A virtual reality based interface for microtelemanipulation

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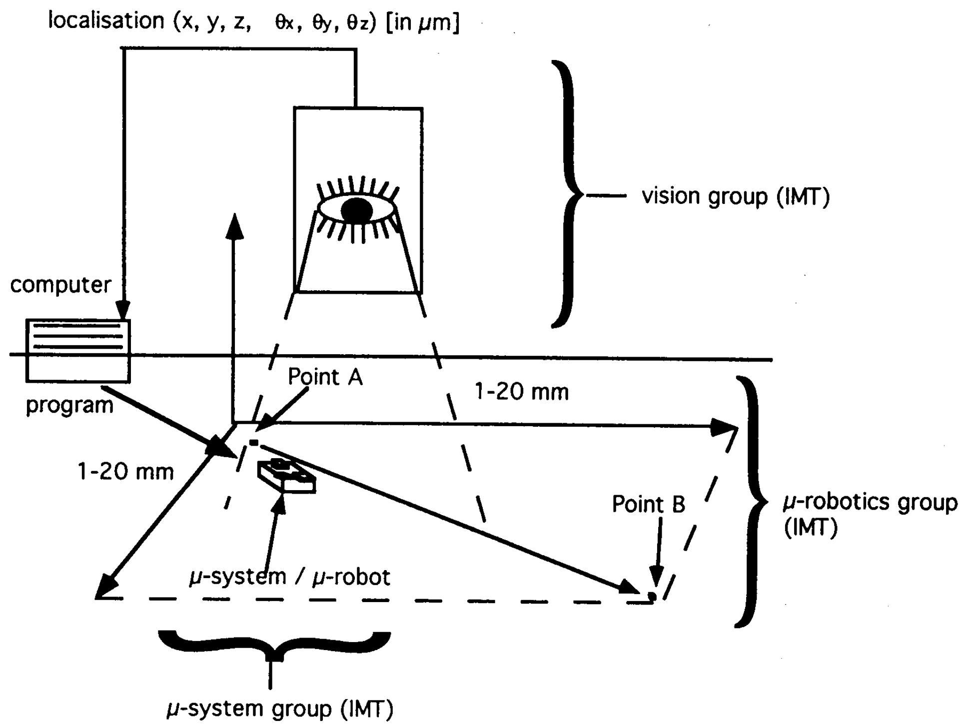
Abstract

The aim of our project is to control the movements of a micro robot and manipulate microsystems in real-time aided by virtual reality (VR), with a sub micron accuracy.
As microsystems and micro structures become smaller, it is necessary to build a micro robot capable of manipulating these systems and structures with a high precision of 1µm or even higher. These movements have to be controlled and guided. This article contains our first results in this new field of research.
The surface information of a Microsystem, e.g. the electrostatic micro motor fabricated with the LIGA-process of Karlsruhe, is digitized with a laser scanning microscope. This motor has an average height of 84 µm. The laser is passed over the surface of the motor placed on a X-Y table and the height-data is registered. This information is formatted to by treated by a VR-software system on a work station. The user of this system is able to simulate the assembly of the missing parts, e.g. the rotor (120 µm in diameter), beforehand in order to verify the assembly manipulation steps.
Work is being undertaken to develop a vision system to guide the assembly directly during the manipulation (real-time). This includes the development of a system to get a direct visual feedback. This work is a direct extension of what the vision group has achieved in the conventional robotics field [Baur_92], [Fluck_94], [Pique_94].

Introduction

Presently microsystems are receiving a lot of interest. Microsystems are small (typically less than $1cm^3$) independent modules, incorporating various functions, such as electronic, micro mechanical, data processing, optical, chemical, medical and biological functions. They are often built of micro structures in the range of 1 to 100 µm in length. As those microsystems and their micro structures become smaller and smaller, it is becoming necessary to build a micro robot capable of manipulating these systems and structures, with a high precision of 1µm or less. These movements must be controlled and guided. Typical assembled microsystems are the micromotor (Guckel_91), the micro machine (Fukuda_92), and the micro pump (Menz_93) just to mention a few.
The capability to control actions when operating at micro- or nanometer dimensions is highly relevant, especially since the nanometer limit has already been reached and even surpassed by a number of manufacturing technologies.
So far, only one aspect related to such a working scale can be considered as really operational and effective in manipulating: the capability of performing measurement ranging down to the nanometer and the atomic scale. That means that it is already technically feasible to perform a very accurate visual analysis of a microsystem and/or its environment.

