Hybrid Assembly for Ultra-Precise Manufacturing

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Abstract. This paper presents a European integrated project in the domain of innovative hybrid assembly - the combination of self-assembly and robotics. Robotics allows for high precision and flexibility with full control of the assembly process. Self-assembly, on the other hand, offers massively parallel, unsupervised processing and thus provides high throughputs that cannot be reached with simple robotics alone. The combination of these approaches thus offers robust, high-speed and high-precision assembly methodologies.
Different approaches to achieve reliable self-assembly are investigated, such as chemical or physical surface modification and structuring and field induced assembly. These techniques are combined with high performance robotic tools such as precise manipulators, innovative vision, force sensing and system control. Selected innovative demonstrator systems prove the industrial impact of these developments. Focus is put on assembly and processing of small parts with dimensions below 1 mm: MEMS parts, RFID tags, cells, optical systems and nanowires.

Keywords: Hybrid assembly, robotics and self-assembly, new production paradigm.

1 Introduction

1.1 Core Approach

Today, emerging highly complex micro-devices with applications in mechanics, electronics, biological engineering, microfluidics and IT demand ultra precision and flexible assembly [1], [2], [3]. A need becomes apparent to develop tomorrow's manufacturing processes for complex micro-products.

Hybrid assembly has been identified as a promising, innovative production technology. It is defined as the combination of two approaches: (i) *positional robotic assembly* where objects are mechanically manipulated and positioned one by one; and (ii) *self-assembly* where objects arrange themselves into ordered structures through physical or chemical interactions. Such hybrid assembly has not yet been achieved at the industrial scale. It will build a production paradigm permitting the development and implementation of fully innovative production processes for assembly of a variety of microproducts.

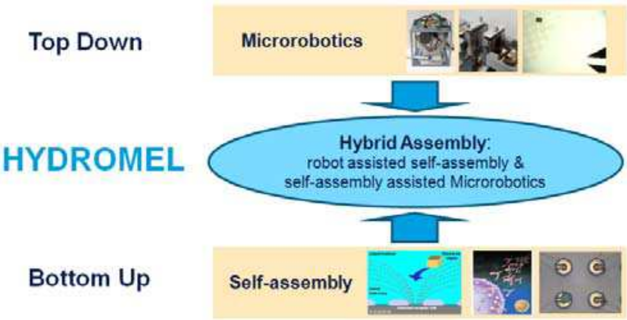

Fig. 1: The HYDROMEL project aims at combining positional robotic assembly with self-assembly to develop a hybrid production approach.

1.2 The HYDROMEL Project

An integrated European project has been launched in order to address the ambitious goal of implementing hybrid assembly at the industrial scale. The HYDROMEL project has been implemented to establish hybrid assembly as an impending production paradigm. The project which began in October 2006 will continue for 4 years concluding in September 2010. It brings together experts in the robotics and self-assembly fields from academia and R&D as well as high-level industrial partners. Currently 23 parties from 9 European countries are involved. Selected industrial partners (highlighted in Fig. 2) will act as end-users demonstrating various applications generated by the project.

The industrial exploitation and implementation is assured by core partners inside the consortium and supported by an external highly qualified industrial advisory board.

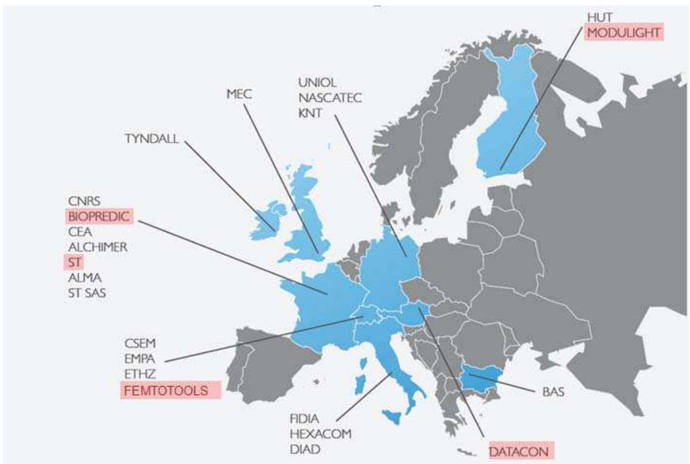

Fig. 2: Partners that are involved in the HYDROMEL project. Selected industrial partners demonstrating application cases are highlighted.

