ADVANCED METHODS AND TOOLS FOR HANDLING AND ASSEMBLY IN MICROTECHNOLOGY – A EUROPEAN APPROACH IN FP6

W. Brenner*, A. Almansa-Martin** and F. Sümecz*

* Institute of Sensor and Actuator Systems ISAS, Vienna University of Technology, Vienna, Austria
** Mechatronic Automation Systems, ARC Seibersdorf research GmbH, Seibersdorf, Austria

Werner.Brenner@TUWien.ac.at

Abstract: An adequate training system for preparing researchers to work in the field of micro-handling and micro-assembly must not only integrate all scientific and technical disciplines involved, such as mechanics, control theory, material physics, electronics and design, but also provide an industrial perspective and additional skills. The European Research Training Network 'Advanced Methods and Tools for Handling and Assembly in Microtechnology ASSEMIC' addresses this need at the European scale, offering an advanced training scheme for early-stage and experienced researchers.

Introduction

Micro-handling and micro-assembly has a strongly multidisciplinary nature, requiring a large number of technologies and tools. For tasks relating to microsystem technology alone, it is necessary to integrate expertise in the field of MEMS design, devices for high-resolution positioning and micro-actuators for gripping systems, etc. In addition, many other scientific and technical fields are also involved: material physics (for optimising tool/component interaction and reducing adverse adhesive effects), laser technology (for joining processes, curing glue, etc.), advanced control theory (including artificial intelligence control techniques and visual pattern recognition), and many others.

Micro-manipulation techniques can include not only handling of micro-components for assembly of MEMS, but also application fields and challenging tasks. Some examples are microsurgery, manipulation of biological material and micro-robotics. One of the aims of this project is to explore and develop new methods, tools and applications for micro-manipulation beyond the limits of traditional assembly techniques for micro-components.

In the last years, MST has turned out to be considered one of the most important technologies. Hybrid MEMS are composed of micro-components with different working principles and functionalities (electronic, optical, fluidic, mechanical...), which need to be integrated and combined into a complete system. As has already mentioned, micro-handling and -assembly of MEMS is an issue of relevant importance, since a great part of the total costs in micro-system production is actually derived from the assembly phase.

State of the art:

Micro-handling and assembly: One of the first large scale European projects concerning this topic was the Research and Training network HAFAM 'Handling and Assembly of Functionally Adapted Micro-components' (Jan 98-Dec. 2001), coordinated by the ISAS. In this project several prototypes were developed for micro-motors and position sensing devices, different vacuum and mechanical gripping tools (including one prototype with optical force sensors and others adapted to blind and parallel assembly), an image recognition handling station capable of performing certain simple operations in an autonomous way, and a test-bench for characterization of assembled micro-motors.

A number of micro-handling stations have been presented in the last years by different institutions and companies. Most of them include on-line image processing, with object recognition and position detection of the tool for closed-loop feedback control, and they can perform certain easy operations in automatic mode. Existing implementations prove the potential and capabilities that such automated micro-assembly stations can offer. However, a number of problems still impede their broad introduction. Some of the topics currently under research include methods to override the limited depth of field in optical microscopes, stereoscopic 3D vision algorithms and calibration procedures for microscopes with adjustable magnification.

Relative little work has been made on practical implementation of methods for dealing with the sticking effects in automated systems. On the other hand, some research groups have proposed and tested the use of specific control methods based on artificial intelligence techniques for certain micro-manipulation operations, but the possibilities of these technologies have not yet been fully exploited.

An approach to industrial applications was aimed by a consortium of German institutions (including one of the ASSEMIC participants) in the frame of a national project devoted to the assembly of hybrid Microsystems 'Sonderforschungsbereich SFB 440- Montage Hybrider Mikrosysteme', focusing on handling and assembly techniques for fabrication of small and medium volumes. This project addressed a series of concepts including micro-welding processes, platforms for integrated micro-assembly operations, and generation of

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a process catalogue. It represented an important step, not only towards the improvement of certain concrete processes and tools for micro-assembly in automated production processes, but also towards the comprehension of the relevant issues, requirements and potentials in this area. The know-how generated within this national initiative will be used to estimate the current research needs and opportunities for untried methods, as well as potential for novel approaches at the European / international level.

Micro-grippers: In the last years, many research teams have concentrated on the development of new micro-gripper designs. As a result, currently there exist a large variety of tools for micro-handling based on different gripping systems: vacuum, mechanical jaws, making use of the adhesive properties of liquids or ice, etc. The utilized actuation principles also cover a wide range of technologies: a mechanical gripper can be actuated by piezoelectric elements, SMAs, electrostatic combs and many others. However, most methods show disadvantages too, such as hysteresis, heating, too small displacements or limited maximum force. This demands further research to find optimal designs or novel techniques offering improved performance and adaptable functionality.