At the Institut for Micro engineering of the Swiss Federal Institut of Technology in Lausanne the vision group is working since 10 years in the field of object recognition and telemanipulation [Baur_87, Baur_89, Baur_92] and the image ranging for object recognition [Nato_94]. These results will be applied in the telemanipulation of micro structures.
A positioning measurement can be performed either internally (sensor directly coupled to the actuator) or externally (a given point of the system is analyzed by a sensor having no immediate mechanical link to the actuator: this will lead to a relative positioning). To develop an internal sensor able to define and measure the micrometer is at present extremely complex whereas performing such a measurement externally is readily feasible. High definition microscopes allow definitions greater than the nanometer.
The idea of this project is to utilize such a capability to perform the position control of a microsystem by following the rules of an external sensor based approach shown in the picture 1 below. The system will recognize the micro structures (several micrometers in diameter) to be manipulated and guide a micro robot in real-time during this assembly while helping the user to plan the trajectories through the user-interface tools.



picture 1: a microsystem or micro robot guided by artificial vision via a microscope

Our development is oriented to treat complex environments and 3D-VR environments in following the use of a global map (in 2D) and a local 3D-tracking system (via 3D measurement - techniques). Our approach [Nato_94] allows to get the location (x, y, z) [in μm] in 3D while at the same time permitting a high frequency update. The μ-system, being developed by the μ-system-group at the IMT, and the μ-robot, being developed by the μ-robotics-group, will not be discussed in this paper.
The first results and further steps of the approach of the vision-group (on/off-line telemanipulation of micro structures) will be discussed in this paper.

Metrology of the micrometer

The measurement of position is central to the problem of performing a controlled motion in the range of the micrometer. To see and to recognize small micro structures for telemanipulation and to define their position in space, strong microscopes are needed. These microscopes will need a high lateral submicronic resolution and at the same time a fast inspection system to insure a real-time teleassembly with the targeted precision of a micron or higher.
In the following table some of the commercially available microscopes are listed with their important characteristics as well as their prices.

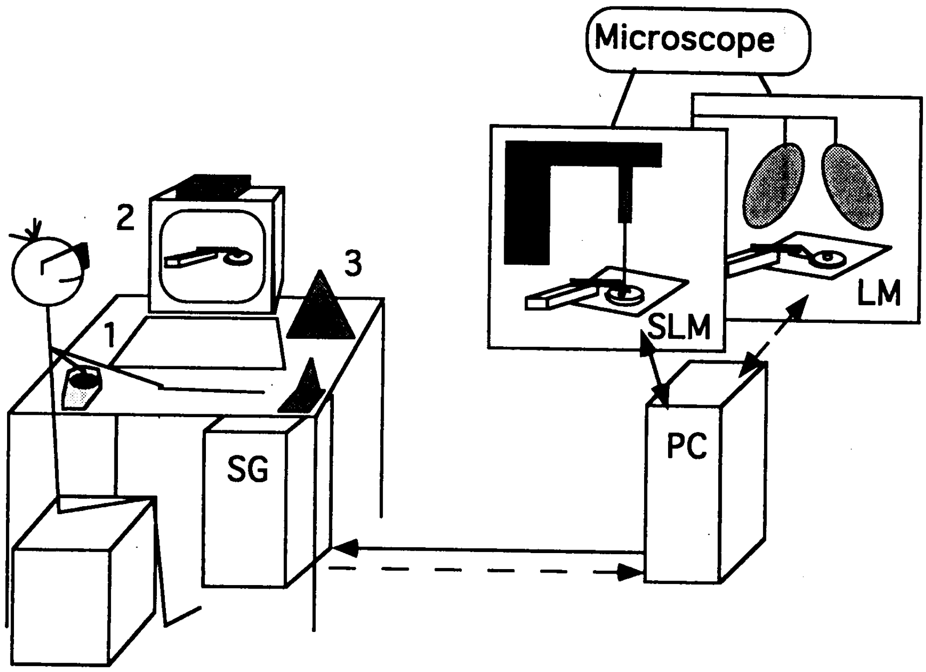
microscope	lateral resolution (µm)	Depth of Focus (µm)	real time imaging	costs in kUS $
LM Light-Microscope	> 0,5	0,01	yes	10-20
SLM Scanning-Laser Microscope	> 0,3	0,1	yes	125-180
SEM Scanning-Elektron Microscope	0,5 to 0,002	10,0	yes	100 ->650
AFM Atomic-Force-Microscope	> 0,001	0,001	yes	> 300
TEM Transmission-Elektron Microscope	>0,002	1,0	yes	>300- 1300