1.3 R&D Progress

R&D activities focus on the following domains: (i) *microrobotics*; (ii) *self-assembly;* and (iii) the combination of both microrobotics and self-assembly to form *hybrid assembly*.

Two hybridization scenarios will be studied. The first scenario focuses on *robotics assisted by self-assembly* in which a robotic process is supported and optimized through self-assembly. For example, the use of self-directing capillary effects and low-adhesion functionalized surfaces will be studied for reliable part handling. The complementary scenario will also be studied in which a self-assembly or *self-alignment process is supported by robotics*. The massively parallel, unassisted positioning of parts (e.g. nanowires) on a substrate and the complementary use of robots to individually correct or manipulate specific target objects is one example of this approach. Another example of this second scenario is the combination of coarse robotics and precise self-assembly. Here the robot initiates the self-assembly process by roughly positioning the part near the attractor allowing the self-assembly process to complete the precise positioning of the part.

Hybrid assembly is aimed to be introduced for a broad range of applications on the industrial scale with very different demands in terms of component size, accuracy and throughput. In the following, five scenarios are briefly sketched: (i) hybrid assembly of fragile MEMS parts; (ii) hybrid assembly for high-throughput production of electrical devices; (iii) self-alignment assisted manipulation of biological cells; (iv) hybrid assembly of nano-structures such as nanowires or nanotubes for photonic applications; and (v) self-alignment in high-throughput quality inspection.

2 The HYDROMEL Technology Platform

Within the project, R&D activities in robotics, self-assembly and their combination is carried out. These activities result in a technology platform that serves as a toolbox to set up different hybrid assembly applications. These applications are demonstrated in selected industrial systems.

2.1 Robotics

Robotics is a well established industrial technology. Nevertheless, if high throughput and high accuracy are desired - especially in the microrobotics area - several needs have been identified: (i) High-speed nano-manipulators by combining long range fast conventional robots and precise nano-robots; (ii) tools and handling strategies for microhandling; and (iii) control and sensor fusion for process control of microhandling.

Improved components for reliable microhandling have been developed. Selected highlights of these improvements are the combination of nanorobots and innovative multidimensional vision sensing for closed-loop robot operation at nanometer precision (in the scanning electron microscope), and the development of tools (gripper, feeder) for microcomponents.

2.2 Self-assembly

Self-assembly can be considered as a new strategy for nano- and microfabrication. It offers a bottom-up production technique with massive parallel throughput. Self-assembly methods based on programmable forces for self-assembly of a range of mesoscale (length scale of parts in the micro- to millimeter-range) components have been developed including the following approaches: (i) surface treatment and patterning for different self-assembly objects – biological cells, chips, and nanowires; (ii) chemical and physical switching of surface properties for controlled adhesion; (iii) directed self-assembly by application of external fields; and (iv) modeling and measuring of bonding forces in self-alignment.

Important goals in the development of self-assembly technologies have been achieved in the HYDROMEL project. The feasibility of various techniques (local surface treatment, global switching of surface properties) could be proven for selected model systems. Precise self-assembly of chips on a substrate has been realized (Fig. 3). Furthermore, important progress has been made in field-induced self-assembly of nanowires.

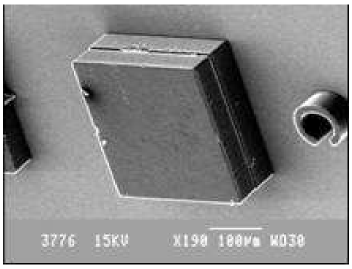

Fig. 3: High-precision fluidic self-assembly (courtesy of HUT).

2.3 Hybrid Assembly

Hybrid assembly is the core technology bringing together robotics and self-assembly. Two ways to implement hybrid assembly are investigated. Several examples of hybrid assembly scenarios are given below:

Improvement of robotics by using self-assembly techniques

Classical robotics can be improved by means of self-assembly in different ways. Structuring techniques can be applied to grippers in order to improve picking, reliable positioning and releasing of micro-objects. Feeding - a classical robotics task - can also benefit from controlled and switchable self-assembly by collecting objects in desired position and thus facilitate the efficient pick- and place process.

Improvement of self-assembly by using robotics
Using robotics to assist or improve self-assembly is useful in various applications. Micro- or nanorobots can be used in processes where the result of a self-assembly process has to be corrected or characterized. Robust and fast coarse robotics will be used to place meso-scale objects close to self-alignment attractors (an example of a mechanical self-alignment structure is given in the Fig. 4). The final alignment in position and/or orientation that reaches the targeted accuracy is carried out by unsupervised self-alignment. As a result, parallelization can be achieved as well as a reduction of investment of equipment.

