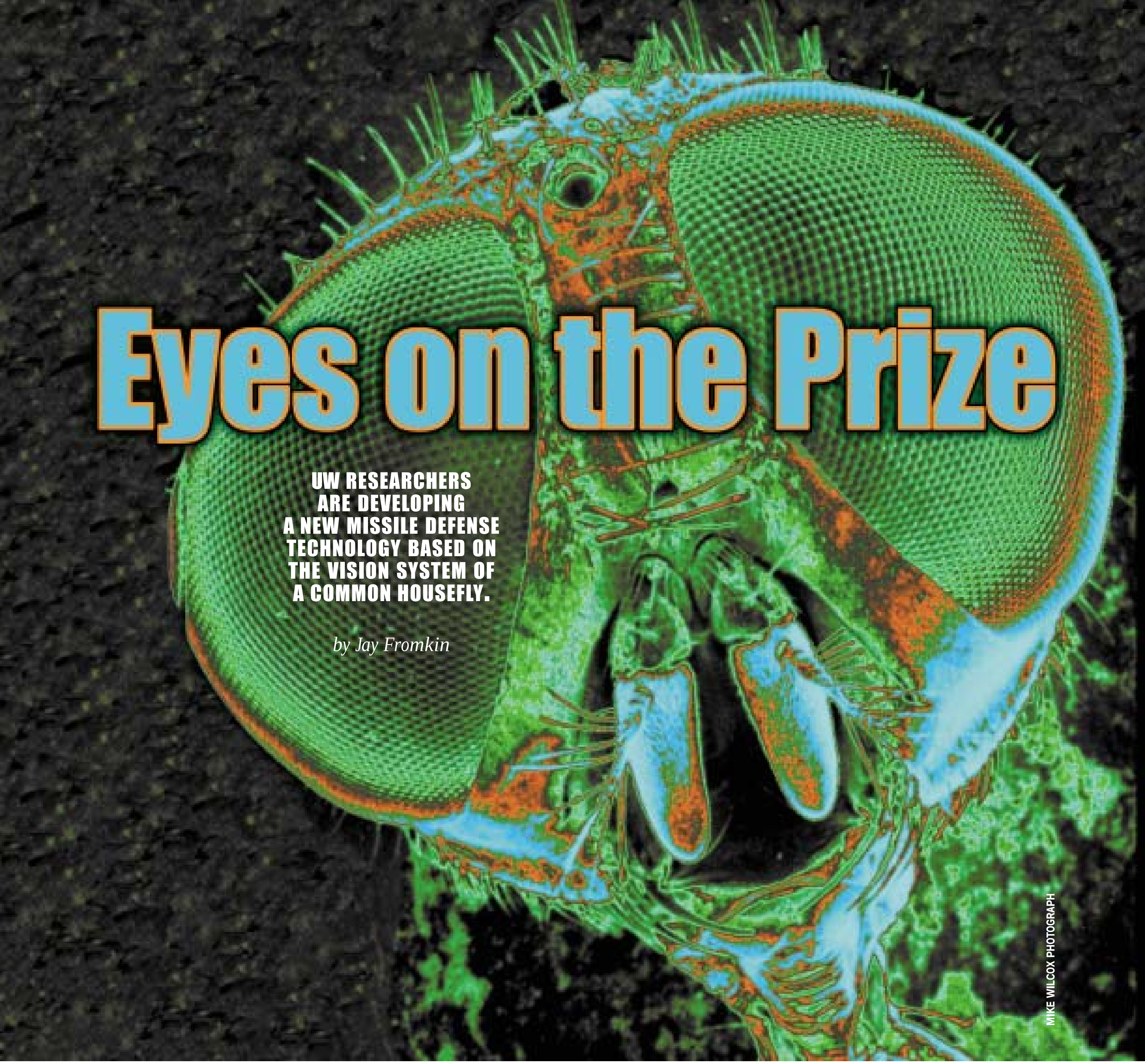
Eyes on the Prize

UW RESEARCHERS ARE DEVELOPING A NEW MISSILE DEFENSE TECHNOLOGY BASED ON THE VISION SYSTEM OF A COMMON HOUSEFLY.

