



quDIS - Displacement Measurement Interferometric Sub-Nanometer Precision



quDIS - Measurement Applications

Highest accuracy for high-end applications in science and industry with the quDIS displacement sensor.

The quDIS is a confocal displacement sensor with a high signal stability and a contrast independent measurement algorithm. The quDIS is based on a laser interferometer like Fabry-Pérot or Michelson setups. Its high precision is required in various high-end applications in science and industry.

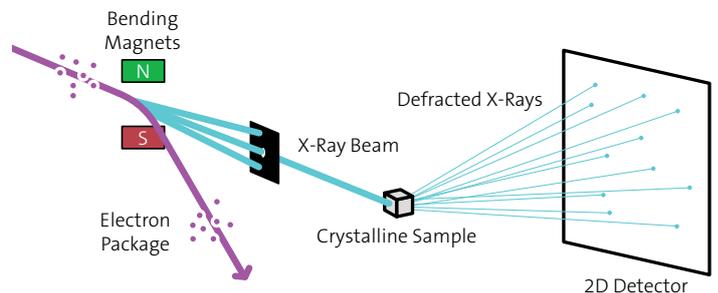
Sample positioning for X-ray diffraction measurements in synchrotron facilities

X-ray crystallography is used to determine the atomic and molecular structure of a crystal. The crystalline structure causes an incident X-ray beam to be diffracted in many specific directions. By measuring the angles and the intensity of these diffracted beams, a three-dimensional image of the electron density in the crystal can be obtained and thus the molecular structure can be identified.

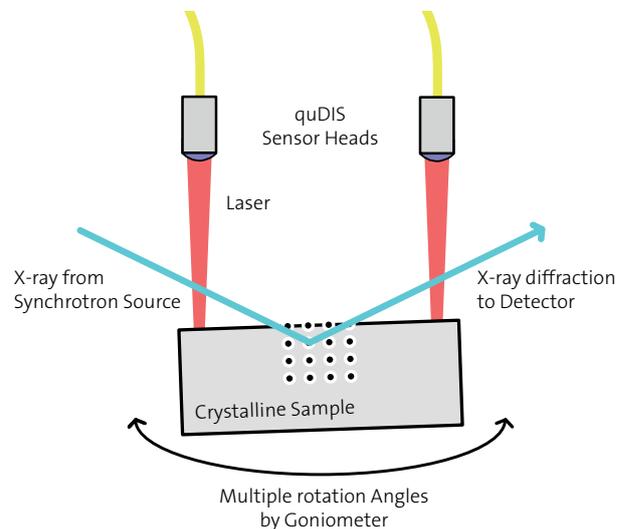
In synchrotrons, charged particles like electrons are accelerated to very high speeds and then laterally deflected once or multiple times at regular intervals by bending magnets and other insertion devices. The X-rays produced by the acceleration of these charged particles are emitted in dozens of thin beams, directed at a beamline adjacent to the accelerator. A synchrotron can generate a much more focused, or brilliant, beam of radiation with highest intensities.

The X-rays in a beamline hit a crystalline sample and get diffracted by its lattice. By rotating the sample through several angles in a vacuum chamber while the X-ray detector measures the diffraction angles, the crystalline structure can be analyzed.

In this application, the quDIS displacement sensor measures the distances between the fixed sensor heads and the sample surface and determines the positioned angles of the sample. It measures the movement of the goniometer stage in a closed-loop setup with sub-nanometer accuracy.



A synchrotron accelerates charged particles - mostly electrons - close to the speed of light. When these particles are then accelerated transversely by magnetic fields, X-rays are produced. Their short wavelength is ideal for crystallography.



Schematic measurement setup for high-resolution positioning of crystalline samples for X-ray crystallography in a synchrotron beamline. The sample is rotated through several angles in a vacuum chamber with a goniometer while the detector measures the diffraction angles. The quDIS measures the distances between the fixed sensor heads and the sample surface and determines the positioned angles in a closed loop with the goniometer.