Table 1: Comparison of different microscopes (Rich_92)

The costs increases from 10-20 kUS$ of a light-microscope (LM) up to 1,3 Mio for a TEM.
If you compare the lateral resolution and the depth of focus of different Microscopes, shown in picture 2, you'll remark that the wavelength of the visible light (about. 400-800 nm) is a natural barrier for the lateral resolution. A guided Micro manipulation is targeted with a precision under 1 micron, so you have to control 1/10 of a micron to insure any manipulation at this scale. This purpose is only reachable with the high resolution microscopes SEM, AFM and TEM. Though we have chosen a SLM, because the working field is bigger than of all the others and you don't have to work under low pressure or even vacuum. Secondly you may reach 10nm in vertical resolution and with a positioning technique you may rise even the lateral resolution. This will be discussed later. The SLM will be combined with a classical 2D-microscope to get a global view.

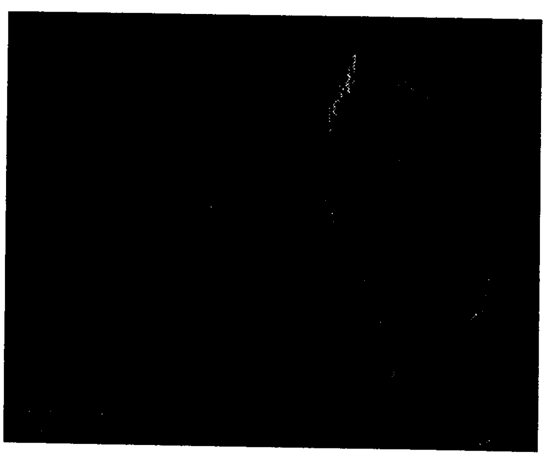
Vision / VR-interface

The next option for an easily programmable high performance controlling system for telemanipulation is the use of a guiding-system based on Virtual Reality. Our experience in the macroscopic world [Baur_94] has shown, that using VR to simulate and insure certain movements and behaviors of manipulators is only half the way to a guiding system preventing collisions and insuring all wanted movements. In combining artificial vision and a VR-based programming system, this specification can be insured. By using vision, the aim is to define the position of a real robot part in the 3D space (usually the end effector) without locally defining the robot joint positions. This 3D information is then, ideally, updated in real time to verify if the scheduled task is performed correctly. The main advantage of such an approach is to present an accuracy which is not directly linked to the mechanical characteristics of the manipulators. The main disadvantage for specific applications is to be obliged to perform a high frequency 3D position update so this slows down the speed of the guided manipulation.
In our approach we want to treat complex environments (3D-VR environment) by using the information of a global map (in 2D) and combining a local 3D-tracking system (via 3D measurement-techniques). Our approach [Nato_94] allows the use of a mid-size workstation to get the location (x, y, z) [in µm] in 3D while at the same time permitting a high frequency update. A user-defined 3D-model is used, when needed, otherwise 2D-information is treated.
Picture 2 shows the user of the system and his tools. In our example the real environment of the microsytem, e.g. the electrostatic micro motor fabricated with the **LIGA**-process of Karlsruhe (IMT-KfK / Germany)[Wall_92], is digitized with a laser scanning microscope. The motor has an average height of 84 µm. The laser is passed over the surface on a X-Y table and registers the height-data. This information is formatted to be treated by the VR-software system on the work station. The user of this system is able to simulate the assembly of the missing parts, e.g. the rotor (120 µm of diameter), in advance, so as to insure the manipulation.



