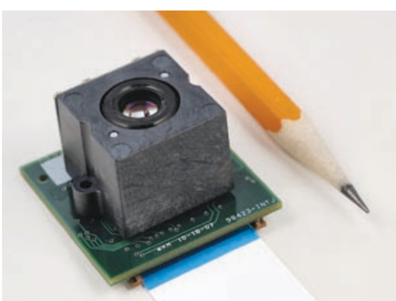
Focus: Industrial strength, smartphone sensibilities

Lens motion technologies developed for phone cameras make their way into small embedded imaging systems for tough jobs

BY DAVID HENDERSON
Chief Technical Officer
New Scale Technologies
www.newscaletech.com

Smartphone cameras are fast becoming "the only camera you need" for consumer photo and video. It's not just about megapixels: much of the quality improvement stems from advanced optics and tiny new motion systems for precision autofocus.



New Scale's piezo lens focus mechanism on a board camera.

Autofocus is more than a convenience. It allows larger apertures (for more light on the sensor), compensating for the resulting lower f-number and reduced depth-of-field by ensuring that the image plane is precisely aligned on the sensor's surface.

Given the capabilities of these tiny smartphone cameras, it's no surprise that engineers want to put them in the nonconsumer products they're designing. The trends are the same — both consumers and industrial users want smaller devices with higher-resolution images and more powerful features.

Unfortunately, even the most impressive phone cameras are not sufficient for most nonconsumer applications. While image quality does matter in a phone, it yields to demands such as a super-thin form factor, low cost, and high-volume manufacturability. In nonconsumer applications, the quality of the image and the detail of the information it contains are not so negotiable — while an iPhone app can perform facial recognition, you may not want to rely on it for access to your bank account.

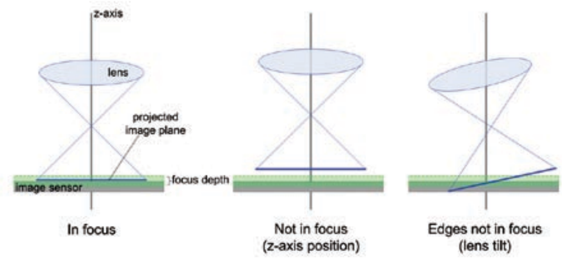


Fig. 1: The depth at which the entire image is in focus is reduced with increasing tilt: When the lens is positioned so that the center of the image is focused on the sensor, one edge of the lens will be further away from the sensor and the opposite edge of the lens will be closer to it.

Nonetheless, much of the technology developed for today's smartphone cameras is being extended for use in nonconsumer applications.

VCMs in phone cameras

Compact and cheap, voice-coil motors (VCMs) were widely used for lens motion in early phone cameras. With image sensors up to 5 Mpixels, VCM motion precision is good enough. However, as phone camera manufacturers push to improve image quality — employing higher-resolution sensors and larger apertures — the need for greater precision in lens motion becomes clear. Precision lens motion has two parts:

1. Positioning of the lens along the z-axis, perpendicular to the sensor. The need for precision increases with decreasing f-number, which lets in more light for better sensor performance but decreases the depth of focus.

2. Lens motion without tilt. Lens tilt decreases depth of focus and leads to blurring on the edges of the image (see *Fig. 1*).

In a VCM-based focus system, a spring or flexure supports a lens assembly that "floats" in a lens barrel (see *Fig. 2*). An electric coil around the lens assembly and permanent magnets in the housing create a closed magnetic flux path. Applying current to the coil generates a proportional Lorentz force along the z-axis. The spring bends and the lens moves along the z-axis with position resolution of about 5 µm. Low spring stiffness leads to overshoot, oscillations, and settling times up to 100 ms. Constant current and power are needed to maintain a position.

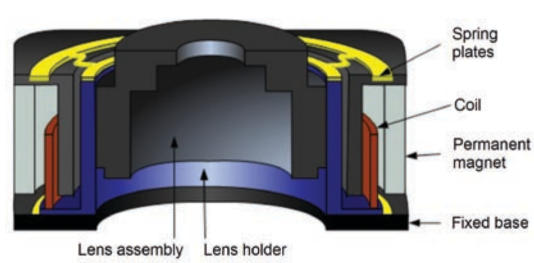


Fig. 2: In a VCM, the spring's performance is key; low spring stiffness leads to overshoot, oscillations, and settling times as long as 100 ms.

The reliance on springs also leads to significant lens tilt; greater than 0.3 degrees. Gravity induces tilt if the camera is used in any nonvertical position. Tilt control can be added at increased cost and size — negating the two key advantages of the VCM.

The use of springs also limits lens mass to about 0.2 g, and lens travel to about 0.3 mm.

Piezo for phone cameras

Phone camera designers have begun using new piezoelectric focus systems in place of VCMs, to improve both z-axis position resolution and tilt. These enable higher-resolution photo and video in the same tiny form factors.