Thermal deformation of a satellite in simulated space environment

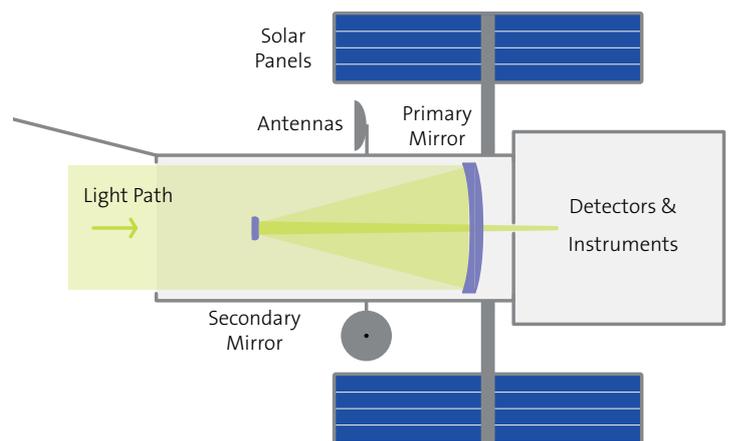
A space telescope is superior to a ground-based one because there is no light pollution or atmospheric aberrations, providing a more stable image, and offering unprecedented angular resolution over a large field. The disadvantages are the high costs and difficult maintenance, therefore the design and the construction must be very carefully prepared.

A Cassegrain reflector, like most large professional telescopes, has a parabolic primary mirror and a hyperbolic secondary mirror that reflects light back down through a hole in the primary. The mirrors and optical systems determine the final performance. Optical telescopes typically have mirrors polished to an accuracy of about a tenth of the desired wavelength.

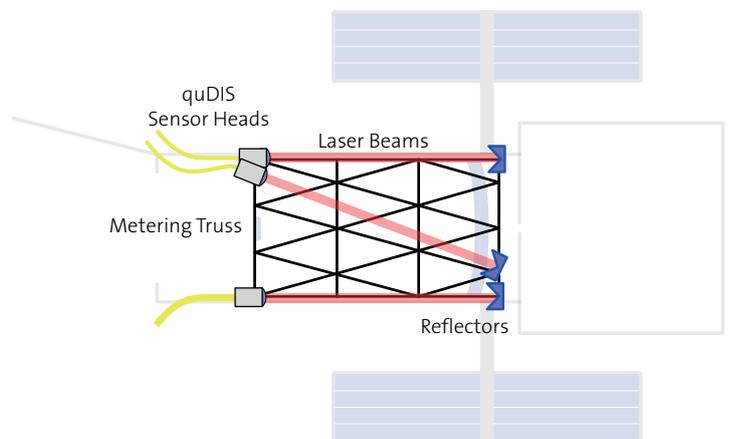
The metering truss, e.g. a graphite-epoxy frame, is the optical telescope assembly and keeps the working parts of the telescope firmly aligned. It must be able to withstand the frequent changes from direct sunlight to the darkness of the Earth's shadow, resulting in large temperature fluctuations, and at the same time be stable enough to allow extremely accurate alignment of the telescope. It is surrounded by multi-layer insulation that keeps the temperature inside the telescope stable.

The design and materials of the measuring truss and its response to the harsh environment in space must be tested on Earth. By enclosing the entire structure, controlling parameters such as temperature and pressure, and measuring the deformation with multiple quDIS axes, the deformation can be determined under simulated conditions.

In this case, twelve quDIS axes were used to measure the deformation of the cylindrical measuring truss in multiple directions with the highest precision and low drift over a long period of time.



Schematic view of a “classic” Cassegrain design used in space telescopes: a parabolic primary mirror and a hyperbolic secondary mirror that reflect the light back down through a hole in the primary. Folding the optics makes this a compact design.



The design and the materials of the metering truss and its response to the harsh environments in space has to be tested on Earth. Enclosing the whole setup, controlling parameters like temperature and pressure and measuring the deformation by quDIS can simulate the operating conditions.

quPID & quDIS - Nano Positioning Systems

Measurement and closed-loop systems for positioning within sub-nanometer precision without nonlinearities, contrast dependencies and signal loss.

