Machinery/Automation

Development of Biomorphic Flyers

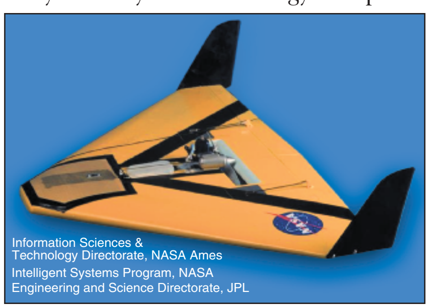
Autonomous flight control and navigation in small size is offered for planetary and terrestrial exploration applications.

NASA's Jet Propulsion Laboratory, Pasadena, California

Biomorphic flyers have recently been demonstrated that utilize the approach described earlier in "Bio-Inspired Engineering of Exploration Systems" (NPO-21142), *NASA Tech Briefs*, Vol. 27, No. 5 (May 2003), page 54, to distill the principles found in successful, nature-tested mechanisms of flight control. Two types of flyers are being built, corresponding to the imaging and shepherding flyers for a biomorphic mission described earlier in "Cooperative Lander-Surface/Aerial Microflyer Missions for Mars Exploration" (NPO-30286), *NASA Tech Briefs*, Vol. 28, No. 5 (May 2004), page 36. The common features of these two types of flyers are that both are delta-wing airplanes incorporating bio-inspired capabilities of control, navigation, and visual search for exploration. The delta-wing design is robust to ~40 G axial load and offers ease of stowing and packaging.

The prototype that we have built recently is shown in the figure. Such levels of miniaturization and autonomous navigation are essential to enable biomorphic microflyers (<1 kg) that can be deployed in large numbers for distributed measurements and exploration of difficult terrain while avoiding hazards. Individual bio-inspired sensors that will be incorporated in a biomorphic flyer have been demonstrated recently. These sensors include a robust, lightweight (~6 g), and low-power (~40 mW) horizon sensor for flight stabilization. It integrates successfully the principles of the dragonfly ocelli. The ocelli are small eyes on the dorsal and forward regions of the heads of many insects. The ocelli are distinct from the compound eyes that are most commonly associated with insect vision. In many insects, the ocelli are little more than single-point detectors of short-wavelength light and behavioral responses to ocelli stimuli are hard to observe. The notable exception is found in dragonflies, where flight control is notably degraded by any interference with the ocellar system. Our team has discovered recently that the ocelli are a dedicated horizon sensor, with substantial optical processing and multiple spectral sensitivity. To our knowledge, this is the world's first demonstrated use of a "biomorphic ocellus" as a flight-stabilization system.

The advantage of the ocelli over a similarly sized system of rate gyroscopes is that both attitude control and rate damping can be realized in one device. A full inertial unit and significant processing would otherwise be required to achieve the same effect. As a prelude to full autonomy, substantial stability augmentation is provided to the pilot at very low cost in terms of space, power, and mass. The sensor is about 40 times lighter than a comparable inertial attitude reference system. Other significant features of the biomorphic flyer shown in the figure include its ability to fly at high angles of attack ~30° and a deep wing chord which allows scaling to small size and low Reynold's number situations. Furthermore, the placement of the propulsion system near the center of gravity allows continued control authority at low speeds. These attributes make such biomorphic flyers uniquely suited to planetary and terrestrial exploration where small size and autonomous airborne operation are required.



Photograph shows the **Biomorphic Flyer Platform**. The platform was successfully demonstrated in 2001.

This work was done by Sarita Thakoor of Caltech for **NASA's Jet Propulsion Laboratory** *and by Dean Soccol, G. Stange, Geno Ewyk, Matt Garratt, M. Srinivasan, and Javaan Chahl of Australian National University and Butler Hine and Steven Zornetzer of Ames Research Center for the NASA Intelligent Systems Program. Automated Precision, Inc. Further information is contained in a TSP (see page 1).*
NPO-30554

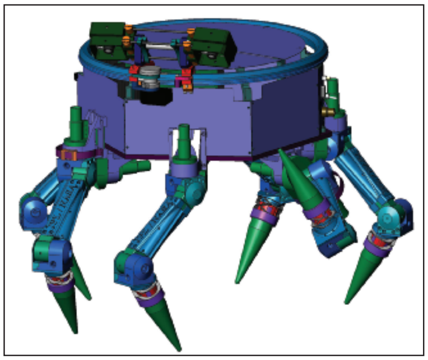
Second-Generation Six-Limbed Experimental Robot

This robot is designed to be more agile and dexterous than its predecessor.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure shows the LEMUR II — the second generation of the Limbed Excursion Mechanical Utility Robot (LEMUR), which was described in "Six-Legged Experimental Robot" (NPO-20897), *NASA Tech Briefs*, Vol. 25, No. 12 (December 2001), page 58. The LEMUR II incorporates a number of improvements, including new features, that extend its capabilities beyond those of its predecessor, which is now denoted the LEMUR I.

