EPSRC Computer Science Compeition 2007 Entry – Matthew Szenher

Better Robotics Through Biology

A cricket walks to a pond-side spot for a drink. Lurking unnoticed nearby, a frog sees a tasty meal. It takes careful aim and unleashes its sticky tongue but a fraction of a second before impact, the cricket evades the strike, leaping to safety. How did the cricket save itself in time? Extraordinary as it sounds, it reacted to the short burst of air preceding the frog's tongue.

The cricket detected this air current with a set of specialised hair sensors located at the end of its abdomen. When deflected, these filiform hairs send signals to neural circuitry which quickly computes the direction of the attack and, remarkably, identifies the predator. Knowing the type of predator allows the cricket to enact an appropriate response: fight or flight. The system is able to ignore air currents from self-movement, wind and other benign sources. It can even operate when many of the hairs have been damaged.

Adaptive, compact, low-power and exceedingly fast, this sensory system is more sophisticated than anything robotics has yet to offer. A team of researchers at the University of Edinburgh hopes this will soon change. They have won an EPSRC grant to reproduce the cricket's wind-mediated escape system in hardware and software. “We have a unique opportunity to establish a collaborative team to tackle a problem of sensing simultaneously from all these angles: design of the physical sensor, efficient hardware processing of the input, and embedding ... on a robot,” said Dr. Barbara Webb, the project's principle investigator.

While other research groups have fabricated parts of the cricket's escape system, no one has put all of the pieces together. This integration is crucial argued Dr. Webb: “We need to gain a more holistic understanding of how these multiple factors interact if we are to understand and emulate the success of biological designs.”

The Edinburgh group built a novel MEMs (Micro-Electro-Mechanical System) chip to model a set of filiform hairs. The hairs are made from tiny silicon strips about 1000 microns long (roughly the length of the cricket's longest filiform hair). Each strip is hand-glued standing on end to the end of a lever etched out of the chip's surface. The lever is made of piezoresistive material whose electrical resistance changes when bent. When the hair is deflected -- by moving air, for example -- so is the piezoresistor. The force deflecting the hair is inferred from the change in resistance of the piezoresistor.

As in real crickets, the signal from each hair is processed by a sensory neuron, a cell whose job is to convert the mechanical activity of the hair to a signal understandable by the nervous system. Sensory neurons are modelled by circuits on an aVLSI (analog Very-Large-Scale Integration) chip. As the name suggests, aVLSI chips pack a lot of processing power into a very small area. Each sensory neuron converts the output from the MEMs into a series of short bursts of electricity called spikes. Spike frequency reflects the strength of the wind impacting the hair.

The aVLSI houses amplifiers to boost the weak signal from the MEMs. Typical amplifiers multiply input by a constant factor. But the strength of the hair signal varies, so constant amplification would increase some signals too much and others too little for the sensory neurons. The team solved this problem using an amplifier whose gain adapts to the strength of the air current impacting the hair.

Spikes from the sensory neurons are fed into an artificial neural network, a computer program simulating a collection of interconnected processing cells which collaboratively perform complex computations. Designed by Webb's PhD student Theophile Gonos and inspired by actual crickets, the network converts information from the hairs into instructions to the wheel motors of a mobile robot. When the network recognises input consistent with an attack, it computes the direction of the threat and instructs the wheels to move away from the threat.

Gonos is interested in how his network can overcome damage to individual hairs. The cricket brain copes by sending its wind-mediated escape network information about any movement it is about to undertake, a so-called "efferent copy." The network predicts the input from each hair that should result from the upcoming movement. If, for a particular hair, prediction repeatedly fails to mirror reality, the hair is judged damaged and its influence is diminished in future decisions.

The Edinburgh team envisions several additional applications for this technology. Dr. Webb suggested that cars could be equipped with "lots of adaptive wind sensors that could control the reconfiguring of panels ... to improve aerodynamics." Also, since the MEMS and aVLSI chips are lightweight, they are ideal for small autonomous aircraft, helping them to, say, fly upwind sniffing traces of chemical explosive in order to locate the source.