The quDIS is a confocal displacement sensor based on an interferometer with high signal stability and a contrast independent measuring algorithm. Next to relative and absolute distance measurement with a bandwidth of 25 kHz in free space, vacuum or glass rods and fibers as cavities, vibration analysis is also possible. Different sensor heads based on Fabry-Pérot or Michelson interferometer configurations are available for a wide range of applications.

quPID

- Interferometric displacement measurement with quDIS
- Stand-alone measurement and control unit
- 3 piezo drivers and feedback control
- 10" touch display for visualization
- Wifi, USB and Ethernet interfaces



quDIS

- Interferometric displacement measurement with sub-nanometer resolution
- 3 axis, synchronization of multiple devices
- Low laser power for safe operation - laser class 1
- Visible coarse adjustment laser
- Interference spectroscopy



Specifications

- < 0.05 nm signal stability
- 25 kHz bandwidth
- 20 ... 1400 mm working distance
- 3 m/s target speed
- 3 sensor axes



Accessories

Ambient Measurement Unit (AMU)

Analysis of environmental parameters temperature, humidity and pressure

Displacement measurement compensation, measurement of refractive index



The ambient parameters temperature, pressure and relative-humidity are measured by the AMU.

Sensor Heads and Reflectors

Tailored solutions to the reflecting target and the measurement dimensions

Variety of sensor heads for beam shaping and individual measurement tasks



The Michelson sensor head is also available in a variant with an open reference arm.

Optional software packages

Distance Measurement

Compensation of height steps or beam interruptions

Vibration & Analysis

Vibration analysis with a bandwidth of 25 kHz

Vibrometry, live calibration

Cavity Analysis

Detection of multiple reflections in a cavity

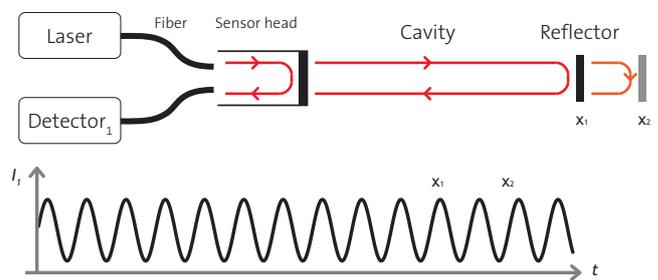
Distance Measurement on the Nanometer Scale

Laser-interferometers offer high precision performances without influencing the measured system.

Interferometry is by far the best method when length measurement require the highest accuracy. The use of stable lasers with low bandwidth and superposition of its coherent radiation allow the observation of interference phenomena. The detected signal corresponds to the optical path length with sub-nanometer resolution.

Interferometry - sub-nanometer accuracy

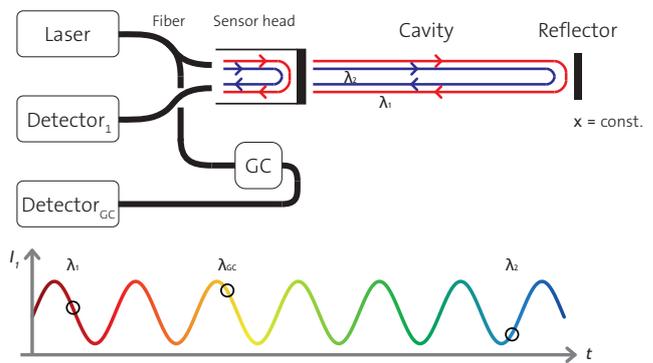
All kinds of interferometers make use of the same principle. A laser beam with high coherence length is split up in two different paths, one reference arm and one measurement arm. When the two beams are superimposed again, constructive and destructive interference $I(x)$ can be observed in dependency on the modification of the optical path length of the measurement arm. But changes in the interference pattern can also correspond to alternation of the target reflectivity or adjustment drifts due to movement. This method does also not indicate the direction of a target movement and has the uncertainty of the periodicity the interference pattern.



