MICRO manufacturing

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PIEZOMOTORS

Big power for small stuff

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COLUMNS

DEPARTMENTS

ON THE COVER

Design by Tom Wright. Shown is a piezoelectric, SQL-series Squiggle motor manufactured by New Scale Technologies, Victor, N.Y.

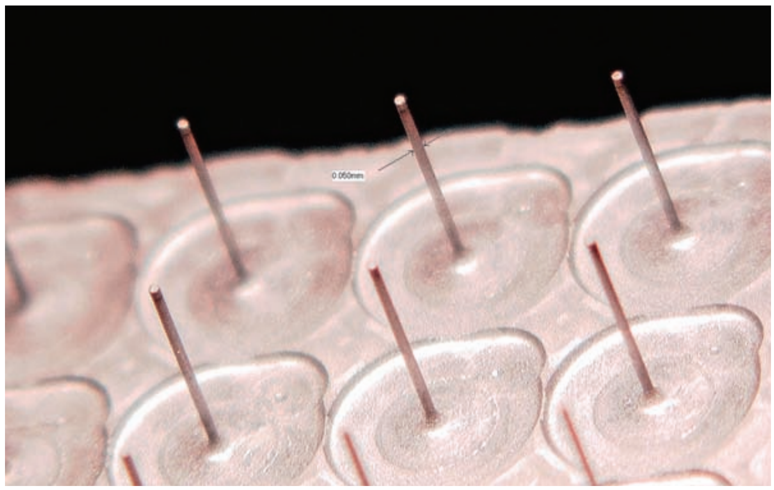
On the Web

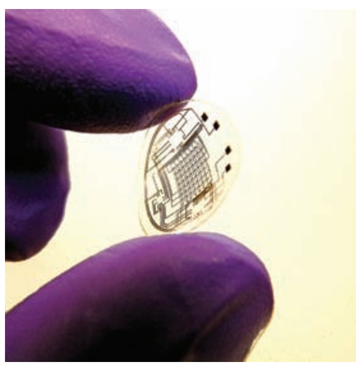
µTube: Video for the micro industry

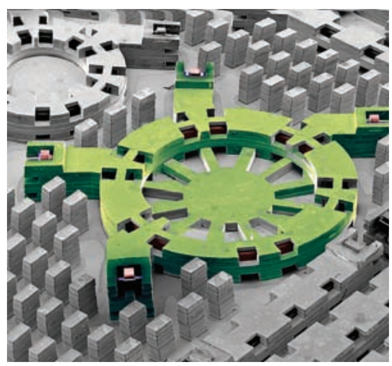
Whether you wish to view video for the micromanufacturing industry or submit a micromanufacturing video of your own, µTube is for you. The newest facet of the MICROmanufacturing Web site, µTube offers an opportunity to do both. With nearly a dozen video reports already available on demand, you can add to the video archive by contacting Dennis Spaeth via e-mail at dspaeth@jwr.com.

The latest µTube videos feature:

- µ The Helicheck measuring machine from Walter, Fredericksburg, Va., measures parts down to 0.1 mm (0.004") in diameter.
- µ Slater Tools Inc. is expanding its product line of Swiss-style adjustment-free, rotary broaching toolholders. Swiss-style tools are used in the aerospace and medical industries to make orthopedic bone screws and small fastener products.