Some state-of-the-art gripper prototypes comprise also integrated position and force sensors, although most designs are application specific and suitable for laboratory experiments, but lacking the flexibility, robustness and long term performance reliability required for industrial production processes. An effort must be done to create optimised micro-tools with a view to modularisation, exchangeability and closer potential of standardization.

Moreover, the problematic of the sticking effects, which has been broadly researched in theory, has been considered in the practice only to a small extent. Moreover, sticking effects have been theoretically investigated in depth, but there exist only few practical implementations of tools adapted to deal with such effects (hydrophobic coatings, controlled roughness of surface of the tool tip, etc.).

Micro-robotics: In the frame of the project MINIMAN (Nov 1998-Jan 2002), a micro robot was developed with 5 degrees of freedom and a size of a few cm3, able of performing certain manipulation tasks in semi-automated mode. The prototype developed didn't have an immediate short-term market expediency, but the attained experience and results open the way to innovative micro-manipulation technologies with a clearly identifiable route for its take-up by the industry. Further research has been recently started in a concept for a manipulating system consisting of a cluster of miniaturized co-operative robots equipped with wireless communication systems (Micron Project). This and other state-of-the-art results demonstrate the potential of this promising technology. However, it is apparent that a lot of research effort will be needed to bring micro-robotics to a level of maturity, which will enable the real exploitation of its capabilities.

Tele-manipulation is also a topic rising a great interest in the research community. On one hand, it facilitates the task of manual manipulation, as the motion of the operator's hands connected to an adequate haptic interface can be transferred at the proper scale into fine and precise movements needed for micromanipulation. On the other hand, tele-operated systems allow to avoid the direct presence of the operator. In this way, for example, operator guided micro-handling can be performed within a vacuum SEM chamber. The latest research topics in this field comprise advanced control systems for reduction of hand tremor movement, novel haptic interfaces, 3-D virtual reality systems and utilisation of complementary image systems (such as ultrasound).

Contribution of the project is to make advance the state of the art: Although a significant research effort has been done till now in all the mentioned areas, it has been shown that many issues still keep open. Most of the research work till now has been performed in a relative fragmented way, with R&D projects focusing on specific topics. In this project a more general approach is proposed, where all the applicable technologies and related applications will be covered, from micromanipulation for biological application to artificial intelligence based control systems, including strategies of design for assembly, study of material interactions between tools and components, etc. On the one hand, only such multidisciplinary approach, merging the complementary expertise of partners working in many different fields, provides the necessary viewpoints to properly address this complex and challenging area. Researchers have the chance of being trained and thus getting a wide perspective of all the practical needs, applicable technologies and classical, as well as extended, non conventional, applications of micro-manipulation.

On the other hand, by joining together in the ASSEMIC consortium many of the partners which have contributed to the state-of-the-art outlined in this section, it will be possible to focus on the most recent and innovative concepts and ideas, concentrating on the weak points and unsolved difficulties detected in the course of the latest research activities realized at the European level. This project aims to make contribution to the advance of the state-of-the art, integrating a series of innovative concepts and new approaches, as is described in the next section.

Novel systems for ultra-high resolution positioning, including an innovative design based on thermally actuated bimorph cantilevers.

Pioneering concepts and methods for teleoperation comprising artificial perception systems.

Approaches for artificial intelligence based control systems in micromanipulation operations, involving neural networks and fuzzy logic

Development of tools of new materials for low-cost production (SU-8), etc.

Innovative sensorized tools, involving nano-tip technology in combination with cantilevers for micro and nano-manipulation

Special materials and coatings, nano-structure metals or nano cristaline thin films for reduction of adhesion forces and parasitic effects

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Learning by doing

ASSEMIC comprises a research programme covering all relevant topics in the field of micro-handling and –assembly. This programme has been defined with a view to enable the appointed fellows to become acquainted with all related tools and technologies, as well as to provide them with specialization opportunities, while performing state-of-the-art research on challenging scientific and technological issues linked to the project's thematic. This training will not only take place in their host institution, but also in the premises of the other participants.

The project is structured in several work-packages, defined to address the following main research objectives: ultra-precision positioning, innovative tools for handling and assembly, advanced control methods, application requisites and industrial production. A brief description of the workpackages' content is given below:

WP 1. Micropositioning: Positioning stages and elements with integrated sensors and feedback control, autonomous and mobile systems, microrobotics.

