

# GLOBAL TELE-OPERATION FOR MICRO-ASSEMBLY TASKS

Michael F. Zaeh, Michael Ehrenstrasser, Johannes Schilp  
Institute for Machine Tools and Industrial Management (*iwb*),  
Technische Universität München,  
85747 Garching, Germany

## 1 INTRODUCTION

New challenges in production technology emerge with the continuing miniaturization of modern products and with the increasing integration of diverse mechatronic components. For prototype assembly and small-lot production, tele-operated micro-assembly systems offer new perspectives concerning ergonomic aspects and process efficiency.

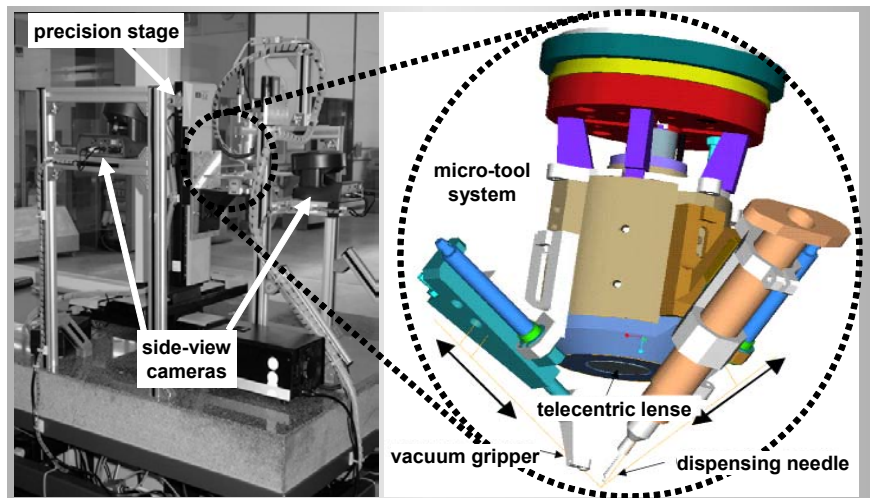
Telepresence and teleaction systems (TPTA) are a promising approach to overcome the scaling barriers between the human operator and the assembly task in microsystem technology (MST). By a TPTA-system an operator can feel physically present in an inaccessible or far-off environment and can carry out manipulations over local or dimensional barriers through the use of suitable tools. In micro production the inaccessibility is mainly caused by the size of the objects to be manipulated and by the required accuracy of the processes [1]. But also clean-room conditions require the local distance of the human operator.

To get a close-to-reality impression of the process conditions, typical TPTA-systems provide haptic input devices, to feel e. g. mounting forces, and user interfaces on the operator side, which visualize the assembly scenario. In this way the operator can control the assembly tools very precisely. Due to the ergonomic working place and the multimodal feedback of relevant process data a tele-operated manual assembly system is more efficient, compared to conventional working environments with microscope and manually triggered tools. Furthermore, new and efficient strategies in global production networks can be realized by using telepresent technologies in conjunction with flexible and modular assembly tools. To investigate these aspects, a tele-operated micro-assembly system has been developed and tested within a transatlantic micro-assembly experiment which is discussed below.

## 2 SYSTEM OVERVIEW

### 2.1 Tele-operator end

The tele-operator of the manual micro-assembly system consists of two core components. The first component is an assembly platform, which provides fasteners for part supply equipment, like chip-trays, and for substrates on which the chips are assembled. The platform is attached to a cartesian coordinate axes system with three precision linear tables. With a positioning resolution of  $0.1 \mu\text{m}$  and a total workspace of  $204 \text{ mm} \times 204 \text{ mm} \times 204 \text{ mm}$  it is suitable for a multitude of assembly processes at a very high accuracy. By a uniaxial force sensor with a measuring range of  $\pm 50 \text{ N}$



**Fig. 1** Setup of tele-operator end: overall view (left) and modular micro-assembly tool head (right)

mounting forces in z-direction can be acquired precisely. In conjunction with a 12 bit data acquisition card, a force resolution of  $\pm 0.024$  N can be achieved. This is a suitable resolution for sensitive handling and mounting tasks for microsystems. Several hard- and software safety features are implemented in a multistage safety concept on the tele-operator-end. E. g. to prevent damages to the sensitive force sensor resulting from overloads or collisions, the assembly platform is secured at first by resiliently mounting it to the axis system by using two miniature frictionless spring-loaded tables and electrical limit switches. Also safety algorithms have been implemented into the control application. When exceeding a predefined force limit a further motion of the z-axis is stopped in order to prevent a collision and overload of the sensor. However, retracting motions are still feasible in order to reduce the sensor load and to continue the assembly process. Additionally at predefined safety areas within the working space the maximum speed of the micromanipulator can be reduced in order to minimize the danger of possible collisions.