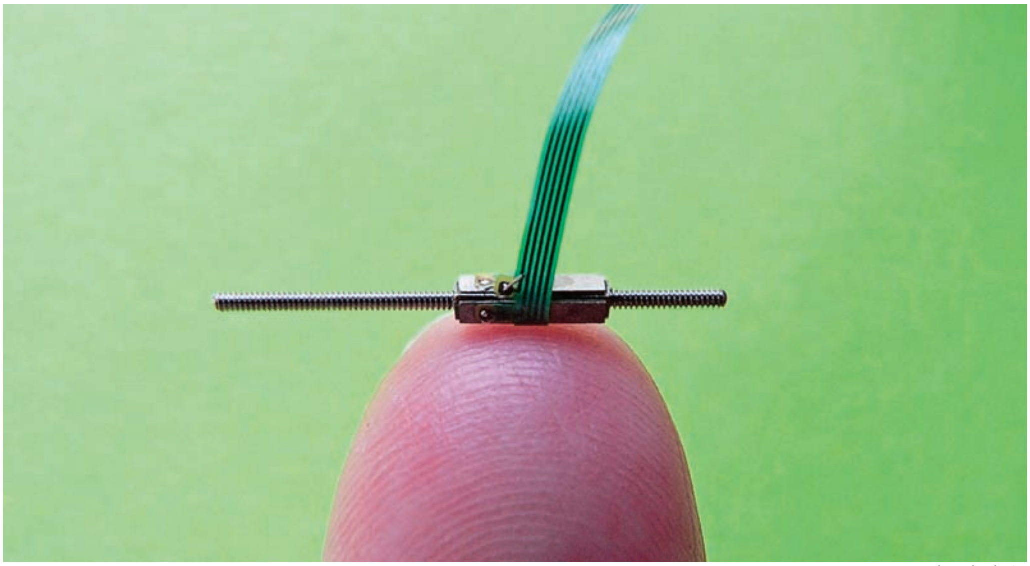


Power Packed

Cover Story

Piezoelectric motors: big power, small package

By Bill Kennedy, Contributing Editor



New Scale Technologies

This Squiggle piezoelectric linear motor measures 1.55mm × 1.55mm × 6mm.

A motor transforms energy into mechanical motion. The piezoelectric effect, an energy-transformation phenomenon first observed more than a century ago, is now the basis for extremely compact and precise motive power. A discovery in 1880 by French brothers Jacques and Pierre Curie formed the foundation for piezoelectric power technology. The two physicists learned that a class of crystalline minerals became electrically polarized when subjected to a mechanical force.

This "piezoelectric" effect (piezo being Greek for push, or squeeze) is employed today in a variety of devices, including tire pressure sensors and lighters for gas grills. Relevant to generating motion, the piezoelectric effect also works in reverse. So, applying an electrical charge to a piezo material causes it to change size, albeit on a tiny scale but with unwavering reliability and repeatability. This inverse piezoelectric effect is put to use in buzzers, speakers, actuators and motors.

Piezoelectric motors offer simplicity and small size, and can generate relatively high forces. As a result, the global market for piezoelectric-operated actuators and motors will grow to $10.7 billion by the year 2011 at an average annual growth rate of more than 15 percent, according to the market research firm Innovative Research and Products Inc., Stamford, Conn. Life science and medical technology demand for piezoelectric-operated actuators and motors is expected to grow about 19 percent annually during this period and could record an even higher growth rate as acceptance of the technology spreads.

That growth will be fueled by all-new applications requiring mechanical motion on a small scale that can be fulfilled only through the singular characteristics and capabilities of piezoelectric motors.

A piezo primer

Most piezoelectric motors employ ceramic materials manufactured from lead-zirconate titanate (Pb, Zr and Ti, abbreviated PZT). As in the manufacture of other ceramics, the metal oxide powders are mixed with an organic binder, shaped as desired and fired. Then, much like a ferrous material is magnetized, the ceramic parts are polarized via exposure to electric fields.

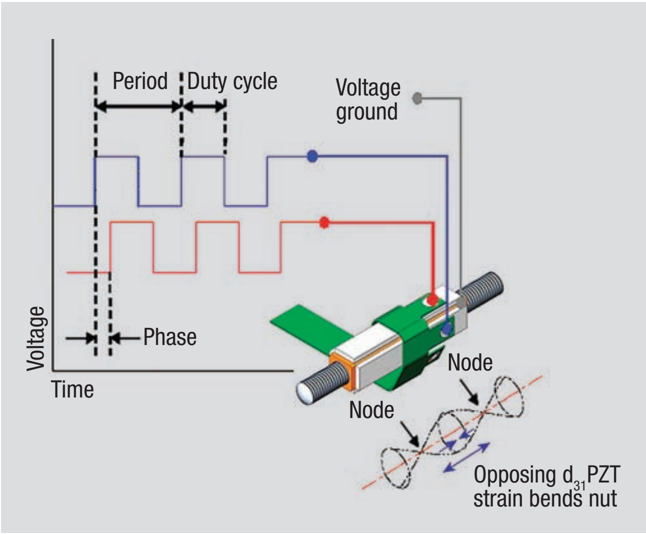
After polarization, if a voltage of the same polarity and direction as the poling voltage is applied to the ceramic part, it will grow longer (while shrinking in width), parallel to the lines of polarization. If a voltage of polarity opposite that of the poling voltage is applied, the part will become shorter and wider. If an alternating voltage is applied, the element will lengthen and shorten at the frequency of the applied voltage.

