Presented at ACTUATOR 2012 , www.actuator.de
Bremen, Germany, June 2012

Micro-Scale Smart Actuator Modules for Imaging Systems

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Micro-scale smart actuator modules have recently been commercialized for imaging systems. These products provide a complete motion solution that requires only battery power (3.3 VDC) and high-level digital commands (I^2C or SPI) to produce precise step and velocity control. Extreme miniaturization is achieved using the latest innovations in piezo motors, drive electronics, position sensors, and microprocessors with embedded firmware. One “killer application” for micro motion is imaging and this market is projected to grow from 1.7 billion image capture devices in 2011 to 2.8 billion in 2015. New Scale Technologies, Inc. has commercialized the UTAF® (Ultra Thin Auto Focus) and M3-F (Micro Mechatronics Module) systems for micro imaging applications. The UTAF module is used in mobile phone cameras with movement less than 300 micrometers and lens mass less than 0.5 grams. The M3-F module is used for non-consumer applications such as iris imaging, facial recognition and medical devices with movement greater than 1.5 millimeters and lens mass up to 5 grams. These new smart actuators enable “plug and play” integration, rapid prototyping and faster times to market.

Keywords: piezoelectric, ultrasonic, motor, smart actuator, optical focus, imaging

Introduction

Micro-scale smart actuator modules have recently been commercialized for imaging systems. These products provide a complete motion solution in a small module that easily fits on your finger tip and requires only battery power (3.3 VDC) and high-level digital commands (I^2C or SPI) to produce precise step and velocity control. Extreme miniaturization is achieved using the latest innovations in motors, drive electronics, position sensors, and microprocessors with control embedded software.

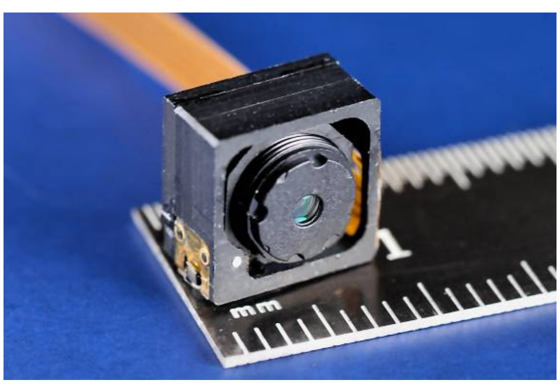

Fig. 1: *UTAF Actuator Module*

The “killer application” for micro motion is imaging systems (cameras) where micrometer scale optical linear movements are needed for automated focus. The most famous applications are in mobile phone cameras and other consumer electronic products and more than 1.3 billion were produced in 2011. Non-consumer imaging applications are also growing fast and are taking advantage of the innovations in mobile devices. These new application include medical diagnostic instruments, biometric identification systems and machine vision modules. The world-wide market for imaging systems is projected to grow from 1.7 billion image capture devices in 2011 to 2.8 billion units in 2015.

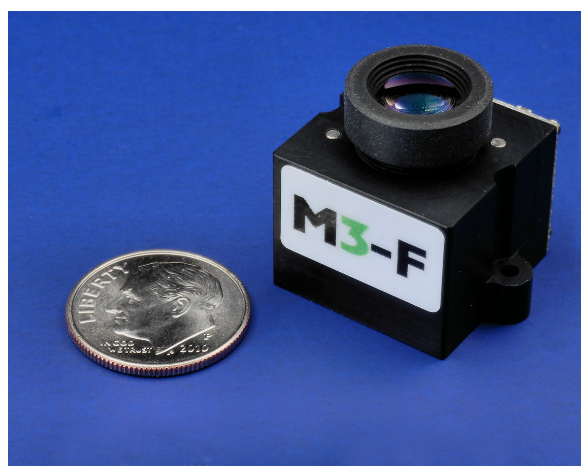

Fig.2: *M3-F Focus Module*

In 2008, New Scale introduced the UTAF® (Ultra Thin Auto Focus) actuator module [1] for use in consumer electronic products including smart phone cameras with greater than 8 mega pixel image sensors. This tiny assembly integrates a piezoelectric ultrasonic motor, NSD2101 drive IC, AS5510 digital Hall position sensor IC, low-friction preload mechanism, precise lens guide, and advanced Smart Step™ control algorithm.