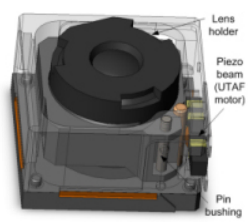


Fig. 3: UTAF piezo lens motion system for phone cameras is thinner than a VCM system and offers better position resolution and lower lens tilt.

In a piezoelectric system, electrical signals produce minute bending motions in a piezoelectric element. Various mechanisms are employed to convert these tiny motions into long-range lens travel.

For example, for phone camera applications, New Scale Technologies has licensed its Ultra-Thin Auto-Focus (UTAF) modules in which an ultrasonically vibrating piezoelectric beam is placed in direct contact with the lens assembly holder (see *Fig. 3*). The minute motions of the piezo element push the lens smoothly along the z-axis with 1-µm position resolution, a 5x improvement over VCMs.

A pin bushing guides the lens and limits tilt to less than 0.1°, a greater than 3x improvement over VCMs.

The UTAF was designed to phone camera specifications: light lenses (up to 0.25 g), very thin form factors, very low power consumption, and high-volume manufacturability at low cost. It has a thinner profile than a VCM and an equivalent x-y footprint. Other piezo focus solutions in development can move lenses up to 0.5 g with size similar to the UTAF system.

A nonconsumer focus

While optical requirements vary, nonconsumer imaging systems almost always require lens assemblies with greater mass than the 0.2 g that VCMs can support. Reasons include the need for larger lens diameters, larger apertures, and heavier materials such as glass for high clarity or transmission at specific wavelengths. They usually require longer lens travel (stroke) as well.

Unlike VCMs, piezo solutions can be scaled to accommodate greater lens mass and longer travel. At the same time, piezo technology keeps overall camera size to a minimum — usually only millimeters larger than the lens assembly itself.

For example, the M3-F focus module supports lens assemblies up to 5 g — 25 times heavier than VCMs can support. It offers lens travel of 1.5 mm or more, compared to 0.3 mm for a VCM.

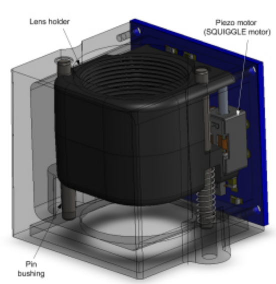


Fig. 4: M3-F piezo lens motion system maintains the benefits of high-position resolution, low lens tilt, and small size, while supporting the longer travel and greater lens mass requirements of most nonconsumer imaging applications.

The M3-F incorporates a long-travel piezoelectric Squiggle motor to move the lens barrel in a housing (see *Fig. 4*). Ultrasonic vibrations of the piezoelectric elements rotate a screw and cause it to translate along the axis of the motor, parallel to the z-axis of the lens barrel. The screw tip is directly coupled to the lens assembly, moving it along the lens barrel with a resolution of 0.5 µm. As with the UTAF, a pin bushing limits tilt to less than 0.1 degree.

For nonconsumer applications, there is additional value in higher position resolution and low tilt offered by piezo systems. For example, for facial or iris scanning security systems, greater depth of focus results in systems that are more "forgiving" about the location of the subject. Scans are easier and faster, reducing intrusiveness and annoyance of biometric security systems.

On the other hand, in medical diagnostics, trends are toward smaller and thinner sample volumes (for example, microfluidics), so the depth of focus of the optics must be moved to align precisely with the sample. Finally, in many machine-vision/inspection—and medical applications as well—the surface to be imaged is not perfectly flat. So low lens tilt and good depth of focus are necessary to provide a sharp image across the entire sensor.

Hysteresis vs. repeatability

VCMs are open-loop systems, with significant hysteresis that is a function of travel and therefore worse with longer stroke. Both the UTAF and M3-F piezo lens motion systems are closed-loop systems, with magnetic position sensor and motor drive ASIC integrated in the module. There is no external controller board, so total system size remains small.

As closed-loop systems they do not have hysteresis. Instead, they have bi-directional repeatability that is fixed over any travel length. For the M3-F, this is better than ±20 µm over the full travel range. Unidirectional repeatability is ±5 µm. Additional benefits include fast response and fast settling time, and stable high-stiffness holding force without oscillation.

A comparison of the systems discussed in this article is shown in *Table 1.* Just as piezo compact focus systems helped drive advances in phone cameras, they are set to add new capability in nonconsumer imaging applications.

Table 1: Comparison of focus system types

Focus system type	Lens mass (g)	Stroke (mm)	Resolution (µm)	Hysteresis	Dynamic tilt (degrees)	Dimensions (mm)
VCM (electromechanical)	0.2	0.3	5	yes	± 0.3	8.5 x 8.5 x 5
UTAF (piezo)	0.25	0.4	1	no	± 0.1	8.5 x 8.5 x 3.8
M3-F (piezo)	5	≥1.5	0.5	no	± 0.1	20 x 22 x 16