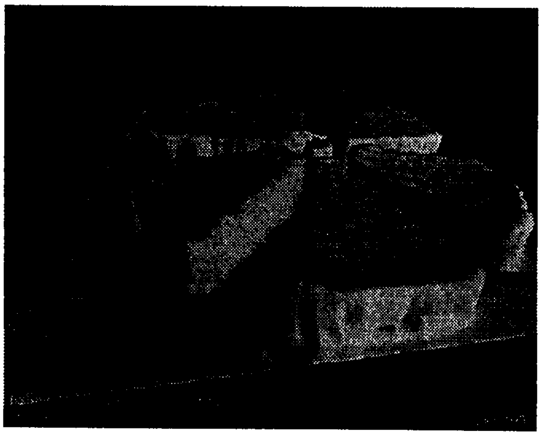
Picture 2: The actual VR-interface via a SLM (full-line) and future developments, integration of a vision feedback and robot control in real-time (dashed line).

The user has the possibility to attach the movements of his spacemouse (1) or the 3-D-mouse (3) to certain system capacities. He may attach his movements directly to the movements of the robot or he may "fly" into the scene (workspace of the μ-robot) to insure the manipulation from all sides. The 3-D-shutterglasses (2) help him get a real 3-D image on the screen to work longer under realistic conditions (3-D-view).
Tests have shown that the performance of the mid-size workstation used is insufficient in the up-date rate to cope with an accurately defined global view at a high precision [μm]. The environmental description has therefore been divided into two parts: a **coarse** and a **fine** description.
The coarse description will allow the user to define a rough 3D model of the Microsystems's environment. Such a description can be updated at a slow scan rate. To define the global (coarse, not so precise) view, we will use a light microscope (LM) with a 3-D object-recognition system in our future development.
The fine description (SLM- Scanning laser microscope) will allow the system to accurately define the 3D position (x,y,z,qx,qy,qz) of the object of interest (end effector, tool, object manipulated, receptacle, etc.).
The first step of this project was to select the adequate technique to perform the global and the local world description and to show the feasibility of such a system in the accuracy-range of 1 micron.
In the following pictures (a-->d) are shown the procedures followed in developing the (fine) environment of the Microsystems and the tools to use in the telemanipulation. To be able to solve the sampling rate problem, it has been decided to combine global (coarse) with local (fine) visual analysis techniques in future steps.