The changes in size are small but consistent. According to Dan Viggiano III, director of the custom products division of piezoelectric motor maker New Scale Technologies Inc., Victor, N.Y., piezoelectric material like that used in New Scale's Squiggle motor has a maximum typical strain of 0.1 percent. "When the maximum voltage is applied, the material will have a maximum change in length or thickness of 0.1 percent, depending on the direction of polarity," he said. "As an example, with a maximum voltage applied to a 1mm-thick piezoelectric plate, the plate thickness will change by 0.001mm, or 1 micrometer." Lower voltages produce correspondingly less change; the relationship is generally linear, with some hysteresis (lag in response) when approaching zero or maximum voltage. Motors can be classified into two basic groups: those that provide motion in discrete steps and operate below the resonant frequency of their piezoelectric actuators, and those that exploit ultrasonic amplification via the principle of resonance to effect continuous movement.

Early examples of piezoelectric motors that operate in a discrete stepping mode are the clamp-and-release motors introduced in the mid-1970s by precision measurement and positioning equipment provider Burleigh Instruments Inc. (Acquired in 2000 by EXFO Electro-Optical Engineering Inc., Quebec City, Quebec.) The motors were developed for optical components. The company named the devices "Inchworm" motors because their mode of operation resembles an inchworm on the move.

Inchworm motors consist of three PZT elements: two configured to clamp a shaft and a third located between them that determines the spacing between the clamps. When voltage is applied to the first element, it clamps the shaft. Then an increasing staircase voltage is applied to the center element, causing it to change length in discrete steps and move the shaft forward. When the voltage to the center element peaks, a voltage is applied to the third element, causing it to grip the shaft. Then the voltage is removed from the first element and it releases the shaft. The voltage on the center element then begins to step down, again moving the shaft forward until it reaches its lower limit. At that point the first element is activated again, the third element is released and the voltage on the center element begins to step up again.

The sequence can be repeated any number of times, and total travel is limited only by the length of the shaft.



New Scale Technologies

Alternating the voltage between pairs of plates in a Squiggle piezoelectric motor produces a wobbling or orbiting motion.

Full extension of the shaft in the center element of a typical Inchworm motor moves the shaft about 2µm. The motors offer positioning resolution of 0.1 nm. EXFO says its Inchworm motors are now being used in advanced research and manufacturing projects such as NASA's next-generation space telescope.

A leg up

As its name implies, the Piezo LEGS motor, from PiezoMotor Uppsala (Sweden) AB, and distributed in the U.S. by MicroMo Electronics Inc., Clearwater, Fla., also generates motion in discrete steps. A motor element, typically 5mm to 20mm long, consists of four bimaterial metal/ceramic actuators, or "legs," cosintered to a single body. When voltage is applied to a leg, the PZT ceramic element changes size and causes the leg to bend. The movement of pairs of legs is synchronized, enabling them to "walk" forward or backward.

Steps typically are no larger than a few microns, and can be as small as a single nanometer. By taking several thousand steps per second, a Piezo LEGS motor can reach traveling speeds of several centimeters per second. Typically, a 22mm × 11mm × 18mm Piezo LEGS motor weighs 30g and has a maximum step length of 3µm, with resolution as precise as 1nm. It can produce a maximum speed of 15 mm/sec. and a stall force of 10 N while consuming 5 mW/Hz.

PiezoMotor marketing director Peo Sollerud said the functional properties and performance of Piezo LEGS are easily adapted to different applications. Typical examples include precision positioning of components in instrumentation and manufacturing. Sollerud said the technology can provide rotary motion as well as linear movement. "The principle is quite simple and very much like the linear Piezo LEGS, only that instead of 'walking' on a straight rod, the rotating motor walks on a disk," he said. The Piezo LEGS motor is available in different versions, including models for vacuum and nonmagnetic applications as well as different sizes that provide from one to several hundred Newtons of pulling force.

