Piezoelectric motors move miniaturization forward

Ceramic micromotors are moving out of the lab and into consumer electronics

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Ultrasonic piezoelectric motors have been around for more than 30 years. With small size and high precision, they are valued nanopositioning tools for laboratory applications from laser and optical alignment to biomedical research.

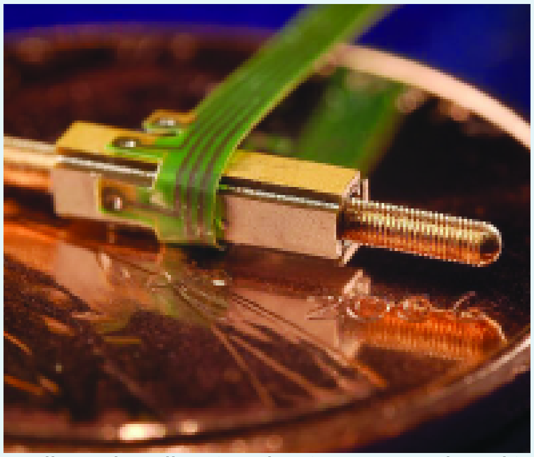
Recent innovations have produced piezoelectric motors with greater robustness, improved manufacturability, and even smaller size. As a result, these tiny ceramic motors have caught the attention of consumer product designers, opening new avenues to pack more features into tinier products.

Mobile phone cameras

The mobile phone camera is shaping up to be the "killer application" for piezo motors. While the demand for digital still cameras has leveled off at about 100 million per year, the world market for phone cameras is forecast to grow from 500 million in 2005 to 900 million by 2009. The phone camera is fast becoming the way a mobile society takes and shares pictures.

What's needed is better image quality. The wireless industry is betting that handsets with higher image resolution will increase consumption of services for photo transmission, sharing, and printing. In fact, according to M:Metrics, 44.3% of subscribers who own camera phones with better than 1-Mpixel resolution actually transmitted a picture over the network. Only 30.5% of subscribers with lower-resolution camera phones transmitted a picture.

Micron, OmniVision, Toshiba, and others have introduced 3-Mpixel CMOS image sensors for high-end phone cameras, with 5-Mpixel sensors in the works. Capturing good images from these high-resolution sensors requires outstanding optics coupled with auto focus and optical zoom. And that's where the piezo motor comes in.



Smaller and smaller piezoelectric motors, such as this SQUIGGLE motor from New Scale, are opening up new applications in consumer electronic devices.

Limits of traditional technologies

A motor for phone cameras must have micrometer precision and low battery-power consumption. It must be priced at less than $2 and not break when the phone is dropped on a concrete floor. Above all, it must be tiny enough to fit into the most sleek, slim, and popular phones.

Several motion technologies for camera optics are presented in the *table*. Voice coils, liquid lenses, and piezoelectric bimorph actuators move over a small range that is sufficient for auto focus but not optical zoom.

Auto focus provides better images than stationary optics do, and is desirable with image sensors of 2 Mpixels or greater. Optical zoom improves image quality even further, and is desirable with image sensors of 3 Mpixels or greater.

Piezo motors and stepper motors deliver the required range of motion for zoom, which is 10 times that of auto focus. A camera with zoom must also have autofocus, which requires two motors per camera. Using the same motion technology for both functions optimizes simplicity and cost.

Electromagnetic stepper motors are the incumbent solution for most optical zoom mechanisms in today's larger still cameras. However, phone cameras need to be one-tenth the size of the smallest digital still camera. It is not practical to make stepper motors this small.

As the diameter of a stepper motor shrinks, the speed increases while less torque is available to overcome friction from gears and slides. Efficiency, accuracy, and reliability drop sharply. Below about 6 mm diameter, piezo motors show a significant efficiency advantage.

Piezo motors for phone cameras

Two types of piezo motors have been commercialized for mobile camera optical zoom and auto focus. Both use the characteristic of piezoelectric ceramic materials (PZTs) to expand or bend when a voltage is applied. Piezo motors multiply this small bending motion by applying high-frequency electrical signals to the PZTs, creating ultrasonic vibrations that add together to create continuous linear motion.

Technologies for Mobile Phone Camera Optics

Parameter	Auto focus and optical zoom		Auto focus only		
	Piezoelectric Ultrasonic Motor	Electromagnetic Stepper Motor	Voice Coil Actuator	Liquid Lens	Piezoelectric Bimorph Actuator
Motion Module Size	Small	Large	Small	Medium	Small
Complexity and Number of Parts	Low	High	Low	Low	Low
Robustness to Temp and Shock	Good	Marginal	Poor	Poor	Poor
Motion Precision	0.1 to 1 µm	10 µm	Poor	N/A	1 to 10 µm
Position Sensor Required	Yes	No	No	No	No
Power Consumption	Low	High	High	Low	Low

In the "side-drive" type of piezo motor, the bending vibration of the PZTs is used to push a slider along a guide, similar to the motion of a fingertip on the scroll button of a mouse. This design requires a spring load to hold the high-friction stator tip of the PZT against the slider.

The slider moves on a linear bearing. The push force (or holding force) of the motor is limited by the coefficient of friction between the stator tip and the slider. Friction of the slider bearing works against the motor driving force, and "stick-slip" in the slider movement makes it difficult to move precisely in small steps.

In the "direct-drive" design patented by New Scale, four PZT plates are bonded to a rectangular metal tube that has a matching threaded screw inside. The bending motion of the PZTs is synchronized to make the tube vibrate in an orbital fashion, causing the screw to rotate and translate.

Thread friction performs useful work by converting rotation to linear motion, providing a mechanical advantage that multiplies output force and resolution. Because the metal threads, not the ceramic PZT plates, support the load, this direct-drive motor has higher push force and withstands higher shock loads than other piezoelectric devices.

Systems integration with piezo motors

Piezo motors require a position sensor and closed-loop control to produce repeatable steps. In a camera assembly, lens focus may be measured by the CMOS image sensor or by using magnetic, optical or potentiometer devices. A number of manufacturers are incorporating piezo motors and position sensors into commercial OEM camera assemblies for the mobile phone market.

Driving a piezo motor requires ultrasonic ac signals at 100 to 200 kHz, corresponding to the resonant frequency of the motor. The required voltage ranges from 3 to 33 V, depending on the motor type. Single-chip ASIC drivers for piezo motors are commercially available from several IC companies. These drive chips are powered directly by the phone battery and deliver the required output voltage and frequency to the motor.