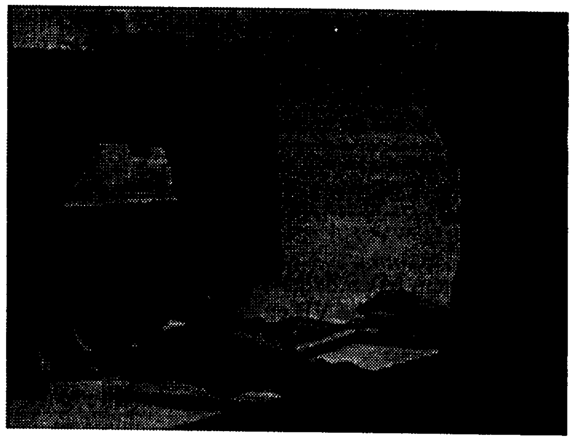


a: 3D triangular mesh of KfK-micromotor after fine scan

b: After a shading of the surface



c: Simulation of a microtelemanipulation

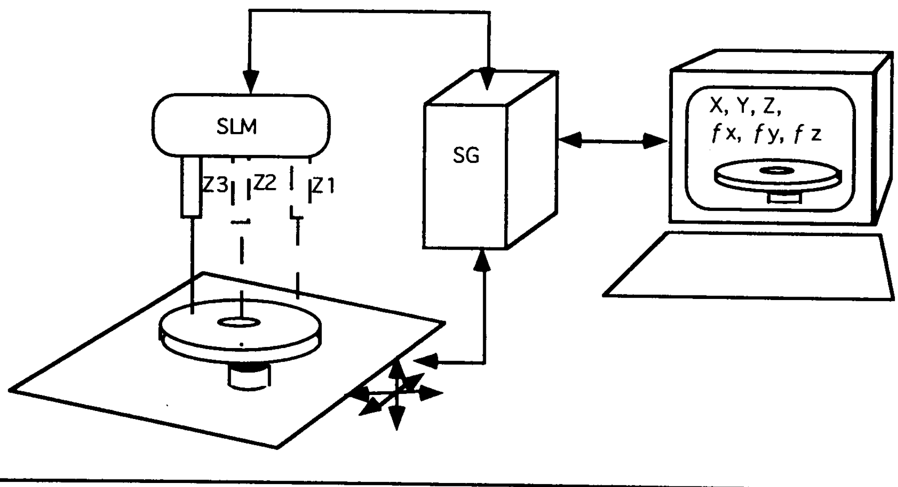


d: User of the VR interface and his tools

picture 4: Procedures followed in creating the VR-environment of a on/off-line microtelemanipulation and the tools used, **LIGA**-micromotor in cooperation with the **KfK**, Karlsruhe, Germany [Wall_92].

Feedback by artificial vision

Two approaches are available to perform a positioning by an external measurement. The first one, the conventional approach, is based on the image supplied by the microscope as the sole source of information. The second one, a more up-to-date approach, uses a model with a representation as detailed as possible with an a-priori-knowledge of the scene that is to be analyzed. The combination of prediction/verification techniques between the real and virtual worlds (i.e. the worlds as viewed by the microscope and that contained by the knowledge representation model) provides the necessary information required to carry out positioning.
Such an approach promises a number of advantages over the classical one: The capability of combining information provided either by the microscope or by a model established in a former stage greatly increases the robustness of the analysis system and in a similar manner improves upon the action of positioning.
Knowing the 3D model of the actuators (micro robots, micro machines, etc.) and their environments, the user can have access to a virtual reality based task description and supervision environment. Tests at the IMT vision group have shown that such an environment can greatly improve the man-machine interface and increase the efficiency for the user and the manipulation system whatever the distance or the scale between them (teleoperation) may be. To perform and insure, in our case, such a manipulation, a real time 3D points tracking system in the micron-range will be proposed to get a high precision feedback by artificial vision. Such laser-tracking-systems already exists in the macroscopic world [Allen_93], [Green_93] and with some changes they could be adapted to the micron scale.



Picture 5: proposed feedback of a defined microtelemanipulation by a 3-point-tracking system using a SLM

To increase the quality of both descriptions, passive as well as active enhancement techniques will be tested. For example, in an active method, the 3 points of interest (Z1-Z3) for 3D positioning can change their property (emisivity, refraction, etc.) relative to the sensor position of the used SLM-Scanning laser microscope. These aspects, which is the third step of our proposal, will lead towards the new positioning techniques on the micron scale required by such a system which is called microvisionsystem.