The setup is inspired by a Fabry–Pérot interferometer. Fiber coupled laser light leads to a sensor head where 4% of the light is reflected back to the detector. The rest passes the cavity, is reflected and also guided to the detector. The graph shows the intensity on a detector of a constantly moved mirror - the interference signal.

Interference Spectroscopy – Frequency stabilization and analysis

Beside the optical path length changes, modification of the laser wavelength at a constant path also leads to signal modulations by interference $I(\lambda, x_{const})$. The wavelength is swept by electric laser control, introducing an artificial motion over multiple wavelengths that avoids the relative blindness in static situations. We call this feature “interference spectroscopy”.



Tuning the wavelength also causes a similar interference pattern as moving the mirror. The graph shows the intensity on a detector with linear decreasing wavelength over time. The absorption lines of a acetylene cell are used for precise wavelength calibration.



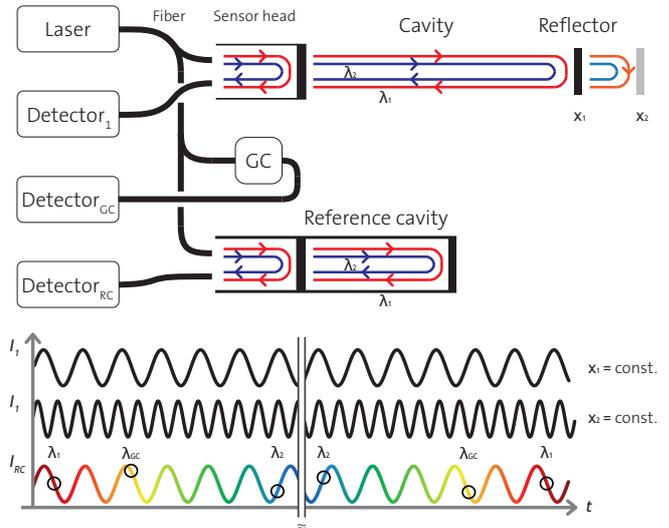
By sweeping the laser frequency much faster than the target movement $\Delta\lambda/\Delta t \gg \Delta x/\Delta t$, relative length changes of the optical path can be determined simply by counting the interference fringes in the pattern and determining the phase at a fixed wavelength. An internal optical reference cavity stabilizes the wavelength change into a linear wavelength sweep. This measurement method is not affected by the contrast nor the intensity of the detected signal. Other interferometric methods only monitor the intensity (arcsin) or its deviation (arctan) at a constant wavelength leading to typical periodical error patterns.

Beyond displacement measurements - high accuracy to pursue distance measurements

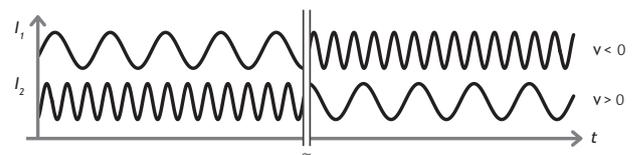
The use of “interference spectroscopy” in combination with a gas cell with well defined absorption lines enables not only displacement, but also absolute distance measurement. The number of fringes in the interference pattern, the calibrated wavelength and the linear wavelength change via the built-in reference cavity with its constant length give all parameters to determine the length of the measured cavity path.

The “interference spectroscopy” carried out by fast up and down wavelength sweeps and a moving reflector target show a Doppler-like effect. When the measurement distance decreases and also the wavelength increases within the up sweep, the number of fringes in the interference pattern decreases, depending on the reflector velocity. The instantly following down sweep with decreasing wavelength shows the opposite, a rising number of fringes in the pattern.

Moreover, the “interference spectroscopy” paves the way for further analysis. In addition to position, velocity and acceleration also information on refractive index, reflectivity or surface tilts can be derived from the signals in real time.



The fiber-based set-up is completed by an internal reference cavity. The graph shows the signal of the internal reference with adjusted wavelength change in color and the two cavities in black. Analyzing the interference pattern, a lot of information is revealed about the measured cavity.