by Jay Fromkin



MIKE WILCOX PHOTOGRAPH

President Ronald Reagan announced the Strategic Defense Initiative, or "Star Wars," in 1983 as a means of protecting the United States against attack from Soviet-based ballistic missiles. In his address to the nation, Reagan did not specify the range of technologies that might be used in missile defense, but in 1984, the Army used a hit-to-kill interceptor rocket to destroy an incoming missile.

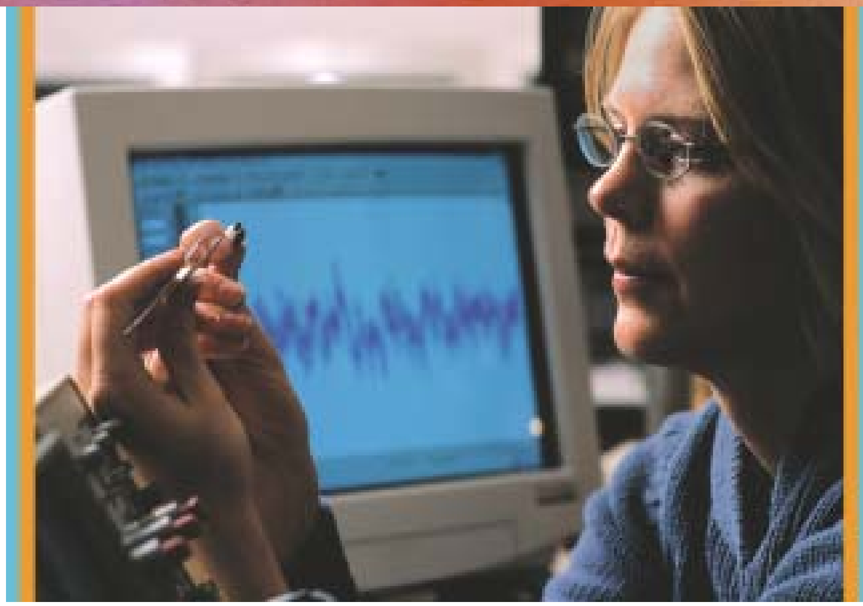
Mike Wilcox isn't impressed.

"If you're tracking a missile that's coming up on a known trajectory, with no collision-avoidance circuitry on it at all, you can track where it's going to be and make sure that your missile hits it," says the electrophysiologist on the faculty of the U.S. Air Force Academy. "That's cheating."

Wilcox is principal investigator for a research team that includes Steve Barrett, an assistant professor of electrical engineering at the University of Wyoming, and an interdisciplinary group of three UW graduate students. Funded by the Navy, the research team is working to develop a new technology that can steer a missile over the horizon and hit a moving target along an unknown trajectory.

That technology is based on the vision system of a common housefly.

Current tracking systems –



Jenny Newton, a UW master's candidate in electrical engineering, prepares a fly for measurement of the insect's electrical response to edge images produced by a green laser.

such as those used in cruise missiles – use programmed map coordinates, global positioning systems, and satellite communications to hit predetermined targets. The digital systems they employ are relatively slow.

A digital system takes a picture, shifts the data to memory for additional processing, then takes another picture. Analog processing essentially duplicates how the eye sees – in one continuous data stream. Sequential images at 30 frames per second are fast enough to fool a human eye into perceiving motion as smooth. A fly, by comparison, sees continuous motion at 300 images per second, using just three or four cell connections. The combination of an analog approach that simulates retinal processing, coupled with parallel electronic circuitry, can process information far in excess of 10,000 frames per second.