The extreme miniaturization of UTAF for mobile devices has inspired product designers to seek similarly small solutions for non-consumer devices. In 2011 New Scale introduced the M3-F (Micro Mechatronics Module) for no-consumer imaging products such as iris imaging, facial recognition, eye tracking and machine vision. The M3-F is larger than the UTAF module because it must move a lens that is 10 times heavier (5 grams) with at least 50 times more stroke (1.5 millimeters). In addition, the M3-F carriage and housing are compatible with larger format image sensors and optics. This system integrates a SQUIGGLE® [2] piezoelectric ultrasonic motor [3], NSD2101 driver IC, NDE5310 linear Hall encoder, pin-bushing guide mechanism, microprocessor and embedded PID control software. This table compares the M3-F and UTAF features.

	Smart Actuator Module	
Parameters	**M3-F**	**UTAF**
Module		
W x L	20 X 22 mm	8.5 X 8.5 mm
H	16 mm	3.8 mm
Lens		
Diameter	M12 or M8	M-6 or M-6.5
Mass	> 5 grams	< 0.5 grams
Optical Format	1/3" to 1/1.8"	1/4" to 1/3"
Stroke	> 1.5 mm	< 300 µm
Speed	5 mm/sec	5-10 mm/sec
Resolution	0.5 µm	1 µm
CAF Power	150 mW	10 mW
Lens Tilt	0.15 deg	< 0.1 deg
Step Time for 30 µm	< 20 msec	< 10 msec
Piezo Motor	Squiggle***	UTAF**
Driver IC	NSD2101*	NSD2101*
Position Sensor IC	NSE5310*	AS5510*

* Available from austriamicrosystems.
** Available from TDK-EPC (EPCOS).
*** Available from New Scale Technologies

SQUIGGLE Piezo Motor

The SQUIGGLE piezoelectric motor was first introduced in 2004 and uses a threaded screw and mating nut. The nut ultrasonically vibrates and causes the screw to turn. The tip of the screw is used to generate linear motion with high force and sub-micrometer resolution. Since 2004 the Squiggle motor has been continuously reduced in size, power, voltage and cost. The latest version is 100 times smaller by volume than the first generation motors. Four multi-layer piezoelectric plates are bonded to a rectangular nut and the motor operates directly from a 3 volt battery without the need for a voltage boost.

Fig. 3: *Smallest SQUIGGLE motor with NSD-2101 ASIC Driver*

NSD2101 Driver IC

The NSD2101 driver was developed in cooperation with austriamicrosystems. This ASIC operates directly from the typical battery voltage and provides a complete 2-channel full-bridge drive solution for operating the SQUIGGLE motor. In a wafer level chip scale package (WLCSP) the dimensions are only1.8 X 1.8 X 0.6 mm. The NSD2101 integrates several on-chip proprietary and patented features:

- Clock frequency generation
- The input voltage range is 2.3 to 5.5 volts.
- Automatic drive frequency adjustment to match the SQUIGGLE motor resonant frequency of approximately 170 kHz.
- Speed control using:
  - Pulse Width Modulated "PWM" speed control which adjusts driving waveforms by adjusting the percentage of ON (duty cycle).
  - "Hybrid" speed control adjusts the ratio of full-bridge to half-bridge motor cycles to adjust the effective voltage from $2V_{DD}$ to V_{DD}.

- Charge control optimizes the full-bridge switch timing to reduce system power by 40%.
- I^2C digital control.

NSE5310 Position Sensor

The NSE5310 is a new system-on-a-chip magnetic linear position sensor with sub-micrometer precision that has been developed in cooperation with austriamicrosystems. This tiny sensor is the perfect compliment to the Squiggle motor. It has many millimeters of measurement range, 0.5 micrometer resolution and a thickness less than 2 mm.

