed using admittance force control. The force and position information will tell whether an assembly is successful or not. If the assembly is unsuccessful, the gripper position is shifted of a few μm, the new position is tested for assembly using force sensing, etc., until a suitable position is found.

The gripper with force sensor is carried by the vertical stage (v-stage) to move up and down for the insertion and retraction (Fig. 3). Contact force control is accomplished by adjusting the v-stage position based on the strainmeter reading using admittance control [7].

After each force controlled assembly action, a side-view image is processed to infer whether the micropart is assembled successfully. If failed, the micropart will be disposed with the releasing structure, a U-shape notch fabricated on a tungsten plate. It was observed that about 1 out 10 microparts was disposed due to some major defect or dimension errors, and the above exception handling strategy succeeded in nearly all cases. The above steps will continue automatically until the whole scaffold is fabricated.

IV. Conclusions

This video presents a fully automatic workstation for microassembly of TE scaffolds, and demonstrates it during the construction of scaffolds made of 50 microparts with large relative error of about 5% (Fig.1), which takes about 1 hour. An unsuccessful assembly is detected efficiently using position and force information, and a local exploration using haptics and no vision is used to adjust the position for successful insertion. This strategy was shown to be efficient for microscopic pin-into-hole problems and can be also used in other microassembly tasks.

V. Acknowledgments

The microparts were fabricated in the Aerospace and Mechanical Department of Nanyang Technology University with the great help of Dr. Franck Chollet.

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