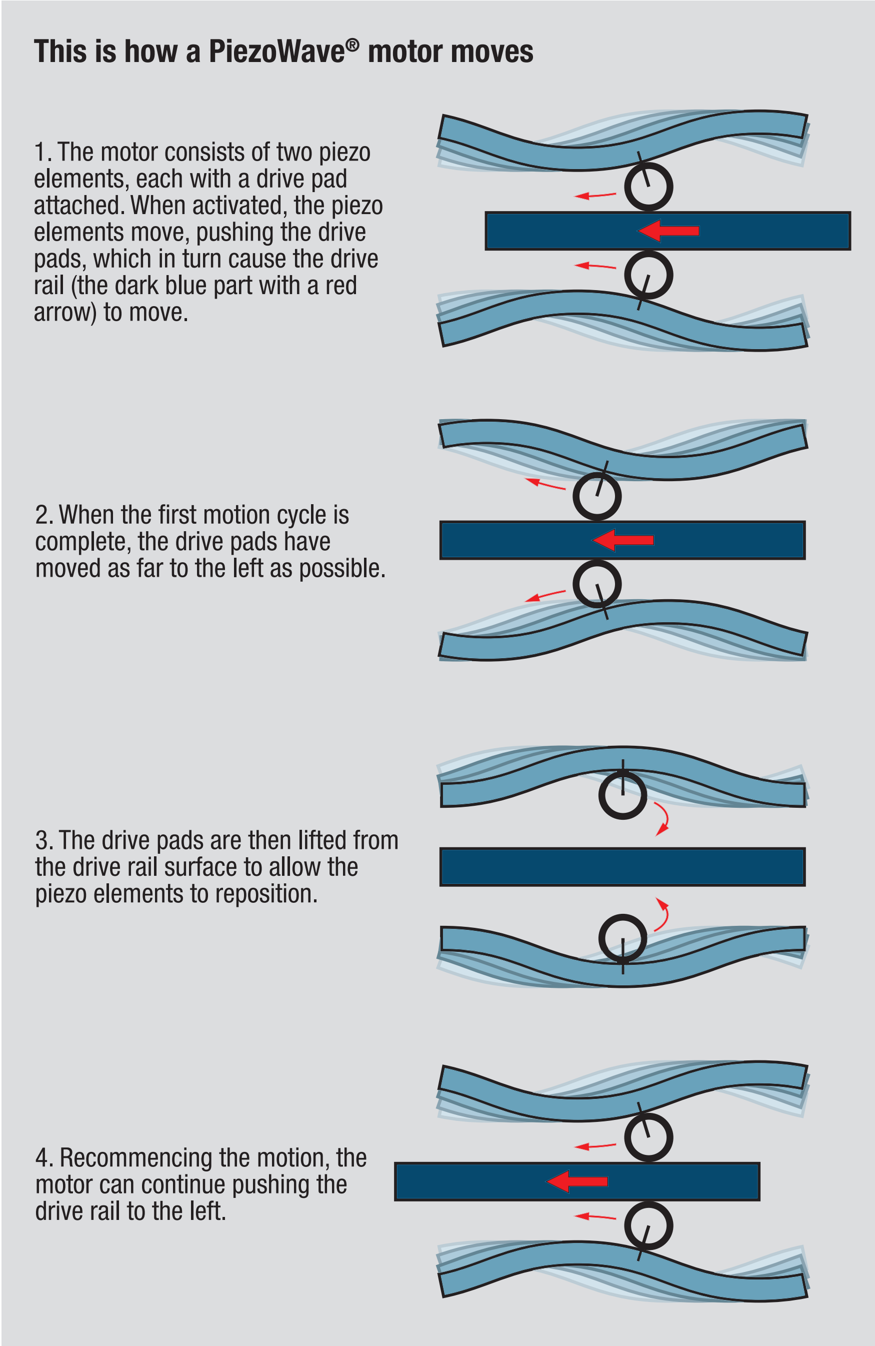
Good vibrations

A parallel development to discrete-step piezoelectric motors takes advantage of the general principle of resonance. That principle states that when a periodic vibration is applied to an elastic system, the system will respond with an amplitude of vibration that grows as the applied frequencies approach the natural frequencies of the resonating element. The composition of the piezo material and the shape and volume of the part determine the part's first resonance frequency, which is the point at which the conversion of energy into mechanical movement is most efficient.

