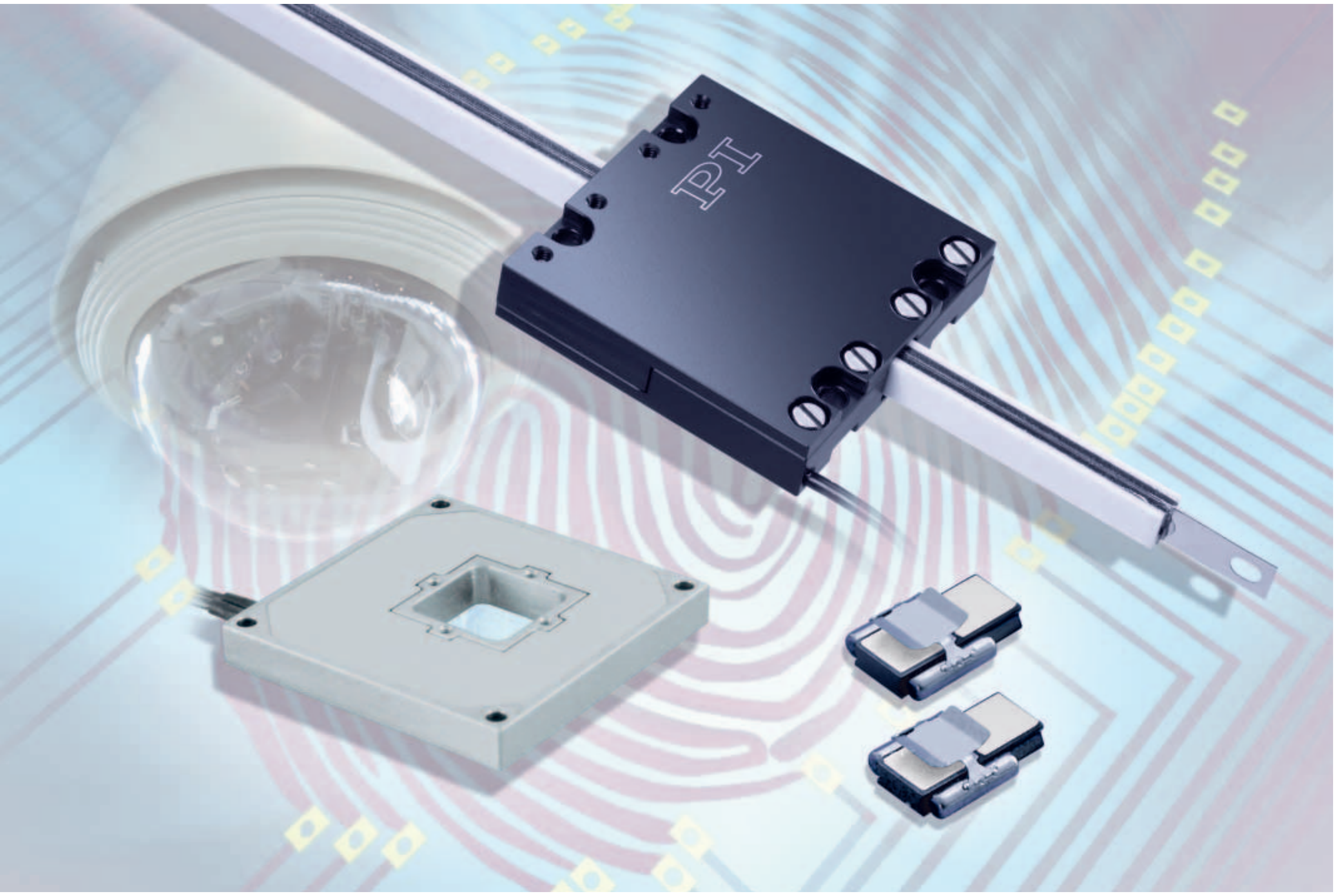
Piezo • Nano • Positioning

Resolution Enhancement of Imaging Chips with Piezo Technology

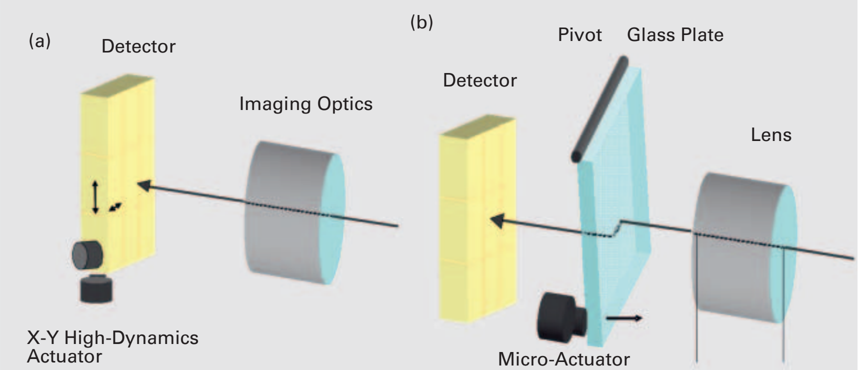


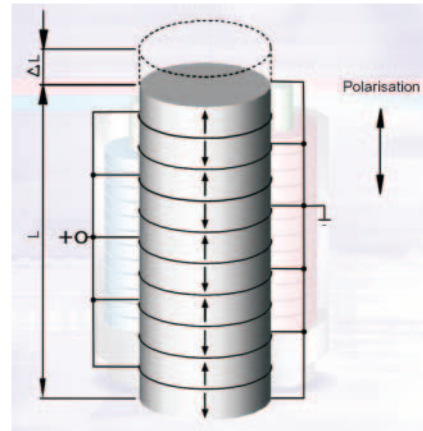
Pixel Sub-Stepping, Vibration Cancellation

Increasing the Resolution of Sensor Chips

Applications of Pixel Sub-Stepping

Schematic diagram for moving a sensor chip (a) or the imaging beam onto the sensor (b).





The inverse piezoelectric effect: Piezoceramic discs expand when an electric field is applied, causing the actuator to move.

Optical Resolution in Imaging

Camera systems and scanners must have high resolutions. This creates difficulties for all applications where low light intensity means neither the resolution of the chip nor the exposure time for changing or moving objects can be freely chosen. Typical applications are fluorescence microscopy, white-light interferometry (OCT in medical technology or general surface structural analysis), or surveillance cameras and cameras for aerial photography. Further fields of application are scanners used to digitize data, e.g. for plans, technical drawings etc. Pixel sub-stepping makes it possible to significantly improve the resolution with relatively little effort.

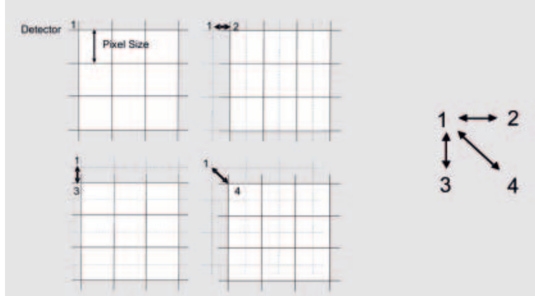
Restrictions of High-Resolution Chips

The resolution of digital recording methods is determined by the number of imaging pixels of a CCD or CMOS chip, for example. If one wishes to increase the resolution, the number of imaging pixels must be increased.