WP 2. Microhandling: Development and test of tools and methods for handling in different environments (normal room conditions, clean room, vacuum, fluids) and applications

WP 3. Microassembly: Innovative tools, special strategies and alternative approaches for efficient high precision and micro-assembly

WP 4. Automation for industrial production: Including production chains, quality assurance, test and characterization issues, etc

WP 5. Know-how management: Technology transfer and dissemination

Some of the expected achievements include the development of a number of system and tools prototypes for handling and assembly in MST, such as various microgrippers and a haptic interface device for telemanipulation. A number of studies and experiments will be performed to propose and analyse new approaches and improved methodologies (artificial intelligence control, enhanced haptic feedback, optimised industrial production, strategies to prevent adhesion, etc). Finally, several experimental setups will be built to demonstrate and evaluate the developed tools and processes for advanced microhandling operation under different environments (normal room conditions, vacuum, within a fluid…) in various application fields, such as assembly of MEMS and biological applications.

Project Objectives

Five different research objectives have been defined for the joint work programme to be undertaken by the network teams. These objectives are briefly described in the following paragraphs:

Research Objective 1: New tools and systems for ultra precision positioning accuracy (micro- and nano-range) with improved performance: Systems for high-precision positioning (in the micro and nano-range) are fundamental for micro-handling and -assembly applications. The relative position of the handling tools must be controlled with extreme precision in order to assemble micro-components into functional devices. Specially adapted closed-loop control schemes will be implemented on stages with new position sensors as part of this project for the purpose of improving the accuracy and repeatability of positioning. The main goals of this objective can be formulated as follows:

- developing ultra-positioning systems based on novel technologies
- integrating specially adapted closed-loop control with integrated position sensors
- performing state-of-the-art research on micro-robots with nano-meter positioning accuracy

Research Objective 2: Innovative tools for micro-handling and –assembly: Many handling tools with various functionalities have already been designed, developed and tested. However, a lot of work remains to be done in this area. Innovative tools can be developed on the basis of novel concepts currently under investigation. Design should be optimised to offer improved performance and functionality which has been adapted to the component's requirements at lower cost and higher reliability. Last but not least, currently available handling and assembly tools lack flexibility, since most devices are application specific (i.e. designed and developed for a concrete purpose). An effort must be made to create optimised micro-tools in light of modularisation, exchangeability and potential standardization issues. This research objective's target issues:

- investigating, designing and developing novel micro-gripping systems
- investigating, designing and developing specialized tools for micro-assembly operations
- creating innovative approaches for flexible tools which integrate various handling and assembly functionalities

Research Objective 3: Advanced control processes and strategies for micro-handling and –assembly

Micro- and nano-manipulation processes are not well suited for classical open-loop control schemes such as the robotic systems typically used for assembly operations of larger components because they cannot provide the required accuracy and repeatability. For this reason, advanced control schemes are required, including combined position and force control with visual and sensor feedback. There are different approaches to this problem, ranging from fully automatic closed-loop control with intelligent image processing to tele-operation with a haptic user interface, where the movements of an operator situated at a different location are transmitted to the handling system. In all cases, retrieval of information from the process through integrated sensors and vision systems is a key issue.

The following points summarize the main aims of this research objective:

- researching and developing innovative approaches for intelligent control systems with vision and sensor feedback systems

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- analysing and researching issues and handling strategies for dealing with problems related to the scaling of laws for which a satisfactory solution has not yet been found
- exploring new possibilities for haptic interfaces and tele-operation in micromanipulation operations
- investigating technologies and developing methods for assembly with improved efficiency.

Research Objective 4: Methodology for micro-handling and -assembly in special applications

Handling operations impose very different conditions and requirements, depending on the concrete application. This is a fundamental issue which must be taken into consideration when selecting the technology, designing the tools and integrating systems for a given application of micro-handling. For example, in cases in which visual feedback from an optical microscope does not provide the required magnification and image resolution, SEM microscopes are commonly used. However, this imposes a series of restrictions on the handling operation, such as the need to work in vacuum, exposure to electron scanning, reduced working space and the need for conductive surfaces. Therefore, special methods and systems have to be considered to address these limitations. The relevant sub-objectives are as follows:

- analysis and in-depth research of the possibilities and needs of and requirements for micro-manipulation in the various potential application fields
- performing a number of experiments in the above-mentioned micro-handling application fields
- developing concrete practical applications and demonstrating the potential of advanced and specialized methods for micro-manipulation applications in the different fields stated

Research Objective 5: Industrial production issues and manufacturability of assembled MEMS: In this research objective, micro-handling and -assembly is approached from the point of view of industrial manufacturing. The aim is to provide a practical focus on issues related to improved MEMS manufacturing, comprising advanced production-oriented micro-assembly techniques and quality assurance, as well as testing and characterization of assembled micro-systems. The goals pursued in this objective are stated below:

- analysing the needs and requirements of industrial micro-assembly processes with an eye to enabling their scale-up for mass production
- exploring, proposing and implementing innovative approaches for industrial assembly processes involving intelligent process supervision and novel quality assurance methods
- investigating and developing new methods for testing and characterization of assembled micro-components.

