A Remote Controllable and Programmable Atomic Force Microscope based on LabView

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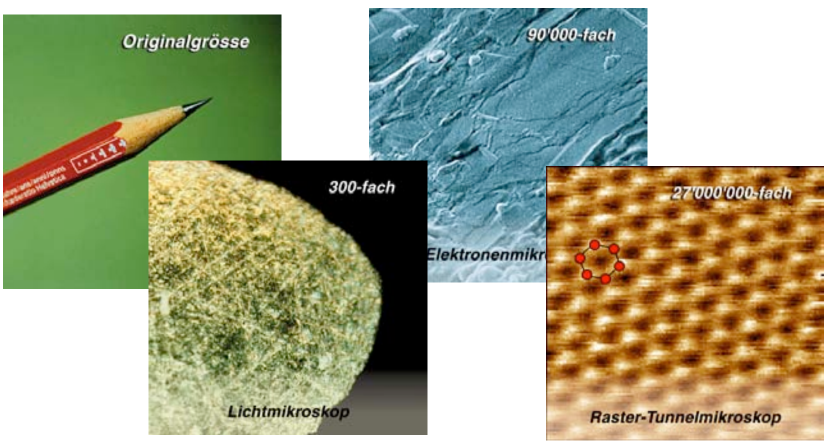
Introduction

We present a fully remote controllable and programmable atomic force microscope. The instrument features a motorized four-axis robotics. This robotics allows a fast and accurate change of position with a precision of below 2µ and can be used as a stage of multiple samples. The instruments software is fully implemented in LabView. The LabView user interface can be easily customized to the needs of different application. Right now the RAFM is running with telnet sessions, Java Applets or a collaborative, web-shared LabView application. The instrument can be programmed to perform whole sequences of measurements automatically or to start a batch of complex operations by one click. The instrument can be controlled and monitored from various locations using a standard network interface. The combination of the programmable instrument and the highly accurate robotics opens a wide range of new applications for science and industry. Four examples it is possible to create a long-range scan by overlapping multiple scans. Due to its features, the RAFM can be integrated in an already existing workflow of a typical industrial application like quality control. LabView allows fast enhancements and customization of the system.

Nano - A Greek Dwarf becomes Leader in Science and Technology

The Greek word nano means dwarf. Therefore, nanoscience deals with tiny structures and objects. Scientists use the prefix nano for the thousandth of a millionth part. Nanoscience and nanotechnology is the world of atoms and molecules. Classical instruments like light microscopes are unable to visualize them. In order to measure and manipulate objects down to the size of a single atom, special instruments are required. One of the most important instruments is the Atomic Force Microscope.

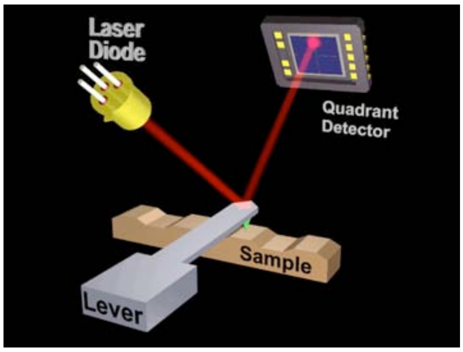
The field of nanoscience has become one of the most successful branches in Swiss research in the last decade. Since nanoscience is a highly experimental and a less theoretical field, textbooks about nanoscience are unable to teach everything the field contains. Our group has developed a student laboratory based on LabView where non-specialists can take images of tiny structures down to single molecules.



A tip of a pencil shown in different magnification. The top right image shows the pencil in real size. The image below shows a image taken with a light microscope. The next image was taken with an electron microscope. The last image is a scan of a scanning tunneling microscope and it shows single atoms at a magnified 37'000'000 times!

A Simple but Efficient Principle of Measurement

An Atomic Force Microscope (AFM) consists of an extremely sharp tip mounted on the end of a tiny cantilever spring, which is moved by a mechanical scanner above the surface to be observed. Every variation of the surface height changes the force acting on the tip and therefore changes the bending of the cantilever. A laser beam measures the bending of the cantilever spring and records line by line in the electronic memory. The interaction between tip and surface can be compared with a classical turntable pickup. However, the force in the AFM is about 1 million times smaller.