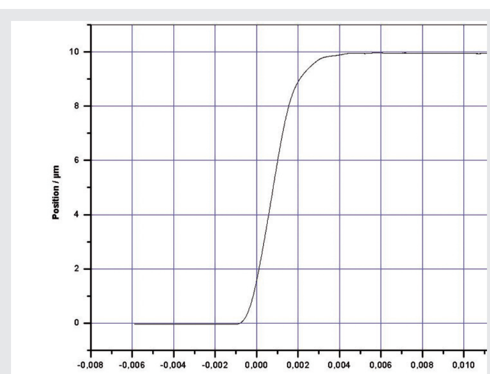
There are basically two ways of doing this, both of which are relatively expensive and require a lot of effort: Either one increases the size of the recording chip or one decreases the size of the pixel. The first case requires a larger recording device and also different imaging optics. In the second case, the light sensitivity decreases with the pixel size. This reduces the separation between image signal and noise signal which, in the end, may even decrease the image quality in spite of the higher resolution.

Super-Resolution with Pixel Sub-Stepping

With so-called pixel sub-stepping, the recording area is moved on predefined paths with a defined frequency. This "dithering", where the travel is less than the size of a pixel, causes the pixel to be exposed several times on the recording area, producing a virtual "pixel multiplier" which can significantly improve the resolution. The rest is data processing. The various images produced in this way are subsequently "superimposed" to form the final, high-resolution image, a process also known as "super resolution".



Moving the detector chip by half a pixel width in the horizontal, vertical and diagonal directions produces 4 different images which can be processed to form an image with increased resolution.



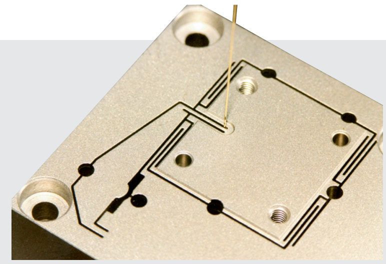
Settling behavior of a piezo flexure stage: 10 µm in < msec


Aerial photograph of a building (PI Ceramic): Improved resolution allows better recognition of details.