To recapitulate: the LEMUR I was a six-limbed robot for demonstrating robotic capabilities for assembly, maintenance, and inspection. The LEMUR I was designed to be capable of walking autonomously along a truss structure toward a mechanical assembly at a prescribed location and to perform other operations. The LEMUR I was equipped with stereoscopic video cameras and image-data-processing circuitry for navigation and mechanical operations. It was also equipped with a wireless modem, through which it could be commanded remotely. Upon arrival at a mechanical assembly, the LEMUR I would perform



The **LEMUR** II can move its stereoscopic cameras along a circular track to view objects at any azimuth. Its symmetrical arrangement of six limbs enables motion along any azimuth heading.

simple mechanical operations with one or both of its front limbs. It could also transmit images to a host computer.

Each of the six limbs of the LEMUR I was operated independently. Each of the four rear limbs had three degrees of freedom (DOFs), while each of the front two limbs had four DOFs. The front two limbs were designed to hold, operate, and/or be integrated with tools. The LEMUR I included an onboard computer equipped with an assortment of digital control circuits, digital input/output circuits, analog-to-digital converters for input, and digital-to-analog (D/A) converters for output. Feedback from optical encoders in the limb actuators was utilized for closed-loop microcomputer control of the positions and velocities of the actuators.

The LEMUR II incorporates the following improvements over the LEMUR I:

- The drive trains for the joints of the LEMUR II are more sophisticated, providing greater torque and accuracy.
- The six limbs are arranged symmetrically about a hexagonal body platform instead of in straight lines along the sides. This symmetrical arrangement is more conducive to omnidirectional movement in a plane.
- The number of degrees of freedom of each of the rear four limbs has been increased by one. Now, every limb has four degrees of freedom: three at the hip (or shoulder, depending on one's perspective) and one at the knee (or elbow, depending on one's perspective).
- Now every limb (instead of only the two front limbs) can perform operations. For this purpose, each limb is tipped with an improved quick-release mechanism for swapping of end-effector tools.
- New end-effector tools have been developed. These include an instrumented rotary driver that accepts all tool bits that have 0.125-in. (3.175-mm)-diameter shanks, a charge-coupled-device video camera, a super bright light-emitting diode for illuminating the work area of the robot, and a generic collet tool that can be quickly and inexpensively modified to accept any cylindrical object up to 0.5 in. (12.7 mm) in diameter.
- The stereoscopic cameras are mounted on a carriage that moves along a circular track, thereby providing for omnidirectional machine vision.
- The control software has been augmented with software that implements innovations reported in two prior *NASA Tech Briefs* articles: the HIPS algorithm ["Hybrid Image-Plane/Stereo Manipulation" (NPO-30492), Vol. 28, No. 7 (July 2004), page 55] and the CAMPOUT architecture ["An Architecture for Controlling Multiple Robots" (NPO-30345), Vol. 28, No. 10 (October 2004), page 65].

This work was done by Brett Kennedy, Avi Okon, Hrand Aghazarian, Matthew Robinson, Michael Garrett, and Lee Magnone of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-35140

Miniature Linear Actuator for Small Spacecraft

Goddard Space Flight Center, Greenbelt, Maryland

A report discusses the development of a kit of mechanisms intended for use aboard future spacecraft having masses between 10 and 100 kg. The report focuses mostly on two prototypes of one of the mechanisms: a miniature linear actuator based on a shape-memory-alloy (SMA) wire. In this actuator, as in SMA-wire actuators described previously in *NASA Tech Briefs*, a spring biases a moving part toward one limit of its stroke and is restrained or pulled toward the other limit of the stroke by an SMA wire, which assumes a slightly lesser or greater "remembered" length, depending on whether or not an electric current is applied to the wire to heat it above a transition temperature. Topics addressed in the report include the need to develop mechanisms like these, the general approach to be taken in designing SMA actuators, tests of the two prototypes of the miniature linear actuators, and improvements in the second prototype over the first prototype resulting in reduced mass and increased stroke. The report also presents recommendations for future development, briefly discusses problems of tolerances and working with small parts, states a need for better understanding of behaviors of SMAs, and presents conclusions.

This work was done by Cliff E. Willey and Stuart W. Hill of Johns Hopkins University Applied Physics Laboratory for **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*
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