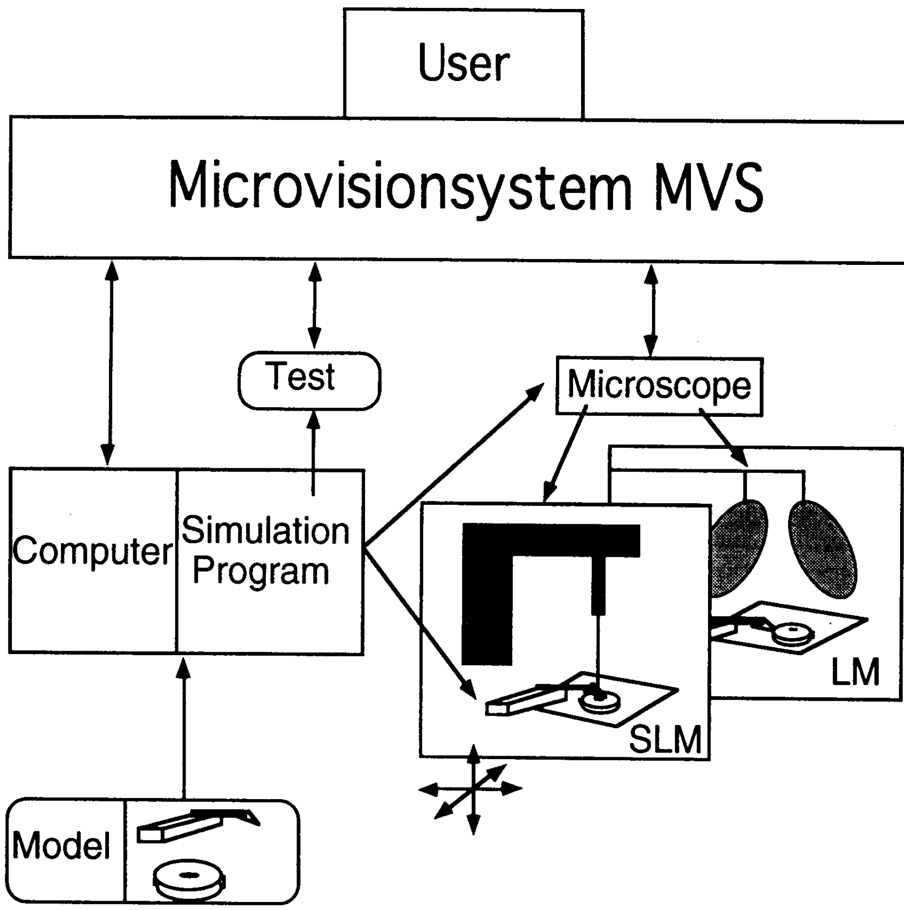
Microvisionsystem MVS

The microvisionsystem MVS helps the user to identify the μ-system and to manipulate it in an intuitive way by using all the advantages of the VR environment.

1. Motivation to build such a system
To be able to generate a movement of a given amplitude requires three steps:

- generation of the movement itself (actuators)
- measurement of the displacement (sensor)
- feedback from the sensor to the actuator (servo control and regulation)

Due to the working scale of a μ-robot, it has been necessary to develop new techniques to cope with manipulation and positioning in general.



Picture 6: concept of the microvisionsystem (MVS) for On-line-control of the movements of the micro manipulator

The user guided by the microvisionsystem (MVS) in Picture 6 treats the surface-information of the manipulated object with a microscope. A scanning laser microscope (SLM) or a light microscope (LM) will be at his disposal.
He uses the models (tools and objects) of his database, which to summarize, it can be stated that the modelisation of the a priori knowledge known about a candidate scene beforehand. The use of this knowledge in a model representation makes a system more reliable and complete.

2. Feedback by vision

Among the advantages, using a vision feedback, we can highlight the following:

- the capability of emphasizing certain characteristics of the object under observation (during its conception as well as during its observation).
- geometrically the models can be three-dimensional (3D); hence the relation between the two worlds is then direct. Of course the modelisation is not limited to geometrical considerations and a number of other parameters can be taken into account (photometry aspects, chemistry aspects, ...).
- these models can be used in environments not limited nor directly related to the context of the positioning problem encountered with the μ-robot. Indeed they can be used in simulations, detailed analysis, support of transmission of information between machines and/or operators, etc.

Industrial potential

The industrial potential for the presented system is seen in

- Micro manipulation in a clean room of a class 10 and higher (teleoperation)
- Quality-insurance of smallest parts and objects,
- Repair of microelectronics and micromecanical devices
- Assembly of Microsystems (pressure-, acceleration- and chemical sensors, micromotors and-gears),
- Positioning of optical fibers and lenses,
- Assembly of optical micro structures in general

Cleanness during assembly allows insurance of wanted functions of a microsystem and is important for systems applied in the medical field (like in the project "Minerva" [Burck_93] in our Institut IMT at Lausanne).
Other Applications are visible in the field of biological and medical research (Manipulation of cells, DNA, biological materials, etc....)