Similar to ringing a bell, when the structure is excited at the proper frequency, its vibration will resonate and be amplified by the resonant constant, or Q, of the system. The higher the system's stiffness, the higher the Q. So, if the part size changes 1µm when vibrating and the Q is 50, at resonance the size change will be 50µm. According to New Scale Technologies, for a typical ultrasonic piezoelectric motor, the amplitude of vibration not at the resonance frequency (where the Q is one) may be tens of nanometers, but when the motor is vibrating at resonance frequency (where the Q is high) the amplitude of vibration can be several micrometers.

PiezoMotor's Piezo Wave motor employs ultrasonic resonance. The motor is composed of ceramic elements that are surface-assembled on a flexible printed circuit board. When activated electrically, the piezo ceramic elements vibrate and bend. The bending board moves drive pads elliptically and transfers movement from the elements to the drive rail.

Originally developed for handheld electronic devices such as mobile phones, Piezo Wave motors are now being used in many other applications, including medical devices, electromechanical door locks and advanced toys. Sollerud provided the example of a shutter unit for an advanced camera that employs two Piezo Wave motors with integrated position sensors. The motors have a force of 10g at a speed of 100 mm/sec. Advantages of the piezoelectric motors in this application include their small dimensions (14mm × 4mm × 7mm), low power consumption, no power consumption in hold position and fast reaction time.



PiezoMotor

In the Piezo Wave motor, two piezo elements with attached drive pads change shape when electrically activated, pushing the pads against the drive rail and moving it. When the pads reach their limit of travel, the piezo elements lift the pads from the drive rail so they can be repositioned to push the rail again.

Tubular approach

In an innovative configuration of ultrasonic piezoelectric technology, New Scale Technologies' patented Squiggle motor employs vibrations in a threaded tube to directly rotate a screw. The piezoelectric motor features four orthogonal PZT plates bonded at 90° intervals to flat surfaces on the outside of the metal tube. The poling directions of the plates are aligned so a common drive voltage on opposite pairs of plates change size and bend the tube. Alternating the voltage between pairs of plates produces a wobbling, or orbiting, motion that New Scale compares to the motion of a Hula Hoop. The tube and screw threads are in continual contact, and the tube's orbital motion produces tangential friction force that rotates the screw. The result is a smooth linear motion without additional mechanical conversion.

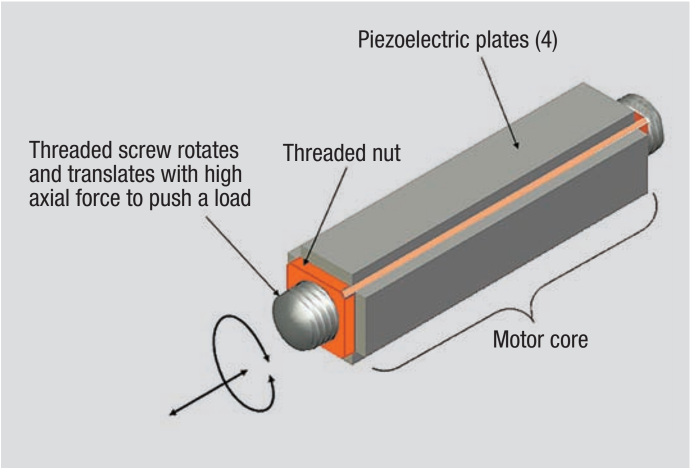
The bending strain in a Squiggle motor is applied at a frequency matched to the first bending resonance frequency of the tube—taking advantage of the resonance principle—and amplifying the small change in the plate size by the Q of the mechanical system. In addition, the threads multiply linear force.

The resulting motors are mighty mites: for example, a 1.8mm × 1.8mm × 6mm Squiggle motor uses less than 100 mW to produce more than 20g of force at 5 mm/sec.