By fostering the development of open standardised and modular procedures and tools for micro-assembly with increased reliability and reproducibility, manufacturing MEMS will be made more profitable. On the other hand, the quality of MEMS products can be improved by dealing with concepts, methods and tools for process supervision, quality assurance and testing of final assembled products. An issue of relevance here is determination of the process variables (exerted force, applied temperature, etc.) and parameter changes (material properties, geometry, etc.) involved in the assembly processes and their influence on the final quality of the assembled product.

Table 1: Project Partners

1.	Institute of Sensor and Actuator Systems, Vienna University of Technology; Co-ordinator	ISAS	Austria
2.	Fondation Suisse pour la Recherche en Microtechnique	FSRM	Switzer-land
3.	ARC Seibersdorf research GmbH	Seibersdorf research	Austria
4.	National Institute for Research and Development in Microtechnologies	IMT	Romania
5.	Politechnika Warszawska (Warsaw University of Technolgy)	PW (WUT)	Poland
6.	Instituto de Desenvolvimento de Novas Tecnologias	UNINOVA	Portugal
7.	University of Oldenburg	Uni-OL	Germany
8.	Fundacion Robotiker	Robotiker	Spain
9.	Foundation for Research and Technology – Hellas	FORTH	Greece
10.	Progenika Biopharma S.A.	Progenika	Spain
11.	Council for the Central Laboratory of the Research Councils - Rutherford Appleton Laboratory	CCLRC-RAL	United Kingdom
12.	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.v.	FhG/ILT	Germany
13.	Scuola Superiore Sant'Anna	SSSA	Italy
14.	Nanoscale Technologies GmbH	Nascatec	Germany

Training Opportunities

This network offers the opportunity for researchers to obtain training in a field of strong multidisciplinary nature. This is made possible thanks to the great variety of experience and infrastructure available in the consortium. The ASSEMIC project provides a new and comprehensive approach to handling and assembly in micro-domains, thus contributing to an overcoming the fragmentation of European research in the related fields. On the other hand, the main project topic covers an area with great promise, as proven by recent market research and surveys on micro-systems technology. Last but not least, early-stage fellows participating in the ASSEMIC network will have the opportunity to receive training in a number of disciplines (artificial intelligence, material science, process control, vision systems, etc.) which are relevant to both MST and other areas such as biomedical engineering, information technologies and production engineering. In this way, the range of

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possible choices for their professional career will be broadened thanks to the opportunity of selecting from among a wider variety of potential working areas and increasing their professional success expectancies.

Figure 1: Transnational training, Countries participating in the ASSEMIC network

ASSEMIC provides a cohesive but flexible framework for the training and professional development of the fellows, especially in the early stages of their career. The network as a whole provides a minimum of 574 person-months of Early Stage and Experienced Researchers whose appointment will be financed by the contract. Measures intended to address training and transfer of knowledge are divided into individual and network-based measures.

1) Individual measures:

- Basic training at the host institution: Training in available technology and with specialized instruments, performance of experiments, basic skills such as preparation of presentations and redaction of technical reports and publications
- Secondments and visits to other network partners. Training in their complementary technology and equipment, participation in joint research tasks, exchange of information and samples
- Other individual training activities: Courses, tutorials, contact with and visits to industrial operations and SMEs, participation in external conferences, etc.

2) Network-based measures are as follows:

- Summer schools: Organized every year by FSRM exclusively for the network, the fellows will be trained by internal and external international experts with regard to micro-handling and -assembly topics
- Training workshops: Oriented to information exchange in which the appointed researchers will present their research results and discuss topics related to their collaborative work
- Open seminars: Organized by the academic partners for students and interested early-stage researchers on topics related to micro-handling and –assembly

The training and transfer of knowledge activities in the ASSEMIC network assist both early-stage and experienced researchers in the development of their professional careers. In order to guarantee this, a personal Career Development Plan will be defined for each fellow, taking into account their personal interests, background and capabilities.