Piezo Actuators: Fast, Reliable and Easy to Integrate

Piezo actuators convert electrical energy directly into mechanical energy and vice versa. Travel ranges of up to one millimeter or so can typically be achieved with resolutions down to the nanometer range, and high dynamics with scanning frequencies of up to several kilohertz are also achievable. Piezo actuators are free of wear and maintenance; no lubrication are required; they are non-magnetic and vacuum compatible.

Integrated into flexure arrangements they can provide multi-axis motion e.g. to be integrated in high-end custom cameras for image stabilization or resolution enhancement based on the pixel sub-stepping principle.

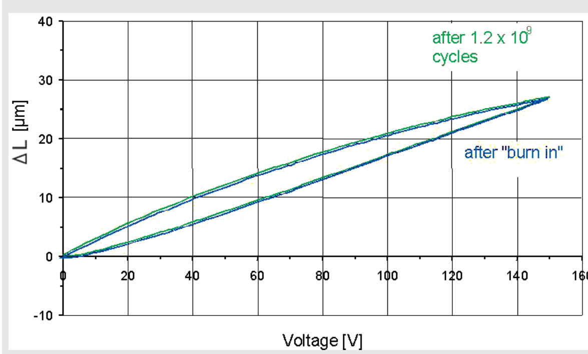

Wire-EDM cutting process provides highest-accuracy flexure guiding systems in compact scanning stages and can also be applied to move microscope objective lenses quickly in the nanometer realm. Applications: 3D imaging, fast autofocus.

Piezo Scanners

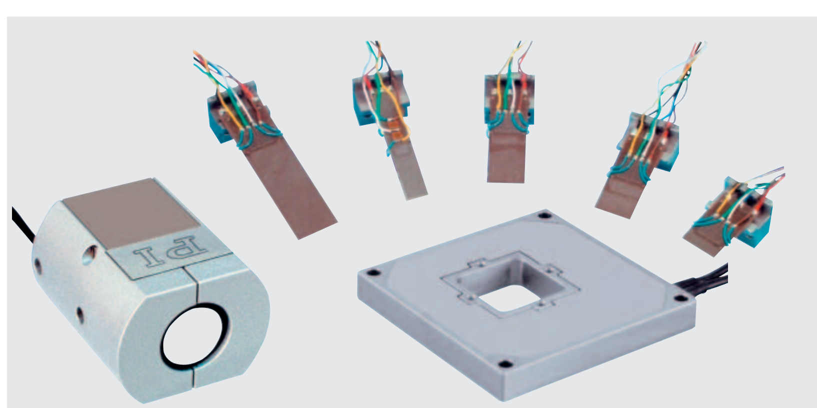
For Pixel Sub-Stepping

Since this method is based on motion, a drive is required which meets all the performance criteria for mechanical precision and lifetime. The drives differ, with the application, but they all have crucial features in common: The motion of the sensor chips must be reproducible in two dimensions with sufficient linearity. The travel is of the order of the pixel size, i.e. a few tens of micrometers or less.

The dynamics required range from a few hertz for still images up to the kilohertz range for video recordings. The basic requirement for high-resolution biometric CCD/CMOS scanners used to identify persons by their fingerprints is a scanning frequency of between 1 and 5 Hz at a response time of less than 1 ms, for example. The travel for the drives is between 5 µm and 15 µm with a precision of better than 0.5 µm. The drive solution must occupy the smallest possible mounting space.



Reliability: Dynamic test series with PICMA® piezo actuators. Total number of cycles 4.0 x 10^9 cycles; 116 Hz sinusoidal control (1.0 x 10^7 cycles per day), 100 V unipolar operating voltage, 15 MPa preloading. Control measurements after each series of 10^9 cycles.


Improved resolution for cameras and scanners. Piezo drives are the driving force behind pixel sub-stepping: Piezo tip/tilt mirrors, low cost bender type actuators and XY scanners (from left to right).

Ultrasonic, High-Speed Precision Ceramic Actuators

Compact motors and motion sub-assemblies

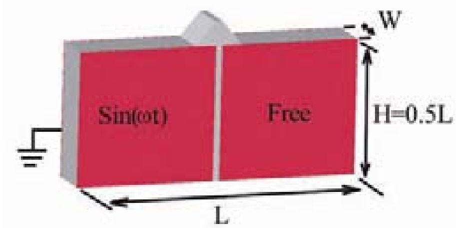
Ultrasonic linear motors are another way to achieve fast and precise motion in a compact package. Ultrasonic oscillations of a piezo ceramic plate are transferred to linear motion along one or two frictions bars attached to the moving part of a mechanical setup.

