true numbers may never be known, because most are expected to have faded to blackness.

–GOVERT SCHILLING

Govert Schilling is an astronomy writer in Utrecht, the Netherlands.

NEUROSCIENCE

A Machine With a Fly's-Eye View

Watch a house fly dart through a kitchen, navigating around obstacles at top speed, and you may not be surprised to learn that this blight of homemakers is a favorite of neurobiologists. For more than 30 years, they have measured brain activity and movement in tethered living flies to learn how the tiny fly brain processes fast-changing visual information and turns it into flight commands. More recently, they have used computer simulations to try out their theories on how these processes work. Now, scientists have a new tool that may help them unravel the secrets of a fly's agility: an analog electronic circuit that models a key part of the fly's visual system and is built into a rudimentary robot so that it can interact with the real world.

The robot fly was developed at the California Institute of Technology (Caltech) in Pasadena by Christof Koch and graduate student Reid Harrison, who says it may turn out to be a better probe of the fly visual system than experiments with live flies or computer simulations. "By building a model that interacts with the real world in real time, one can easily expose the model to complex stimuli that might be difficult to simulate," says Harrison. The robot fly's eye may also benefit robotics, because its analog design is fast, very stable, and uses little power. "[These experiments] show that much can be learned from biology for robotics," says fly vision expert Martin Egelhaaf of the University of Bielefeld in Germany.

Harrison and Koch, whose results will soon be published in *Neural Computation* and *Autonomous Robots*, based their visual system on three layers of structure in the fly's eye. The top layer of photoreceptors each send a signal to a cell called an elementary motion detector, which detects motion by working in concert with neighboring EMDs. When a photodetector picks up a signal, its EMD compares that signal with what its neighbors are seeing. If a neighbor detects an identical but delayed signal, then the EMD decides that they are coming from a single source moving in that direction and sends a message to the next layer of cells. These are the large "horizontal system" (HS) cells, which collect the outputs from all the EMDs and sum them to produce a signal that drives the fly's motor system to react to the detected motion.

The researchers duplicated this structure in a single integrated computer chip. Each electronic EMD consists of a light detector and a simple circuit to compare signals and generate an output signal—all covering an area 60 by 200 micrometers. The chip contains 144 such devices arranged in a 6-by-24 grid. Each EMD in the array sends its signals to another circuit—the equivalent of the HS cells—that

Seeing straight. This robot naturally wants to move in loops *(bottom right)*, but a fly-inspired vision chip keeps it in a straight line *(top)*.
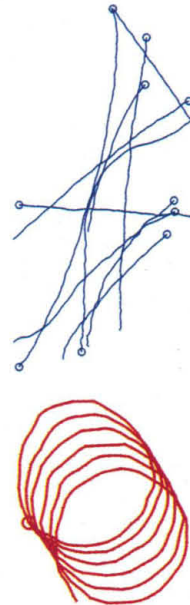
sums the outputs to produce a response to the observed movement.

To see if this vision system would successfully respond to real-world stimuli, the researchers mounted it on a wheeled Lego robot. The robot had two powered wheels with very different gear ratios, so it naturally ran in tight circles. The vision system would therefore see a lot of horizontal motion and produce a large signal. The team wanted to use the signal to get the robot to compensate for the motion and move in a straight line. So the Caltech team used the output from the vision system to boost the power driving the low-geared wheel and reduce the power driving the high-geared wheel. Hence the more the robot turned, the bigger the signal, causing the small wheel to run faster and the big wheel to run slower and hence slowing the turn. This optical feedback worked well, and, with the vision system installed, the robot moved in near-straight lines despite the huge asymmetry in its wheels.

Insect vision specialists told *Science* that the success of the robot is an important validation of current theories of fly vision. Alexander Borst of the University of California, Berkeley, believes the way the Caltech vision array feeds straight into the motor system, and hence gets automatic feedback, mirrors biology well. "The big advantage that I see is that the visual system is automatically in a closed loop, which neuroscientists usually forget when thinking of the computational tasks of the visual system," he says.

The nature of the circuits may also hold lessons for roboticists. The vision system contains no digital electronics, which would involve a complex computational recipe containing thousands of operations, but instead uses analog circuits, processing light signals by employing the innate physics of the device—a technique pioneered by Caltech's Carver Mead. This makes its power consumption extremely low—just 5 microwatts for the array. Harrison compares this with the charge-coupled device imagers on the Sojourner rover used in the recent Mars Pathfinder mission. These used 0.75 watt just to acquire images, and much more power to process the data.

The Caltech researchers are now continuing to refine their vision controller system, while at the same time giving their robot fly a smaller and more biologically inspired body that they hope might one day take flight. In particular, they are in the process of designing micromechanical "halteres": vestigial wings that assist a real fly with attitude control and stabilization.

–SUNNY BAINS

Sunny Bains is a scientist and journalist based in the San Francisco Bay area.

COMPUTER SCIENCE

Internet Security Code Is Cracked

A popular encryption tool for keeping credit card numbers and other information secret on the Internet has been cracked. Last week, scientists announced at a press conference in Amsterdam that, using a sophisticated mathematical algorithm and cleverly written software, they had broken the RSA-155 code, which protects credit card transactions and secure e-mail in Europe. The number-crunching legerdemain suggests that anyone trafficking in confidential information on the Internet may soon have to switch to more sophisticated encryption software.

Using RSA-155, one party can send a secure message to another by using the recipient's "public key"—a 155-digit product of two large prime numbers—to transform the original message into ciphertext. Decoding the message, however, requires the two prime numbers, known only to the recipient. For a long time this encryption was considered secure. Factoring a 155-digit number was thought to be beyond the scope of practical computations.

Two years ago, however, a group led by Herman te Riele of the Centre for Mathe-