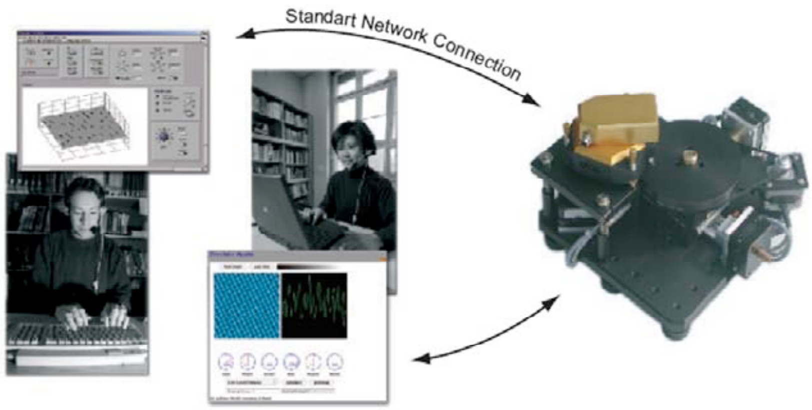
RAFM - A Remote Controllable AFM for Education and Industrial Applications

Collaborative Remote Measurements

Two decades after the invention of the two major instruments for nanoscale science, the Scanning Tunneling Microscope (STM) [1] and the Atomic Force Microscope (AFM) [2], a fully programmable remote controllable atomic force microscope (RAFM) is presented, which can be accessed by an interdisciplinary community in nanoscale science all over the world.

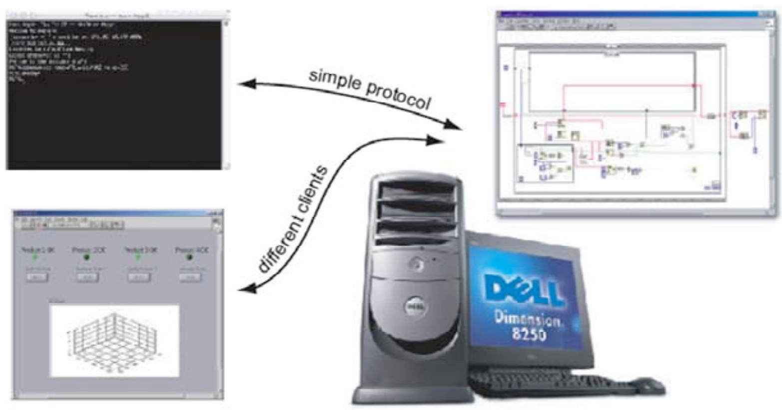
The field of remote microscopy became very active in the 1990s, where there was a desire to give researchers better access to expensive and specialized electron microscopes. In this field, work has been done by Culiver in 1996[3], McClellan and Winokur in 1997 [4], Ellisman et al. [5], Mansfield [6] and Zaluzec [7] in 1998. Early attempts to remotely control a SPM started in 1992, when the National Center for Supercomputing Applications, in collaboration with the STM group at the Beckman Institute for Advanced Science and Technology at the University of Illionis at Urbana/Champaign, developed a software module that allowed remote control from within a commercial software environment Advanced Visual System (AVS) and CAVE. The accessibility to reliable, state-of-the-art, user-friendly, well-documented remote operation of an AFM through standard Web browsers, allows the sharing of nanoscale investigations over a large number of laboratories. It allows scientists and students to perform various investigations with an AFM anywhere, anytime remotely [8].

An atomic force microscope (AFM) is an apparatus of high complexity designed to get maximum resolution and accuracy in scanned surfaces. Operating such instruments needs a lot of know-how and a lot of very specific experience. It can be compared to learning to fly an airplane. The RAFM was originally designed as the last stage in a virtual e-learning environment called Nano-World and is accomplished by a commercial Nanosurf *easyscan* microscope. Students can collaboratively work on real experiments from multiple clients, anywhere and anytime. One single remote, multi-accessible apparatus keeps the time of support at a minimum level and offers a maximum of usability. In addition, our remote atomic force microscope (RAFM) features an automatic positioning robotic to choose from different samples. This means, various experiments can be done using the same instrument without the need of an operator.



The RAFM is fully remote controllable. A server enables the connection to various clients. Because of the easy protocol, the clients can have customized graphical interfaces. This means the look and feel can be adjusted to the actual user and the specific application.