"Let's say the Navy launches a missile from a ship, which flies over the horizon at an enemy ship," says Barrett, who spent the second half of his military career teaching at the Air Force Academy. "They know it's the correct target, but they want to strike the conning tower rather than the bow, which can produce a glancing blow. The missile's coming in so fast that digital systems aren't fast enough to keep up with last minute corrections. The Navy's hoping this fly-vision system, based on analog processing at a much faster rate, will be able to make last-minute corrections a lot quicker and a lot more accurately."

Down on the 'fly ranch'

To understand how a fly sees, one first has to unlearn the pseudoscience dished up by horror movies of the late 1950s. A fly looking at a screaming woman does not process the same image on each of its 6,000 eye retinas; it sees only one image, at high resolution and at continuous high speed. The speed at which a missile must "see" a target in motion becomes absolutely critical when the missiles are to have a head-on collision at a minimum of six times the speed of sound.

The fly's ability to process visual information is based on how its compound eyes are constructed. Each eye is composed of 3,000 mini-retinas, each under its own lens. The retinas' photoreceptors talk to cells arranged in "cartridges," self-contained vision units. These cells communicate with cells in the next layer that detect horizontal and vertical image features, motion, direction, and speed. Sets of six adjacent cartridges process the information simultaneously – or in parallel – rather than sequentially. Tim Olson, a 2001 master's graduate from UW in electrical engineering, has modeled and simulated cellular interaction within a fly cartridge. Those information-processing principles are being tested in live flies by recording responses of their eye cells.

Jenny Newton, a UW master's candidate in electrical engineering, is the team's fly wrangler; the fly ranch is a cubic foot of window screening containing several hundred houseflies. On any given day, she will pop a few flies into a freezer to slow them down and select one for the day's experiment. Newton glues the fly into a tiny collar, glues its legs together to eliminate muscular movement, and uses a razor blade chip to slice off a few facets from one of its compound eyes. She inserts into the fly's eye a hollow glass probe, filled with electrolyte and carrying a silver wire filament that forms an electrical connection between the eye and a collection of lasers, mirrors, computers, and oscilloscopes.

Newton plays a green laser beam across the fly's eye, which responds to the stimulus by sending an electrical signal through an amplifier to an oscilloscope and a computer hard drive. The system measures the fly's response to edge images produced by the laser.

The recognition of edges is key to the team's project. In the film *Courage Under Fire*, a tank commander orders his gunner, during a confusing night battle, to fire at what he believes is an enemy tank. The target turns out to be an American tank, and the crewmembers become victims of "friendly fire."

Tanks produced by different countries look markedly different. The turrets, cannons, and chassis have different shapes, or edges. Newton is studying intercellular connections and electrical signals from the flies' eyes to determine how they see edges – the precursor of an object-recognition chip that can specify which targets to hit, and which to avoid.

UW's research team on missile tracking technology includes (from left), Ph.D. candidate Jeff Anderson, master's candidate Jenny Newton, Assistant Professor Steve Barrett, and master's candidate John Davis. Eric Tomberlin (not pictured) will join the team after graduation in May.

At the same time, Jeff Anderson, a UW Ph.D. candidate in electrical engineering, is working to determine how each cartridge is constructed. On a wall of his office is a series of 10 black-and-white photographs, about four feet in length, that together represent one of 150 vertical slices taken of a single column of a fly's eye. These images are the beginning of a 1.5-gigabyte data set that will use computers to model the column. The end result, analogous to a computer circuit board, will allow the researchers to see which cells talk to each other, as well as the path that electrical signals take through the cartridge.

"We want to identify these cells, tag them in a three-dimensional computer model, and find out how they interconnect," says Anderson. "It's an approach to mapping out cell interactions in the fly's eye. We can compare the structural 'map' with the signals Jenny gets when she actually measures electrical responses from the eye."