The interference patterns show a Doppler-like effect over the up and down sweep of the laser wavelength. First graph I_1 shows a constant negative velocity of the target, the second one I_2 a constant movement in the other direction.

quDIS - Sensor Head Portfolio

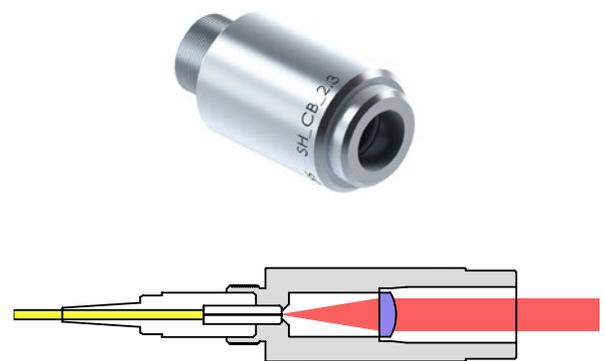
Applications require different requirements for collimation, focusing and beam profile, depending on their reflecting targets.

All applications require different collimation, focusing and beam profile requirements depending on the reflective target. The shaping of the laser beam is achieved by different sensor heads. All these sensor heads for quDIS are based on optical fibers established in the telecommunication market. In addition to focusing heads and collimators, quTools also develops special heads for applications in harsh environments, such as vacuum or low temperatures.

Collimated Sensor Heads

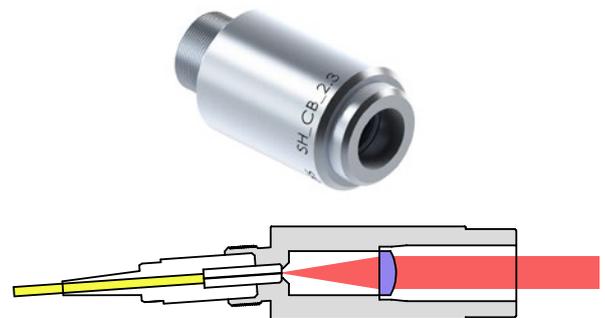
CB 2.3 - Collimated beam, standard sensor head

Interferometer type	Fabry-Pérot
Working range	20 ... 5000 mm
Spot size ($2w_0$)	2.3 mm
Fiber connectors	FC/PC Mating Sleeves
Dimensions	12.7 mm, length 30 mm
Targets	mirror, retroreflector



CB 2.3 APC - Collimated beam without reference reflex for individual usage

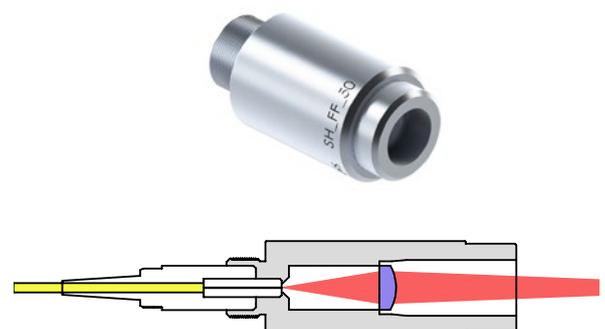
Interferometer type	none - only beam shaping
Working range	20 ... 5000 mm
Spot size ($2w_0$)	2.3 mm
Fiber connectors	FC/APC Mating Sleeves
Dimensions	12.7 mm, length 30 mm
Targets	mirror, retroreflector



Focused Sensor Heads

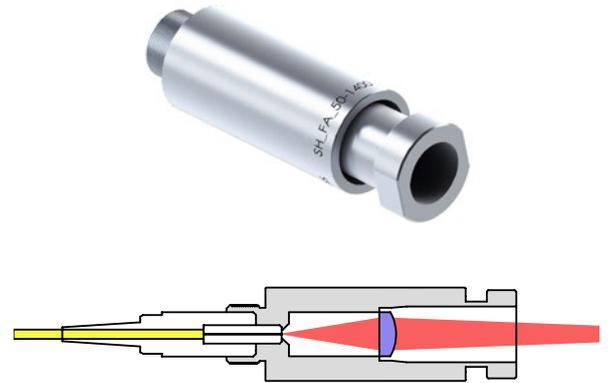
FF 50 - Focused beam with fixed focal length