The main project activity is the implementation of hybrid assembly and integration into dedicated systems. The functionality of modules and sub-systems has been proven for various applications with industrial relevance.

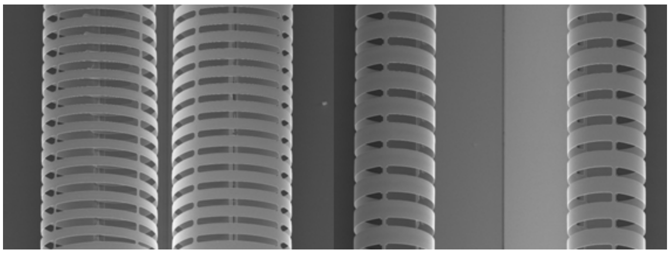

Fig. 4: Clipping structures that allow precise fiber positioning with coarse robotic approach (courtsey of CSEM).

3 Technology Demonstrators for Industrial Applications

The industrial integration of the core technologies that have been presented in the previous section is demonstrated for selected applications. The technology demonstrators address complementary assembly cases with very different system specifications and application areas.

3.1 Advanced Micromechanics: Hybrid Assembly of fragile MEMS parts

MEMS parts for measuring micro forces and for force controlled microgripping must be assembled into a package. It is important to obtain a mechanical and electrical connection between the fragile MEMS component and a printed circuit board (PCB). The MEMS parts consist of fine mechanical structures and are very brittle. A parallel handling process is implemented with the aim of overcoming tedious one-by-one processing. Coarse robotics will be combined with precise self-alignment to achieve high throughput and high alignment accuracy of the package.

The production equipment will be cost effective, reduce assembly effort and increase the process yield targeting mid- to high-production rates.

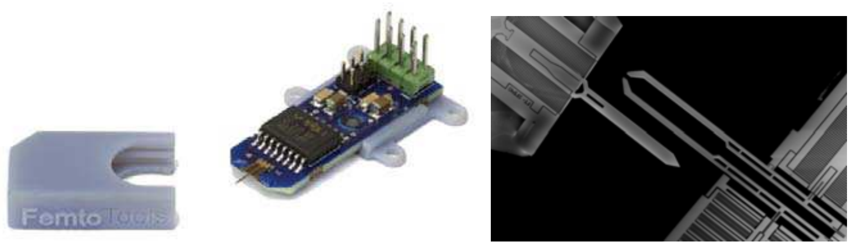

Fig. 5: Force sensor. System overview (left) and close-up view (courtesey of FemtoTools).

3.2 Electronics: Hybrid Assembly of RFID Tags

A hybrid assembly solution for high-precision and high-speed assembly of RFID chips on an antenna web will be developed. The state-of art production process for RFID tags is a pick-and-place procedure with dedicated and highly optimized die bonding equipment. An alternative industry compatible approach will be implemented offering the opportunity for parallelization and cost reduction by an optimum combination of coarse robotic placement and fine capillary self-alignment of the RFID chip. High-speed and high-throughput processes are targeted.

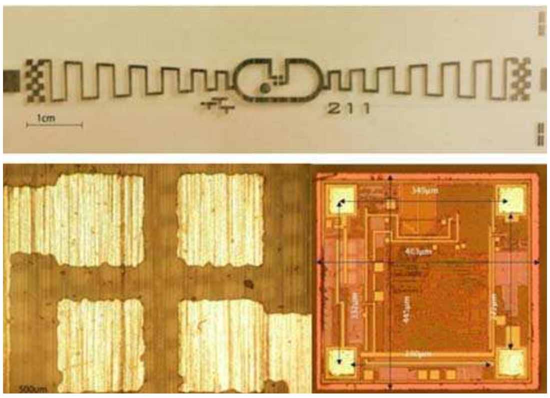

Fig. 6: Antenna web (top) and RFID chip with contact pads (bottom, courtsey of DATACON).

3.3 Bio- and Life-Sciences: Self-alignment assisted Handling of Cells

A lab-automation system is being integrated that combines several aspects of cell handling. It offers automated procedures for cell selection, immobilization, and a microinjection process. The system combines microfluidics for prior cell sorting and separation, self-assembly for reversible immobilization of the cell, and microrobotics for force-controlled cell injection. The complete system will be an automated, high throughput cell processing system. Specifically, cells with sizes between 1 and 0.02 mm will be targeted.

