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Vol. 31, July 2012. MAKE (ISSN 1556-2336) is published quarterly by O’Reilly Media, Inc. in the months of January, April, July, and October. O’Reilly Media is located at 1005 Gravenstein Hwy. North, Sebastopol, CA 95477. (707) 827-0000. Subscriptions:
SEND ALL SUBSCRIPTION REQUESTS TO MAKE, PO. BOX 17046, NORTH HOLLYWOOD, CA 91615-9588 OR SUBSCRIBE ONLINE AT MAKEZINE.COM/OFFER OR VIA PHONE AT (866) 289-8847 (U.S. AND CANADA), ALL OTHER COUNTRIES CALL 650-487-2057. Subscriptions are available for $24.95 for 1 year (4 quarterly issues) in the United States; in Canada: $33.95 USD; all other countries: $49.95 USD. Periodical postage paid at Sebastopol, CA, and at additional mailing offices. POSTMASTER: Send address changes to MAKE, PO. BOX 17046, NORTH HOLLYWOOD, CA 91615-9588. Canada Post Publications Mail Agreement No. 4129568. CANADA POSTMASTER: Send address changes to: O’Reilly Media, PO Box 456, Niagara Falls, ON L2E 6V2
Building your very own cockroach cyborgs.

BY TIMOTHY MARZULLO, PH.D., AND GREGORY GAGE, PH.D.

You wake up with a desire to do some neural engineering. You open up your insect terrarium, bring out your pet flower beetle, your tobacco moth, or your cockroach, and turn on a switch on the insect’s back. With your remote control, you begin steering your insect around the room.
While this may sound like science fiction, remote controlled insects have been around for 15 years. Starting in the late 1990s, two groups of researchers (at the University of Tokyo and the University of Michigan) achieved rudimentary control of cockroach turning. The American work was undertaken with the ultimate goal of creating “hybrid robots” able to do disaster relief monitoring and reconnaissance. The work was published in small trade journals and received some press, but went largely unnoticed. The research eventually faded away, with the scientists working on other adventures.

Years later, two more universities (Cornell and UC Berkeley) achieved notable success and press for their proof-of-concept work in flying beetles and moths using modern small-electrode design and innovative surgical techniques.

Cool? Weird? Revolutionary? Horrendous? It depends on your disposition. Perhaps you’re inspired by these insect cyborgs and you want to work on such experiments as well. Unfortunately, unless you’re in one of these four research labs (a total of maybe 15 people in the world) you won’t have access to the extensive equipment and government funding required to build your robot insect interface.

A DIY Robot Insect Interface

Sound totally unfair? You’re in luck. For the past two years, we at Backyard Brains have been working to make neurotechnology previously found only in advanced research labs available to students of all ages (well, mainly over the age of 12). By making equipment that’s cheap and easy to use, we’re making it possible for everyone to do neuro-experiments and accelerate our understanding of the nervous system.

For our latest project, we wanted to develop a super-low-cost “RoboRoach” to demonstrate principles of neurostimulation to students. This project began as a senior design assignment we managed and sponsored at the University of Michigan in 2010. For cost reasons, we didn’t want to build our own remote control circuits from scratch, so we scoured toy stores for the smallest, lightest, cheapest remote control circuit we could find (a tough job, but someone has to do it). We settled on the Hexbug Inchworm, as the circuit is light (1 gram), runs on only 3 volts (so we can use a small coin cell battery), has 2 degrees of freedom, and costs only $20.

To steer the RoboRoach, we removed the circuit from the toy and fed the motor controller output into the cockroach antennae using very thin silver wires (0.003" in diameter, or 40 gauge). The neural tissue inside the antennae likes biphasic pulses (both + and – square pulses), but the Hexbug powers its motors with DC (direct current). We were able to convert this signal using the most common timer in existence, the 555 (actually, a low-power cousin, the 551). By configuring the timer chip into an astable mode and placing a capacitor on the output (removing DC offset), we were able to make the stimulator circuit deliver 55Hz pulses. This is right in the range that neurons prefer.

The final total package, which includes the connector, 2016 battery, our custom 551 circuit boards, and Hexbug platform, weighs 7 grams. A large cockroach weighing 3 grams can carry upwards of 9 grams for 10-minute experiments. The backpack is detachable so the cockroach only wears it temporarily (when not plugged in, the bug is free to eat fresh lettuce, drink water, make babies, run around in the dark, and do what ever cockroaches do and think about).

How to Steer a Cockroach

To get the cockroach to turn when running, we take advantage of its natural motor behaviors. Cockroaches like to run next to a wall. When their antenna brushes against something, they turn so that they’re running parallel to it. This is part of their “escape mechanism.” The biphasic pulses trick the bug into thinking it felt a brush on one of its antenna, by stimulating the nerves that normally conduct information about things the
“By making equipment that’s cheap and easy to use, we’re making it possible for everyone to do neuro-experiments.

antenna touches. The pulses cause the nerves to fire electrical messages (called “spikes”) to the brain. The end result is that the cockroach will turn in the opposite direction of the antenna we activate through stimulation.

As biologists, we must emphasize that the cockroaches are not really robots. They have fully functioning nervous systems that show some wonderful properties like learning and adaptation. The reason the research was never ultimately pushed further is that insects eventually learn to ignore the stimulation. Our brains (as do theirs) eventually disregard things that have no behavioral relevance (things that neither hurt nor help us). After approximately 10 stimulation trials, the cockroach turning response noticeably diminishes, and eventually stops all together.

But — if the cockroach is placed back in his cage for a couple hours, it forgets and the stimulation works again. After about a week, however, the stimulation stops working entirely. We don’t know why, but we suspect it’s most likely due to biofouling of the electrodes.

The RoboRoach Kit
That aside, we’re happy to report that after a year of development work, we have working prototypes and we’re beginning to demonstrate and distribute our remote control cockroach kits to amateurs, high schools, and universities. We’re also proud to say that the project was entirely self-funded, and the total prototyping cost (not including brainpower and labor of course) over the past year was in the neighborhood of $1,000.

There are real educational benefits to these bio-robots. The same techniques used in the

RoboRoach are also used in deep brain stimulation (DBS) for the treatment of Parkinson’s disease and in cochlear implants to restore hearing in the deaf. These clinical devices are still relatively crude and have much room for improvement. If more and more young engineers and biologists work on the problems of neural interfaces, perhaps a renaissance in neurotechnology and treatment of nervous system afflictions can occur.

We hope that what we had to spend taxpayer money and years of our time in graduate school to study (i.e., neurophysiology of the mammalian brain) will become accessible and common high school knowledge over the next 20 years.

If you’d like to learn more, please visit us at roboroach.backyardbrains.com.

Timothy Marzullo and Gregory Gage are the co-founders of Backyard Brains, which makes neuroscience kits for students.