Interferometer type	Fabry-Pérot
Focal length	50 mm
Spot size ($2w_0$)	0.5 mm
Fiber connectors	FC/PC Mating Sleeves
Dimensions	12.7 mm, length 30 mm
Targets	mirror, high reflective surface



FA 50-1400 - Focused beam with adjustable focal length

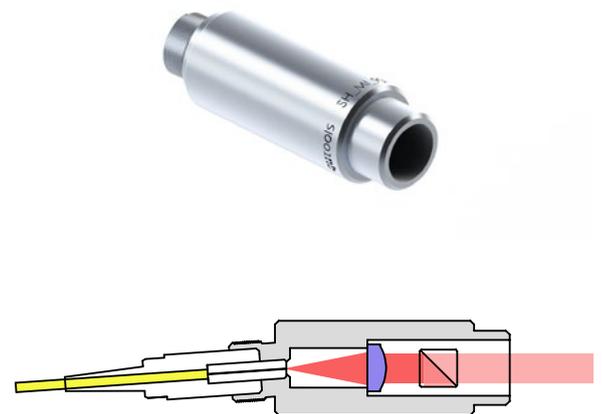
Interferometer type	Fabry-Pérot
Focal length	50 ... 1400 mm
Spot size ($2w_0$)	< 1 mm
Fiber connectors	FC/PC Mating Sleeves
Dimensions	12.7 mm, length 30 mm
Targets	mirror, high reflective surface



Michelson Sensor Heads

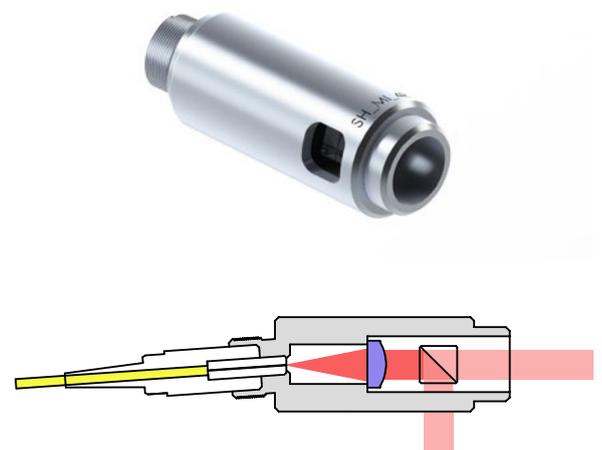
MI SR50:50 - Michelson sensor head with different splitting ratios SR for different reflecting targets

Interferometer type	Michelson
Working range	20 ... 5000 mm
Spot size ($2w_0$)	2.3 mm
Beam splitting ratio	50:50, 80:20, 90:10
Fiber connectors	FC/APC Mating Sleeves
Dimensions	12.7 mm, length 30 mm
Targets	mirror, retroreflector



MI OR SR50:50 - Michelson sensor head with open reference and different splitting ratios SR

Interferometer type	Michelson
Working range	20 ... 5000 mm
Spot size ($2w_0$)	2.3 mm
Reference reflectivity	> 90%
Fiber connectors	FC/APC Mating Sleeves
Dimensions	12.7 mm, length 30 mm
Targets	mirror, high reflective surface

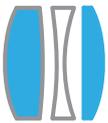


Company Portrait qutools

Highly individualized tasks can be mastered as we have flat hierarchy and a great spectrum which covers all competences.

We are convinced of all of our products – and our costumers rely on our long-term development competences, our understanding of science and honest consultation on highest level. All products can be customized as we always focus on optimizing the device for your application. We have special experience and know-how on the following fields:

Optics



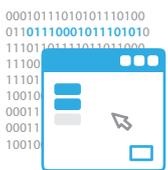
In 2005 qutools started building demonstrators for entangled photons, fiber optics and single photon sources. Since then we gained further experience on many fields like interferometric length measurements, color centers in diamond, quantum dots or fluorescence spectroscopy.