Synergies of the network

The network ASSEMIC is not envisaged as a closed research project, but rather as a tool to promote and enhance advanced training in micro-handling and assembly throughout Europe. Thus, it is expected to have important synergy effects with education at the European level, as well as with the European academic and research communities.

In the first place, ASSEMIC offers interesting job opportunities for post-graduate students immediately after the conclusion of their studies, with specialized training and possibility to pursue doctoral studies. Although the fellows are only appointed in a country different to that of their nationality, the links of the appointed researchers to their original scientific community will be ensured, fostering the possibility of their return back after the training period, if they wish to do that.

More advanced training opportunities exist also for post-doctoral researchers, who have a Career Development Plan and training programme adapted to their particular needs, which are different to those of early-stage researchers. On the other hand, the Open University Seminars organized in the frame of the network are open also for non-ASSEMIC participants, broadening in this way the reach of the education activities. Finally, external speakers will be invited for some of the training events, providing them with the valuable input and perspective of other experts outside the network.

Significant synergy effects are also expected with the industry. The network ASSEMIC has an important industrial component. Links with industrial companies have already been established and are expected to be expanded through a series of dissemination and technology transfer activities. The objective is to complement the researchers' training with a view to address the industrial needs. In parallel, training sessions for the industry will also be offered.

Conclusion

Micro-handling and –assembly is a modern research area which imposes challenging requirements. In order to prepare the new generation of researchers to work in this field, special training schemes are needed, adapted to its multidisciplinary and intersectorial character.

The European Research and Training Network 'Advanced Methods and Tools for Handling and Assembly in Microtechnology ASSEMIC' addresses this need at the European scale, by providing advanced training for early-stage and experienced researchers in an 4 years duration collaborative research project with 14 participants from 10 different countries. ASSEMIC is expected to enhance the quality of European research

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training in the field of Micro-handling and assembly. Further, it will provide the European industry with a pool of qualified researchers in state-of-the-art technologies, trained to understand the industrial needs.

The ASSEMIC network addresses several objectives of the European Research Areas and of the programme

Networking the players and users and encouraging interaction between them. In addition to the networking and interaction between the ASSEMIC research teams, additional interfaces between research and industry are encouraged, thanks to the direct existing links of the network with a significant number of industrial companies who have the status as associated partners. These are involved as end-users in the innovation process of developing new tools and processes for microassembly by helping to define the requirements and needs, as well as interacting with the network though communication, transfer and sharing of knowledge actions. Thus, this network opens the way to technology transfer from the scientific to the industrial level.

Experimenting with new tools and approaches. It will be an experiment with new innovation concepts and methods in the field of handling and assembly in micro-domain. Existing prototypes and designs, proven in other contexts, are to be implemented for new approaches in micro-handling operations. The reproducibility of their performance and their potential for exploitation in will be analysed in the ASSEMIC network.

Stepping up economic and technological intelligence. The innovation players involved in ASSEMIC (research teams from R&D companies and universities) concentre their research effort in the scientific and technological themes related to Micro-handling and Assembly. The innovation in SMEs will be promoted by endorsing dissemination activities (Information Day), establishment of communication means (visits of the young researchers, newsletters distribution, etc.) and direct participation of the companies expressing their interest, including the associated partners, in the network events (meetings and workshops).

Increasing European attractiveness for researchers and European competitiveness: Micro-handling and assembly is a key issue. By stimulating the technology development, advanced research and high quality transnational cooperation in this field, the attractiveness of the European research community for researchers will be increased. A factor for this are also the augmented communication links, training and transfer of knowledge between universities and R&D institutions, fostered by the collaboration of 14 teams covering complementary disciplines. Interfaces between research and industry help to increase the European competitiveness.

Fellows trained by this network will learn to solve problems in microhandling and assembly, supporting the competitiveness of the European industry. There will be also activities to transfer knowledge directly from European experts to European industry.

Coordination and synergy with regional, national or international activities: Links are established between ASSEMIC and a series of international networks and organizations, in which the participants are either already registered or have direct close contact. This synergy generates mutual benefits, which can be stated in terms of relevant information exchange, closer contact with the industry, integration in standardization activities, etc. Existing links with national associations include the Austrian Society for Microsystems Technologies and the Standards Committee - Production Equipment for Microsystems (DIN) in Germany. Among European networks should be mentioned: Assembly-net and NEXUS, while international initiatives include SEMI “MEMS standardization committee”.

Contact

http://www.assemic.net
Werner.Brenner@TUWien.ac.at, Project Co-ordinator

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