Conclusion

The discussed system has an VR-interfaced environment, integrating a microscope, a command and a simulation system and will permit (on-off-line) microtelemanipulation of μ-systems or μ-robots. These movements will be guided and controlled. In combining 2D and 3D-measurement-techniques mid-size-workstations will be fast enough to cope with the high update-rate.
This work is a direct extension of what vision group has achieved in conventional robotics field [Baur_92], [Fluck_94], [Pique_94].
Work is being undertaken to develop a vision system to guide the assembly directly during the manipulation (real-time). This includes the second step of development of a system to get a direct visual feedback. The generation of the 3-point-tracking system will be the final step.

References

[Allen_93] Allen, C., Mistry, N.;
A camera based stereo tracking system for robot positioning applications,
SPIE-Vol. 2056 Intelligent Robots and Computer vision XII, 1993 pp. 286-295

[Baur_87] Baur, C.
Introduction à la vision artificielle, Support de cours EPF Lausanne, 1987

[Baur_89] Baur, C. und Beer, S.
Bildanalyse mit Hilfe von CAD-Oberfächenmodellen,
Robotersysteme, Band 5, S. 105-110, 1989

[Baur_92] Baur, C.
Un système de vision fonde sur les modeles utilisant l'imagerie de sysnthese
et la correlation normalisée, Thèse no. 998 EPF Lausanne, 1992

[Beck_86] Becker, E.W., et all.
Fabrication of microstructures with high ratios and great structural heights by synchrotron radiation lithography, galvanoforming and plastic moulding (LIGA-process),
Microelectronic Engineering 4, 1986,S. 35-56

[Burk_93] Burkhardt, C.W. et all,
Neurosurgical Operation with the Dedicated Robot Minerva
ICAR Int Conf. on Advanced Robotics, S.347-351 , Tokyo, Japan, November 1-2, 1993

[Guckel_91] Guckel, H., Skrobis, K.L., Christencon, T.R., Klein, J., Han, S. Choi, B. and Lovel, E. G.:
Fabrication of Assembled Micromechanical components via Deep X-Ray Lithigraphy;
Proceedings of Micro Electron Mechanical Systems, 1991, pp. 74-79.

[Green_93] [3] from [Allen_93], Green A.,
LTMS-Development in Germany

[Fluck_94] Fluckiger, L., Natonek, E.;
Réalité virtuelle, vision et robotique;
Diploma Theses at IMT / EPF Lausanne, Feb. 1994 (in french)

[Fukuda_92] Fukuda, T., Arai, F;
Microrobotics-approach to the realization;
Micro Systems Technologies '92, Berlin, 21-23, October 1992, pp. 15-23.

[Lamp_89] Lamprecht, .
Was ist Vakuum ?; Volum 1, 2, 1989 (in german)

[Menz_91] Menz, W., Blei, P.;
Mikrosystemtechnik für Ingenieure, VHC-Verlag, 1991 (in german)

[Menz_93] Rapp, R. , Bley, P., Menz, W., Schomburg, W.K.;
Micropump fabricated with the LIGA process
6th IEEE Workshop on Micro Electro Mechanical, Systems, 7.-10. Feb. 1993, Fort Lauderdale, USA

[Nato_94] Natonek, E.
Recognition of 3-D objects on complex backrounds using model based and range images;
IEEE Image Analysis and Interpretation; Dallas, Texas, April, 21/22 1994

[Pique_94] Piquet, L., Baur, C. ;
General kinematics simulation of serial links mecanisms
Diploma theses Laurent Piqeut, Cooperation AMES/NASA and IMT/EPF Lausanne, Feb. 1994

[Rich_92] Richards, B.P., Footner, P.K.
The role of microscopy in semiconductor failure analysis
Oxford University Press, Royal Microscopical Society, 1992

[US-FS_209b] US-federal Standard 209b, classification of clean rooms

[Wall_92] Wallrabe, U.
Entwicklung, Simulation und Test von mittels LIGA-Technik hergestellten
elektrostatischen Mikromotoren, in german , Diss. Karlsruhe1992