Electronics



Our competence in analogue- and mixed-signal-electronics enables ultra-fast time measurements on the picosecond scale. Moreover, individual interfaces and ports for communication can be realized on demand.

Software

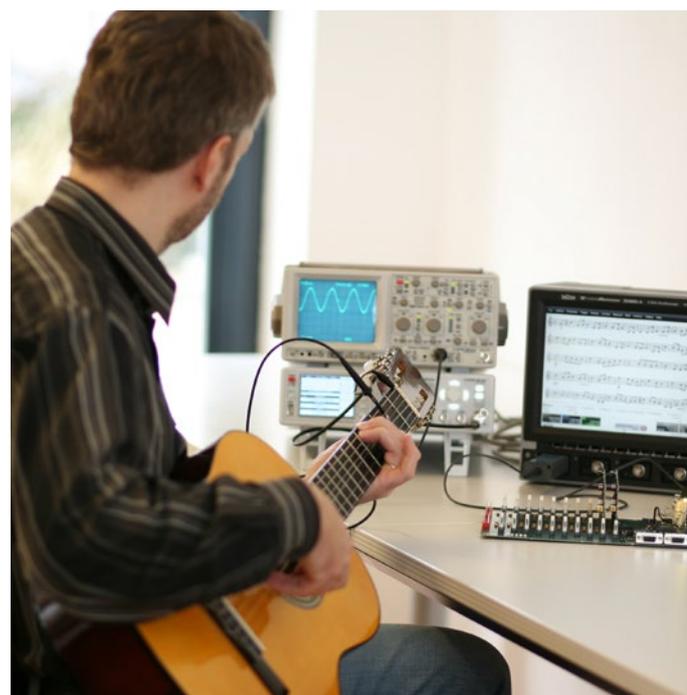


We provide and develop software for data collection and analysis as well as the GUI for all operating systems. Even atomic force microscopes can be controlled via tablet app.

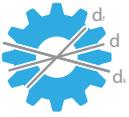
Embedded Software



More than 15 years of experience in programming logic for algorithmic, control technology and analysis in ultra-fast time detection, microscopy and interferometry.



Construction



Our designers created designs ranging from simple mirror mounts up to complex mechanics of movable components. We use those for all of our products. An example is our Quantenkoffer, a science kit for quantum physics with more than 400 milled aluminum parts ensuring stability and all mechanical interactions.

Production



The production assembly of high-quality parts is also done by ourselves. Drilling and cutting of aluminum, steel, stainless steel, non-ferrous metals and plastics allows for realization all possible designs. The final assembly of all optical, electric and mechanical parts is also performed in-house.

Team



qutools and our partners can cover all desired abilities as physicists, developers, designers, electronics- and software-specialists are employed. Our own production completes the portfolio. Therefore, we can do everything from scratch, starting with patents and building prototypes and ending with serial production.

Company network for competency



qutools
Picometer or picosecond – high precision devices for research, teaching and industry.



N-Hands
Specialized in complex electronic- and embedded-systems, control engineering and software.



MIT - Made in Thüringen
CNC drilling, milling and assembly of high quality parts for prototypes, small and medium series.



 **qutools and N nHands**
Darmstadt, Idstein and Munich, Germany

 **MIT - Made in Thüringen**
Meiningen, Germany

Further products

Precision measurement technique for research and industry,
Quantum physics demonstrators for teaching

Teaching quantum physics

The **Quantenkoffer** is a science kit for a multitude of experiments with single photons or entangled photon pairs for experimenters of any age.

Our entanglement demonstrator **quED** is the equivalent for university. Experiments ranging from particle-wave-dualism to quantum cryptography can be performed.

The quantum diamond magnetometer **quNV** is a science kit based on nitrogen-vacancy centers in diamonds. The world of quanta can be discovered from spin manipulation up to single qubit control.



Time tagging for research and industry

The **quTAG** family are precise time tagging devices with picosecond resolution. Next to time-correlated single photon counting (TCSPC), Lidar and characterization of single photon sources it is used for many applications in time resolved fluorescence microscopy like FLIM, FCS and FRET.



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