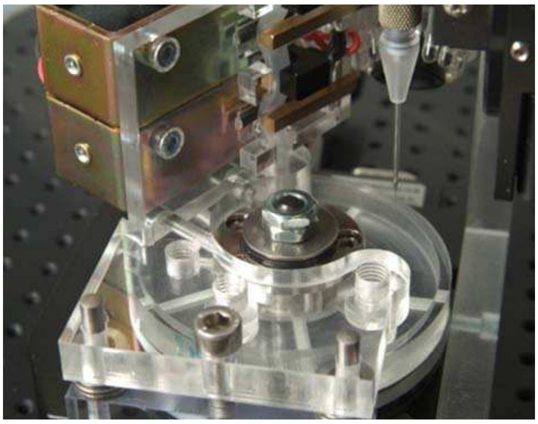

Fig. 7: System for hybrid cell-sorting and micro-injection (courtesey of CSEM).

3.4 Future Technologies: Self-assembly for emerging Nanophotonics and Nanoelectronics

A palette of hybrid robotic / self-assembly techniques for nanowires or nanotubes will be developed and applied to a variety of nanostructures. The assembly methodology will be demonstrated but also the function of resulting nanoscale devices. Self-assembly of nano-objects will allow the organization of nanoscopic objects much smaller than those that can be defined with classical top-down approaches. This approach is mandatory for Systems on Chip or even in future 3D circuits.

Hybrid approaches are investigated addressing production and characterization of self-assembled nanostructures combined with robotic quality control and error-correction measures. Key technologies are: field-induced, guided assembly of nanowires; self-alignment of large areas of nanowires; and, individual robotic manipulation of nano-components for selective processing.

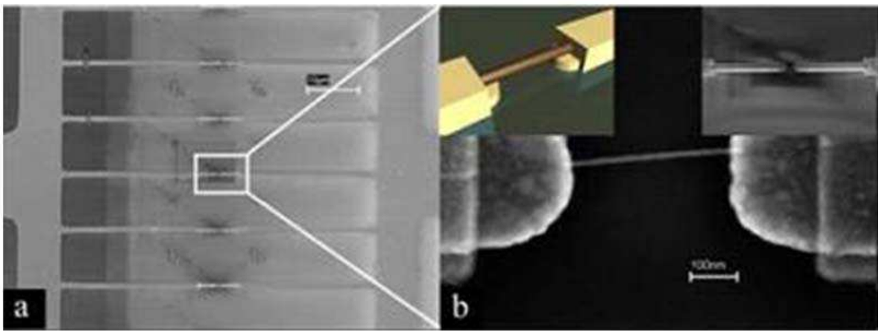

Fig. 8: Hybrid nanofabrication approach to realize integrated nano-systems (a) Nanoarray design, (b) multi-walled nanotube on a nanostructure with schematic and a scanning electron microscope image shown in insets (courtesy of ETHZ).

3.5 Opto-electronics: Hybrid Self-alignment in optical Inspection

A high-speed handling and inspection solution for laser diodes has been developed which overcomes precise pure robotic pick-and-place approaches. The hybrid inspection system handles laser diode chips with sizes down to 0.1 mm. The system combines coarse handling robotics with high precision self-alignment and self-positioning of the chips.

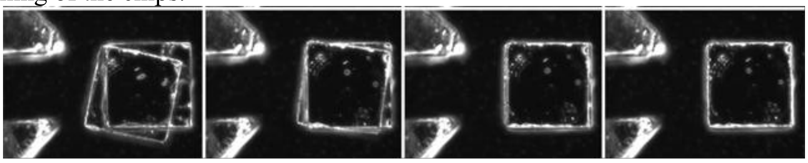

Fig. 9: Study of dynamic self-alignment of microparts(courtesy of HUT).

4 Outlook

Hybrid assembly defined as combination of self-assembly and robotics offers a new assembly paradigm in various production scenarios. It allows for high-precision and high-throughput assembly processes for hybrid micro-devices. An essential component of successful implementation is the application of specific design rules already in an early product development stage, taking into account integration of features that support self-assembly (e.g. surface structure / chemical composition of target areas).

Conventional robotics can benefit from the self-positioning and -alignment of components in target positions. On the other side, high specificity and customization of self-assembly can be achieved by combining them with advanced robotics.

5 Acknowledgements

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