Squiggle motors also feature precise off-power hold and can be manually adjusted by turning the screw. Motor components can be made of nonferrous materials, enabling them to be safely used in areas with high magnetic fields, such as MRI (magnetic resonance imaging) machines.

One of the motor's key design features, according to Ralph Weber, standard products division director for New Scale, is decoupling the PZT ceramic plates from the load path. In other piezoelectric motor configurations, the ceramic element is directly engaged with the load. Movements in the load or some type of impact, such as when a handheld device is dropped, could fracture the brittle ceramic. In the Squiggle motor, ceramic is bonded to the metal nut, and the load is borne by the screw and the nut threads, not the ceramic element. The arrangement provides enhanced strength and shock resistance, according to New Scale.

Weber said initially the motors were intended for research applications and they have been used widely in aerospace, optical alignment and microscopy applications since 2004. However, as the motors shrank in size and their capabilities became better understood, more original equipment manufacturers became interested.



New Scale Technologies

The Squiggle piezoelectric motor features four PZT plates bonded at 90° intervals to flat surfaces on the outside of a threaded metal tube that contains a threaded rod. Ultrasonic vibrations in the PZT plates produce an orbital motion in the tube to directly rotate the rod and produce linear motion.

One application with great potential is powering autofocus and zoom functions for cell phone cameras.

The market for phone cameras is forecast to grow nearly 1 billion units a year by 2009. Image sensors are expected to grow in resolution and sensitivity as well, requiring precise autofocus and zoom capability. New Scale is partnering with Japanese precision-optics maker Tamron to create combination autofocus/zoom modules for phone cameras.

Downsizing manufacturing costs

Assembly cost for microscale mechanisms is often a major stumbling block. Small electromagnetic motors, such as rotary DC servomotors and stepper motors, have many complex parts, including cores, windings, gears, bearings and lead screws. As the motors become smaller, parts become more fragile, potentially limiting power output. Assembly becomes more difficult and expensive. According to New Scale Technologies, efficiency also decreases when motor diameter falls below about 10mm and an increasing percentage of power is converted to heat instead of motion. Smaller diameters dictate higher operating speeds and gear reduction ratios to produce equivalent power, further reducing efficiency.

However, mass production of piezoelectric motors can lead to major efficiencies and savings, according to Weber. At production volumes of 1,000 per year, a typical Squiggle motor might cost about $30, plus control electronics; at 10,000 per year, that cost could fall to about $10, again before the cost of electronics. When production of the motors reaches the millions-per-month required for a cell phone camera application, for example, it is expected the per-motor cost will be less than the $2 unit price desired by phone manufacturers. That compares to $250 for a 1.8mm ×1.8mm × 6mm motor that New Scale sells as part of an evaluation kit for design engineers.

Choose your motor

Weber said a piezoelectric motor is usually not a direct replacement for an existing motor, because "the only reason you'd want to replace a cheap, proven solenoid or servomotor is if it is not small enough, or if it draws too much power." Instead, the singular size, simplicity and cost characteristics of piezoelectric motors give design engineers new ways to add motion where prior motive technology was too large or drew too much power. For example, Weber said, "we've received quite a bit of interest from people doing medical applications; we have researchers looking at the motors for things like robotic surgical tools and focusing the lens in the endoscopes" (see sidebar on page 27).

PiezoMotor's Sollerud said that an engineer's questions about choosing a piezoelectric motor configuration "are not so easy to answer in a simple way." The decision often includes evaluating a

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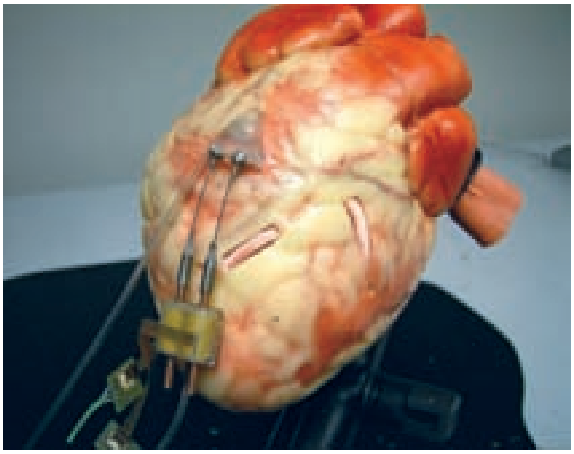
Launch of the HeartLander