At the heart of the system is a monolithic piezoceramic plate, segmented by two electrodes. Depending on the desired direction of motion, the left or right electrode of the piezoceramic plate is excited to produce high-frequency eigenmode oscillations at tens to hundreds of kilohertz.

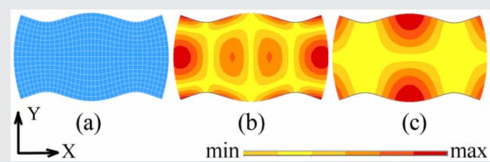
With each oscillatory cycle, the mechanics executes a step of a few nanometers; the macroscopic result is smooth motion with a virtually unlimited travel range. State-of-the-art ultrasonic motors can produce accelerations to 5 g and velocities to 500 mm/s.

Simple Integration

The integration of ultrasonic piezo systems in a positioning application is simple, because the moving slider for load coupling and the piezo ceramic stator are available fully assembled on a PCB driver board running on only 12 VDC.

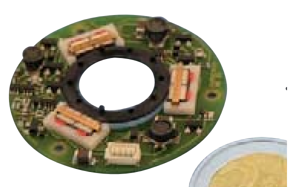


State-of-the-art ultrasonic motors are based on a simple construction allowing for the design of low-cost drive units and extremely compact, high-speed micro-positioning stages. An alumina friction tip (pusher) attached to the plate moves along an inclined linear path at the eigenmode frequency.

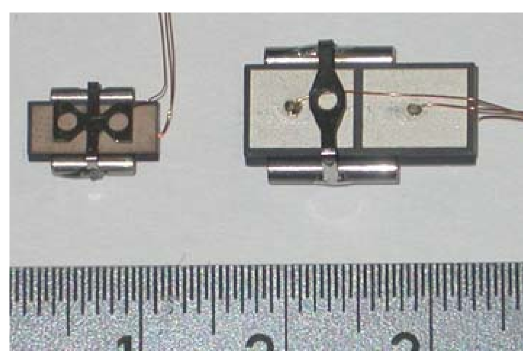


E(3,1) Modes in a rectangular piezoceramic plate. (a) Deformation; (b) Length oscillation velocity distribution (X-direction); (c) height oscillation velocity distribution (Y-direction); (FEM simulation).

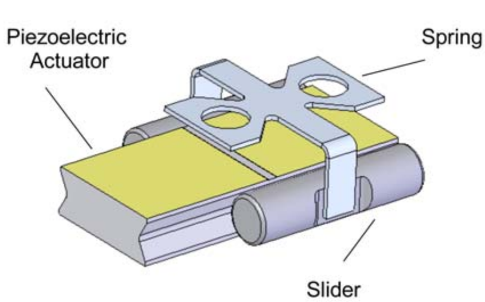
Sub-thumb-sized: a U-155 integrated piezo linearmotor for micro mechanic systems, with control electronics. The silver spring doubles as a moving carriage.



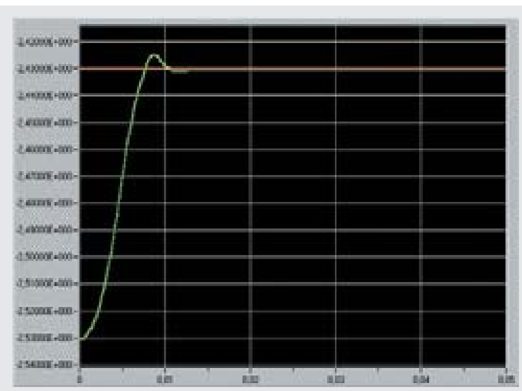
Centerless rotary motor based on 3 ultrasonic actuators.



Two minature motors, with piezoceramic stator plates as small as 9x4x1.5mm. Application: autofocus and miniature zoom lenses.



CAD drawing of a novel miniature ultrasonic motor. The motor has the simplest possible design, comprising only 4 parts -- an ultrasonic piezoelectric resonator and two lateral sliders pressed against it by a spring doubling as moving carriage.
The load to be moved is mounted directly on the carriage



Settling behavior of a PILine® M-663 linear stage, 100 µm step. A stable position to within 0.1 µm can be reached in only 10 ms

The current edition of the main PI catalog "Piezo – Nano – Positioning: Inspirations 2009" is now available. The catalog demonstrates the broad PI product range and new technical solutions in the areas of:

Nanopositioning systems/scanning systems
Fast scanning stages for microscopy
Piezo actuators
Piezo motors
Piezo controllers
Motorized micro-translation stages and linear actuators
Motor controllers
Six-axis adjustment systems, hexapods

For more information, about piezo-ceramic materials and elements see the PI Ceramic catalog or visit their website (www.piceramic.de)

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