Customizeable "look and feel"
The RAFM represents a state-of-the-art system using modern Internet technologies and a robust, accurate and easy to handle robotics. The instrument is controlled by a LabView server, that manages the robotics as well as the remote accessibility. The implemented server supports a simple and open command line language. This keeps the accessibility very flexible. Using LabView, the graphical user interface (GUI) can be customized to fit the needs of users with various knowledge levels. This feature is interesting in context with students and for industrial application. The GUI can be adjusted to a specific application or experiment within minutes.

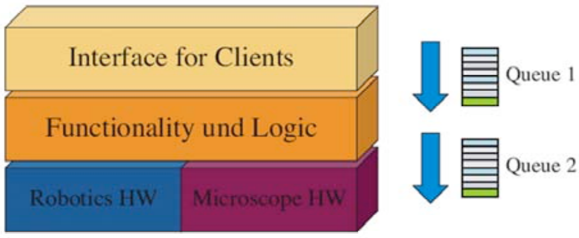


The fundamental protocol is based on a command language. Every operation like changing the sample or starting a scan can be executed by using the corresponding command line. (bottom left) A LabView user interface as it could be used in an industrial application. Every element of the front panel can be customized and the executing command can be defined autonomously. (right) The microscope server runs multiple LabView applications for the network connection and the hardware control.

Technical Details
To control the RAFM, an instrumentation server was programmed. This server software has completely been implemented in LabView, an industry standard graphical programming

language. The design basically features four, strongly separated layers. Every layer runs as an autonomous application (thread). These layers are:

1. A hardware layer encapsulating the hardware protocol of the microscope and the logic to generate the electrical TTL signals to drive the sample stage. Parameters of the robotics like the maximum linear speed of the movement and the maximum acceleration[3] of every axis are defined in the hardware layer as well.
2. A middle-ware layer containing the whole functionality, including the list of valid commands and the security management. Security management means for example the implication that the sample can't be changed if the microscope is in the approached state.
3. A top layer to support the connection to the local or network GUIs.
4. The GUI itself



Different layers keep the software stable and flexible. Every layer runs as an autonomous application. The communication is done with queues.

The instrument can be operated locally as well as from any place by using a standard Ethernet network connection. The software is kept strongly modular and encapsulated, which means that, modifications and customizations can be done very quickly with *LabView*. Each layer can be replaced or enhanced to optimize and customize the system to the needs of the user. Replacing a layer just means to run another corresponding application. *LabView* offers a wide range of pre-designed modules that can easily be integrated within the microscope software. Such modules are filters, mathematical functions or tools to visualize data. In addition a set of microscope specific modules have been implemented to keep the implementation of new features of the AFM and the robotics as simple as possible. To execute a process, a command of low complexity has to be sent to the instrumentation server. In general commands are structured like the following examples:

- command=approach
  Automatically moves the cantilever tip to the surface.

- command=start
  Starts a scan; scan data is being sent as a 2D array of words.

- command=stop
  Stops the running scan.

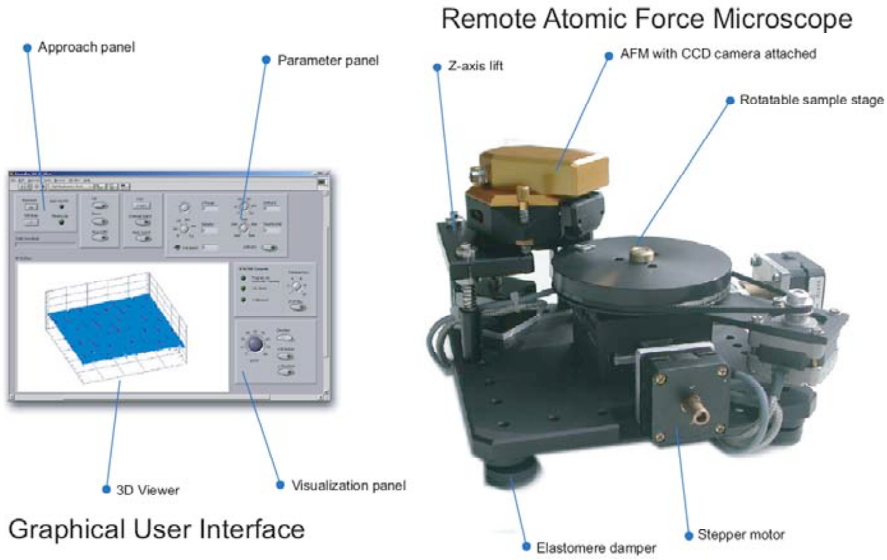
- command=withdraw
  Removes the tip from the surface.