Piezoelectric motors are a key component in a fascinating research collaboration between the Robotics Institute of Carnegie Mellon University and the Division of Cardiac Surgery at the University of Pittsburgh. The researchers are developing a mobile robot called the HeartLander that they describe as the first step in creating a wireless mobile robot for minimally invasive cardiac surgery. The 76.1mm × 15.5mm × 8.8mm tandem-bodied robot will be inserted into a patient's chest through a small incision beneath the breastbone, and then actually travel on the surface of the beating heart by alternating suction and extension, like an inchworm.

Each of the robot's two bodies contains a suction chamber to grip the heart. The front body tapers to a point so it can burrow under the pericardium, the sac of fibrous tissue surrounding the heart. The front body also contains a port for therapeutic tools used to inject substances into the heart, ablate certain areas or place pacemaker electrodes.

The rear body of the robot houses two Squiggle SQL-3.4 piezoelectric motors, placed side by side. Each motor's threaded rod is connected to miniature ball bearings at the rear of the front body via a length of Nitinol wire. By extending one rod and retracting the other, the robot can change direction as it creeps across the heart. Motor control circuitry is located outside the patient, and a graphical user interface enables a surgeon to control the robot using the arrow keys of a computer keyboard. When fully developed and approved, the robot may help surgeons avoid the use of a cardiopulmonary bypass machine and even general anesthesia.

The project began when Cameron N. Riviere, associate research professor at the Robotics Institute and director of its medical instrumentation laboratory, approached Pitt heart surgeon Marco Zenati, M.D., seeking ways to apply surgically oriented robotic concepts. Riviere and Zenati conceived the HeartLander and received an initial grant for it from the Pittsburgh Foundation, followed later by funding from the National Institutes of Health.



The Robotics Institute

The tandem-bodied HeartLander robot is engineered to travel on the surface of the beating heart by alternating suction and extension, like an inchworm.

Riviere said the robot's name reflects its independence of the world outside the patient. "It could detach itself from a rigid endoscopic introducing tool," he said, "and sort of land on the heart like a lunar lander … a HeartLander."

Early versions of the robot had no onboard motors, moving via nitinol push wires connected to larger motors in a box outside the patient. The most recent model, the HeartLander OMNI (Onboard Motor Navigational Instrument), came to be after one of Riviere's students, Peter Allen, found Squiggle motors in the course of online searches for compact motor technologies. Riviere said other electric motors were evaluated, but the Squiggle motors (3.4mm × 3.4mm × 7.0mm) were chosen for their compact size, robust nature and ability to generate high axial forces.

Riviere said the Squiggle motor was "the only motor that would give us the amount of force that we needed at the size we needed." He added that the research team is presently working with New Scale Technologies to achieve further miniaturization.

A company spun off from Carnegie Mellon University to commercialize the technology will handle testing and further development of the HeartLander OMNI, leading to its possible use in humans.

—B. Kennedy

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combination of size, precision and cost. "That is a tough combination to meet for engineers in many applications.

"There are almost as many types of piezoelectric motors as there are electromagnetic motors, and each of these motors has its advantages and disadvantages," he continued. For example, an engineer should only consider the Piezo LEGS motor if he has a move-and-hold application or wants slow, continuous motion. "For fast, continuous motion there are other alternatives."

In a move-and-hold application, considerations may include limited space, high demand for precision and accuracy, demand for a reduction of components (especially true for linear motion) and better energy efficiency (a piezoelectric motor consumes no energy in hold position, has no peak current draw in start or stop mode and exhibits no inertia). Other special requirements include manual override (possible without damaging the motor because it is friction based) or extremely slow motion under full control.

PiezoMotor's most widely applied piezoelectric motor is the linear Piezo LEGS motor, said Sollerud. "This is the first motor introduced by PiezoMotor AB, and has therefore been on the market the longest time. Over time, though, we see the biggest potential for the Piezo Wave motor."

Given the continuing downsizing of a wide range of products, the potential seems big for piezoelectric motors in general. µ

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