The second core component, a micro-assembly tool system for tele-operation, is based on the flexible and modular micro-assembly tool head SATURN (**s**ensor-based **a**ssembly **t**ool **u**sing **r**obot **v**ision) [2, 3], which was developed at the *iwb* for automated micro-assembly tasks (Fig.1, right). An optical system, consisting of a CCD-camera, a highly precise telecentric lens and a coaxial illumination has been integrated in the centre of the tool head. At a working distance of 34.9 mm and a magnification scale of 2:1, the field of view of the mentioned objective amounts to 1.9 x 2.5 mm and the depth of focus is  $\pm 0.5$  mm. For adjusting the optical focus, the whole optical system can be moved within a range of  $\pm 5$  mm in the vertical direction. The sensor-based tool head can be rotated by 360° with an angular resolution of 0.005°. Up to four process-specific endeffectors can be flexibly attached onto special interfaces which are arranged equally around the tool head cylinder. The specific tools, e. g. grippers and dispense units, can be extended into the focus plane of the camera by pneumatic cylinders. In summary the tele-operated assembly tool system provides a total number of four degrees of freedom and a total number of four endeffectors, which is sufficient for a multitude of micro-assembly tasks.

## 2.2 Operator end

The tele-operated micro-assembly system can be controlled with a haptic input device for micro-assembly operations and a non-haptic input device for auxiliary motions and functions. For achieving a close-to-reality-impression during the manual assembly process, a force-feedback control stick is implemented for controlling the motions of the three precision axes separately. Motions in x and y-direction can be triggered by moving the stick while pushing button 1. The assembly platform can be moved in z-direction by moving the control stick forward and backward while pushing button 1 and 2 together. In conjunction with the mentioned high-resolution force sensor and customized data-processing on the tele-operator side, a close-to-reality impression can be achieved by realistic contact forces.



For auxiliary functions like adapting the view-point and the tool position by rotation, the assembly tool system is driven by a non-haptic input device with six degrees of freedom (SpaceMouse®). Also the adjustment of the focus plane is done by this input device. By pushing its functional keys each endeffector of the assembly tool system can be extended or retracted separately. In addition, specific tool functions, e. g. opening and closing of grippers, can be activated. Visual supervision of the whole micro-assembly platform is achieved by two side-cameras with different viewpoints and zoom functions. Usually the video image of the above mentioned top-view camera is used for the accurate positioning process and the side-view cameras for coarse-positioning.

## 2.2 Communication platform

Communication between the operator-end and the tele-operator-end is based on an UDP-client-server application in order to be run easily from anywhere by available internet connections. The server

application controls the sensor and kinematic components of the assembly system (tele-operator). All fail-safe features are integrated as closed-loop algorithms into the server program. After processing the sensor-data customized to the operator, the server sends the data like forces, positions etc. to the operator-end by a UDP-socket connection. The control system of the operator-end, e. g. of haptic and non-haptic input devices, serves as the client-application. The achieved sensor-data from the server is directly presented to the user without further processing. The operator-end itself sends the monitored position-data and key-inputs of the input devices to the server-application. At the same time data-streams of the vision-system are sent continuously from the tele-operator-end to the operator-side.

### 3 TRANSATLANTIC MICRO-ASSEMBLY EXPERIMENT

#### 3.1 Experimental Setup

For evaluation purposes a transatlantic tele-operated micro-assembly experiment was performed (see Fig. 3). The tele-operator-end was located in a clean-room at the research laboratory of the *iwb* in Munich. The tele-operator could be controlled from two different operator stations. The first operator



Fig. 3 Transatlantic tele-operated micro-assembly: experimental setup

station was located at the research laboratory of the *iwb* in Munich. The second operator station was located at the Microdynamic Systems Laboratory of the Robotics Institute at the Carnegie Mellon University in Pittsburgh, USA. To communicate verbally and visually, both operators were connected using a video conferencing application.

The task was to pick up an integrated circuit from a chip-tray and place it on a test-circuit board. The dimensions of the integrated circuit were about  $1.5 \text{ mm} \times 1.5 \text{ mm} \times 0.5 \text{ mm}$ . To show the ability to switch the control between Munich and Pittsburgh during operation, the assembly task was divided in two sub-tasks.

The first sub-task was performed by the operator in Munich. The operator had to pick up the integrated circuit from the chip-tray and to move it into the middle between the chip-tray and the test circuit board. In order to facilitate the navigation, a European 20-Cent coin was placed on the middle between the chip-tray and the test-circuit board.

The second sub-task had to be accomplished by the operator in Pittsburgh. As soon as the integrated circuit was placed above the coin, control was switched to the operator station in Pittsburgh. He then moved the gripper with the integrated circuit above the desired position on the test-circuit board, adjusted the orientation and placed it there. As the top-view video camera provided no information about the distance between the integrated circuit and the substrate, the operator had to rely on haptic information provided by the 1-DOF-force sensor, which was integrated into the teleoperator.