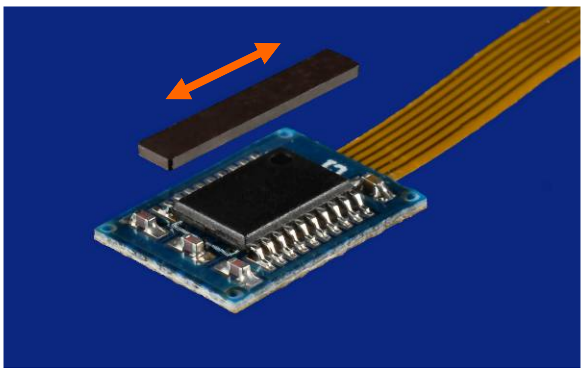

Fig. 4: *NSE5310 Hall Array Position Sensor and Multi-Pole Magnet*

This linear sensor uses an array of Hall magnetic sensors that measure the changing magnetic field of a moving multi-pole magnet. The Hall sensor array is matched to the 1 mm pole pitch of the magnet to measure a sinusoidally varying field with a period of 2 mm. Automatic gain control compensates for changing average field strength which minimizes sensitivity to external magnetic fields. A single period of measurement (2 mm) is divided by 12 bits to achieve a measurement resolution of 0.5 µm which is read via an I^2C digital output.

Module Integration

The M3-F module integrates the SQUIGGLE motor, NSD2101 driver IC and NSE5310 position sensor in compact mechanisms that guides the lens with very small angular tilt. The moving carriage accepts standard M12 lens assemblies or smaller diameters with an adaptor. The housing of the module fits over standard CMOS image sensor boards. The lens is guided by a two parallel pins mated with bushings with micrometer-scale clearance. The guide pin fits in a cylindrical bushing in the carriage and has a return spring that maintains nearly constant preload force on the tip of the motor screw. The anti-rotation pin fits in a slot in the carriage and prevents the module from rotating around the axis of the guide pin. All electrical components are assembled to a single printed circuit board mounted to one side of the module housing.

The housing and carriage are molded from high-strength polycarbonate to achieve both high precision and low cost.

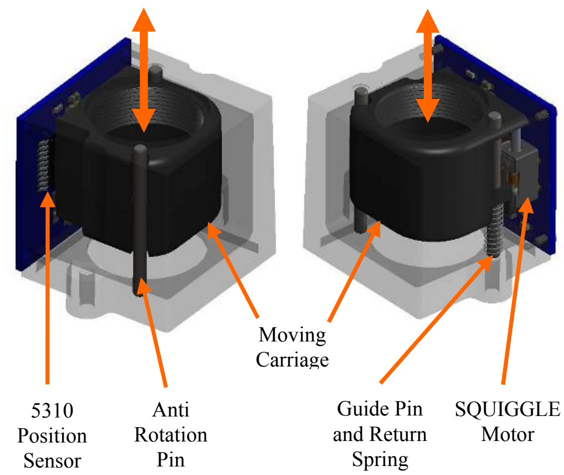

Fig. 5: *M3-F Mechanical Integration inside the Module Housing*

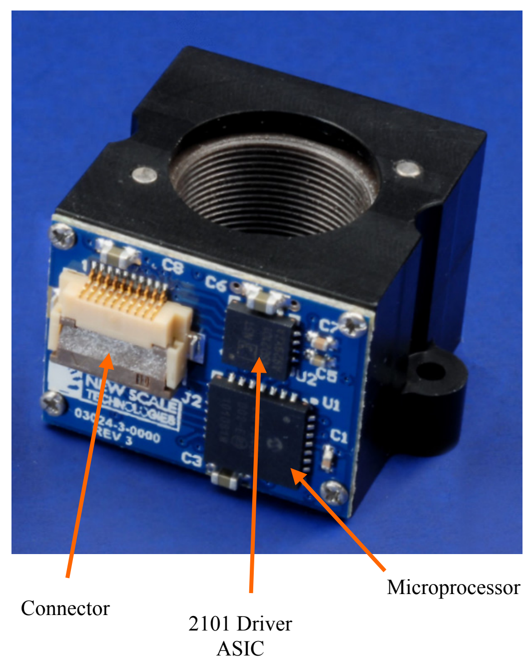

Fig. 6: *M3-F Electrical Integration on the Printed Circuit Board*

Plug-And-Play Closed-Loop Performance

The M3-F module has an integrated microprocessor with embedded firmware for closed-loop position and velocity control. The microprocessor communicates with the position sensor and driver IC via I^{2}C. Firmware operates a digital PID control loop and commands the SQUIGGLE motor to adjust the lens location in response to direct position measurements from linear sensor and external commands from the host computer. Since all closed-loop controls are included in the microprocessor this module can be very quickly integrated into a larger camera system.