Then, perhaps, the team can build its knowledge of how a fly's eye works into a functional multi-level tracking chip. Wilcox already has developed a two-millimeter-square photoreceptor chip that functions in the same way as a fly's photoreceptor cell, and which contains pre-processing hardware in its outer layer. But a tracking chip built into the nose of a cruise missile would need additional

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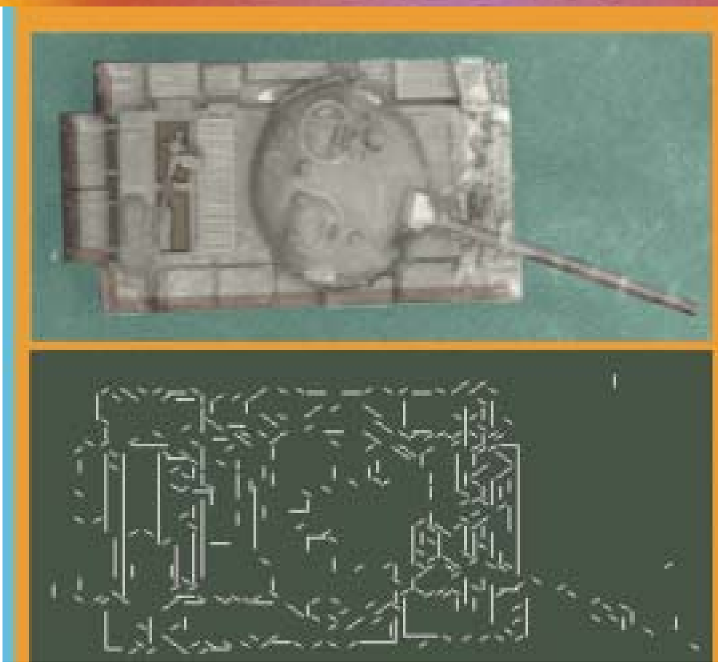

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Digital processing demonstrates edge-recognition of a Soviet tank model. Edge recognition is a key to the success of missile tracking technology being developed by researchers at UW and the U.S. Air Force Academy.

inner layers – an edge-detection layer, an object recognition layer, and a tracking layer – assembled in a vertical array to speed communication between layers.

"I'm really confident we can do the edge-detection layer probably within the next year," says Barrett, "but we want to make sure we fully understand what the edge detection mechanisms are."

Weapon of the future

John Davis, a UW master's candidate in electrical engineering, also is working on edge-detection, but from an application standpoint, emulating the edge-recognition and tracking system that the team eventually hopes to create for use in a weapons system. Davis will remove the radio-control mechanism from a toy car, replace it with a photoreceptor chip and microprocessor, and affix commercially available photo sensors along the front bumper. By programming into the microprocessor the edge dimensions of a target radio-controlled car (including the ability to predict the target's size based on distance from the chase car) as well as the dimensions of obstacles along a simulated roadway, he plans to create a chase car that will sense a passing target, track it, and catch it, while avoiding obstacles. According to Barrett, this kind of sensor technology has never been applied to a three-dimensional problem.

How long will the fly-eye project take?

"We could put a chip into a missile five years down the road," says Barrett, "three, if we had all the money and the time in the world."

They have neither. Current Navy funding is set at $315,000. And the team won't be together forever. Newton was scheduled to leave UW in April for a full-time position with the Naval Air Warfare Center. Davis is scheduled to earn his graduate degree in December.

But the team does have continuity. Barrett has been at UW only since 1999. Eric Tomberlin, a senior undergraduate student in electrical engineering will join the team as a graduate student to replace Newton. Anderson says he hopes to join the UW faculty after earning his doctoral degree.

In his January 2002 State of the Union address, President George W. Bush said, "We will develop and deploy effective missile defenses to protect America and our allies from sudden attack," and added that,"This campaign may not be finished on our watch – yet it must be and it will be waged on our watch."

His watch may be fewer than three years or nearly seven. And within that watch, the work of five UW scientists and engineers and their colleagues might well have produced a computer chip, an electronic analog of a fly's eye, that could help make our world just a bit more secure. ❖