- command=goto3
  Replaces the current sample with the one stored as position three.

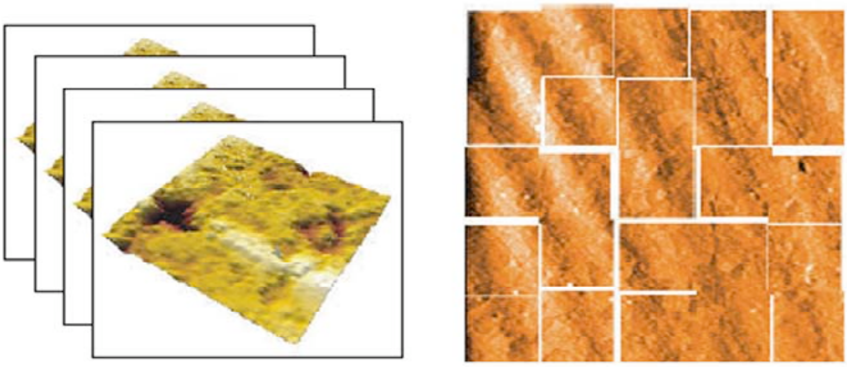
To change parameters or to execute more sophisticated commands the following structure is needed:

- command=moveaxis name=x value=1205
  Moves the x-axis to position 1205 (measured from zero)
- command=set name=ATR-AxisUnit value=128
  Changes a certain parameter of the AFM to 128 (sampling rate)

Because of the simple command structure, processes can be started with nearly every apparatus with access to a computer network and the ability to send and receive a string. Tests were done with Notebooks, PDAs and even mobile cell phones using http or persistent sockets. Because the needed commands can be generated in different ways, user interfaces can be kept very flexible. Right now the RAFM is running with telnet sessions, Java Applets or a collaborative, web-shared LabView application.
The communication is based on two different channels. One for the mentioned commands and events and the other for scan data. The scanned data is sent as a one-dimensional array of words representing a line of the ongoing scan. The scanned frame is represented with a 2D array of words composed by the one-dimensional data. The word values represent the height of the corresponding pixel at location xi, yj. Because of the simple format, the scanned data can be analyzed and visualized in many different ways using the mentioned libraries available in LabView. In our setup the instrument is used in different modes of accessibility. Depending on the user interface and the associated commands, it is possible to operate the RAFM in an expert or novice mode. The novice mode allows basic operations with a high level of security to prevent a damage of the high sensitive force sensor. The expert mode allows the full control of the RAFM with all operational risks.



Programmability
Besides of being remote-controlled, the instrument can be fully programmed in order to perform complete sequences of measurements by applying multiple commands. We did automated long-term measurements and puzzles like long-range scans. A long-range scan is a picture generated by multiple overlapping scans, which are composed to get an image of a large range without loosing the instruments resolution. The instrument still worked even after long sequences of 48h and more reliable.



Multiple measurements over a long time can be arranged to a movie. Using this method, time depending effect can be visualized. Using the same technique multiple measurements over a long range can be arranged to a big image. This increases the range of a high-resolution instrument.

Conclusion

In a first steps the instruments capabilities using the remote interface have been tested with up to five simultaneous users. The remote usage of the instrument showed how important a video image for realistic operation is. Using the feature of the programmability; automated procedures of measurements to define the instruments accuracy were performed. The instrument worked even after long automated sequences of 48h and more reliable. The usability was tested in a classroom environment with high school students and was very successful.

In the future the automated scans will be enhanced as well as the instrument's automation capabilities for industrial quality control. That allows an easy integration in an already existing workflow environment. The sensor software is being enhanced by means of an automated measurement of large AFM data sets and a reduction to a small set of characteristic properties of the sample. By means of the computed meaningful parameter it is straightforward to integrate the RAFM into an industrial environment.

The RAFM represents a state of the art system, based on a commercial *Easyscan* AFM [10], enhanced with a remote controllable, robust and accurate robotics.

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