#### 3.2 Results

The experiment has confirmed the capabilities and the applicability of TPTA technologies for manual micro-assembly processes. The average assembly time for performing the above described task was about 3.5 min. Despite the long distance and the resulting time delay between the operator in Pittsburgh and the tele-operator in Munich, no significant detractions of the system performance could be observed. The haptic feedback facilitated sensitive handling of micro-parts very much. E. g., it was possible to stack four integrated circuits exactly upon each other.

For estimating the time delay between the operator-station in Pittsburgh and the tele-operator in Munich the round trip time (RTT) was measured (see Fig. 4). As figure 4 shows, internet data packages are passing through 19 intermediate stations. The measured RTT amounted to about 120 ms. Assuming

a symmetric internet communication between both stations in Munich and Pittsburgh the average one-way time delay therefore can be estimated to 60 ms, which did not have any negative influences on the subjective impression during the assembly process.

In order to estimate the fluctuations of the internet connectivity over a longer time period, another simple experiment was carried out. About 90000 ping-packets

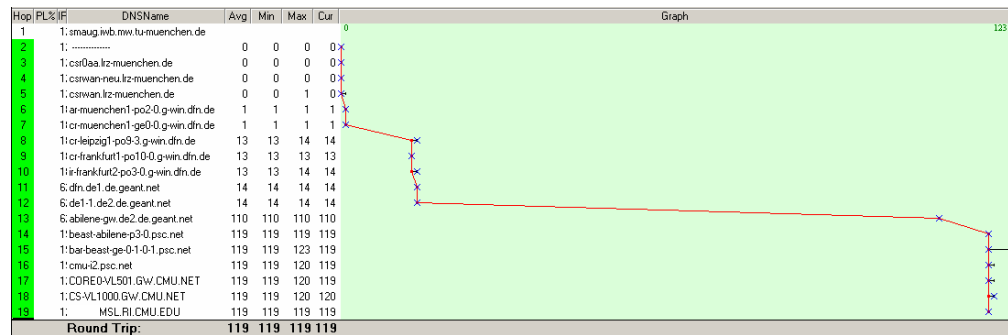


Fig. 4 Traceroute screenshot between Munich and Pittsburgh

have been sent continuously to

the target computer at the Robotics Institute in Pittsburgh over a time period of 24 h. No significant differences occurred during the 24 h-experiment. Only one data package was lost and no significant variations of the measured RTT could be detected. Outliers occurred only sporadically.

## 4 SUMMARY AND OUTLOOK

This paper describes a global, internet-based production system for manual tele-operated micro-assembly. The system structure and its components have been presented. For verifying the performance of the developed system a transatlantic micro-assembly experiment was performed. The system performance has been verified and evaluated.

Furthermore the experiment shows some interesting options for future industrial applications: By use of TPTA technologies the operator does not have to be physically present in the clean-room, where the micro-assembly system is located. Hence, this enables better working conditions. Furthermore, the workload of tele-operated micro-assembly systems can be improved by shifting to another operator at a different location. For example, short-term lack of staff, e.g. due to illness, holidays, strikes etc., can be easily compensated. Also, cost-effective 24 h production can be achieved by shifting to operators in different time-zones.

## 5 ACKNOWLEDGEMENTS

The work presented is funded within the 'SFB 453' Collaborative Research Center "High-Fidelity Telepresence and Teleaction" of the DFG (Deutsche Forschungsgemeinschaft). Furthermore, the authors thank Christian Schuberth and Mark Endress for their contributions to the concept and the implementation. Furthermore the authors thank Dr. Ralph Hollis from Carnegie Mellon University in Pittsburgh, USA. With his friendly support an operator station could be set up in Pittsburgh.

## 6 REFERENCES

- [1] Fearing, R. S.: Survey of sticking effects for micro parts handling. In: Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, August 5th-9th 1995, Pittsburgh, Pennsylvania, USA. Los Alamos, Calif.: IEEE Computer Soc. Press 1995, pp. 2212 - 2217.
- [2] Reinhart, G.; Jacob, D.: Automated assembly of holder chips to AFM probes. In: Nelson, B. J.; Breguet, J.-M. (Eds.): Microrobotics and Microassembly III, Boston, USA. Washington: Proceedings of SPIE Vol. 4568 (2001), pp. 310 -317.
- [3] Zaeh, M. F.; Jacob, D.; Ehrenstrasser, M.; Schilp, J.: Hybrid Micro-Assembly System for Tele-Operated and Automated Micro-Manipulation. In: Ziegert, J.C.: Machines and Processes for Micro-scale and Meso-scale Fabrication, Metrology and Assembly, Florida. North Carolina: Proceedings of ASPE Vol. 28 (2003), S. 119 – 124.