Each module is fully tested for motion performance. Figure 7 show the results of one test. The lens is moving ten 5 µm steps forward and backward at approximate the center of travel (~ 700 µm). This result shows that 100% of the steps reach their target within the required time and accuracy. The average step and settle time is 13.4 msec and the average error is 2.7 µm compared to an external optical measurement system.

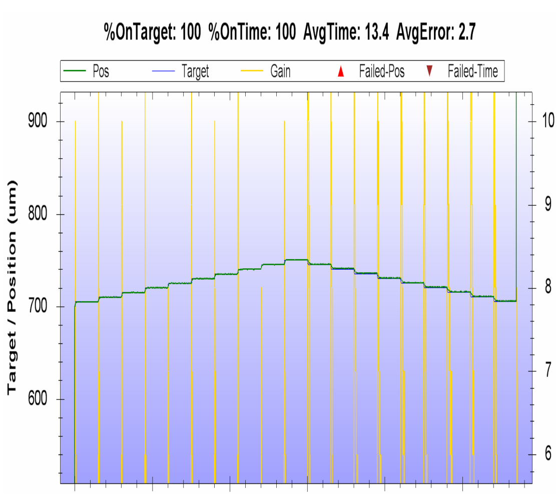

Fig. 7: *Standard Lens Stepping Test (Position vs. Time)*

Tilt is also measured while the lens is moving parallel to the optical axis. Tilt is especially important for cameras with large apertures and smaller f-numbers. These optical systems have a very short depth of focus. The optical axis of the lens must be orthogonal to the plane of the image sensor. If not, the plane defined by the depth of focus of the lens will not fully overlap with the plane of the digital image sensor. When this happens it is not possible to make the entire image be in focus at the same time.

These are some specific non-consumer camera applications that need precision focus.

- Face recognition and iris scanning benefit from the ability to actively focus. Focusing systems are more “forgiving” about the location of the subject. Scans are easier, faster, less intrusive, and reduce stress for people who used them routinely.

- For medical diagnostics the trends are toward smaller and thinner sample volumes (e.g. micro fluidics). The short depth-of-focus of the optics requires active alignment align of the image sensor with the small sample.

- In many machine vision, inspection and medical applications, the surface to be imaged is not perfectly flat. Small lens tilt and good depth of focus are necessary to provide a sharp image across the entire part surface. In addition, different parts can be inspected without having to manually adjust the camera.

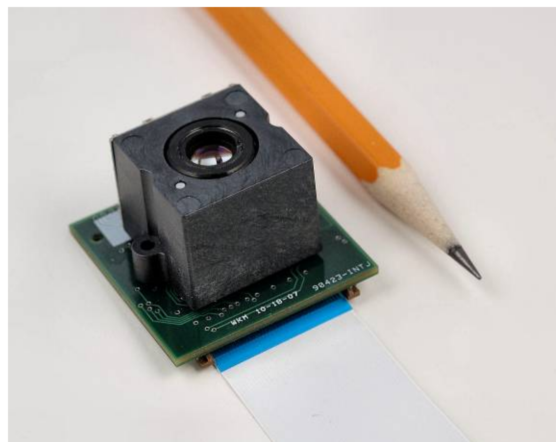

Fig. 8: *Camera System Using M3-F*

Summary

New micro-scale smart actuator modules provide a complete focus solution for digital imaging that keeps pace with the miniaturization trends of the latest CMOS image sensors and optics. The M3-F modules enable “plug and play” integration and enable camera designers to quickly prototype new product ideas and achieve faster times to market.

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[1] D. A. Henderson, Q. Xu and D. Piazza, Continuous Auto Focus for Next Generation Phone Cameras, Actuator 2010.
[2] SQUIGGLE is a registered trademark of New Scale Technologies.
[3] D. A. Henderson, Simple Ceramic Motor . . . Inspiring Smaller Products, Actuator 2006.