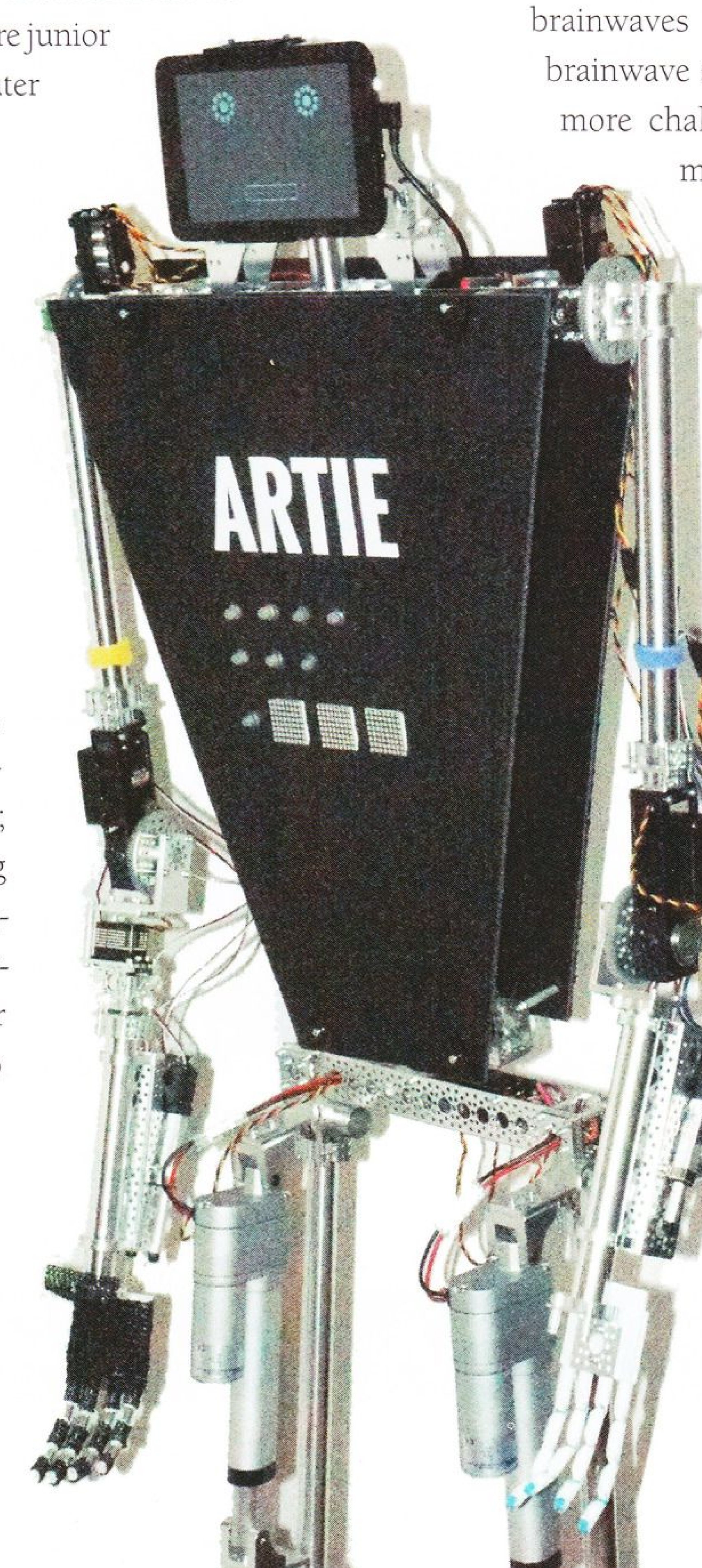
Turning Brainwaves into ACTION

by Ava Lakmazaheri

TWO SUMMERS AGO, I SAW A VIDEO CLIP OF A QUADRIPLEGIC WOMAN WHO, USING HER BRAINWAVES, CONTROLLED A ROBOTIC ARM TO PICK UP A THERMOS OF COFFEE AND DRINK FROM IT—WITHOUT HUMAN ASSISTANCE. THIS WAS A REMARKABLE MOMENT FOR THE WOMAN, WHO HADN'T BEEN ABLE TO PERFORM SUCH TASKS SINCE SUFFERING A STROKE 15 YEARS EARLIER. AS I WATCHED, CHEERING FOR HER, I KNEW I WANTED TO BE PART OF A TEAM RESPONSIBLE FOR PRODUCING SUCH LIFE-ALTERING TECHNOLOGIES.

In elementary school, I had built a few robots in an after-school club, and in middle school, I founded a VEX Robotics team. But after three years of building robots, I was ready for more. So, after having been exposed to some of the fascinating mysteries of the human brain through a school biology course, I decided to conduct research at the intersection of robotics and neuroscience. To facilitate my research, I spent the summer before junior year taking an online course on brain-computer interfaces and building a conceptual framework for my project.



Plan of Action

Early in the academic year, my school established a lab for underclassmen interested in pursuing independent research projects. I submitted an application and was granted space in the lab and offered mentorship by its director, Dr. Dan Burden.

My overarching goal was to build a humanoid robot and control it using my brainwaves. Previous work in this area had led to the quadriplegic woman's ability to control a robot using her brainwaves; I wanted to expand on this by developing a method that allowed the use of brain signals to actually program the robot to perform new tasks. The work entailed four key objectives: First, I had to find a way to record the user's brainwaves. Next, to interpret the user's intentions, I had to design an algorithm to process and classify these brain signals. I then needed a method to map the user's intentions into a set of machine instructions to be executed by the robot. Finally, I would have to build the robot and program it to perform the instructions.

Tools and Techniques

I first determined that the user would wear an electroencephalography (EEG) headset fitted with electrodes that would record brainwaves from the scalp. Deciphering the meaning of brainwave signals and translating them into intentions was more challenging. Did a particular EEG signal segment mean the user wanted to raise her left hand or her right? To grab the book from the shelf, or put it on the table? Trying to interpret someone's intent by looking at all the brainwaves related to the many muscles involved would be enormously complex.

I decided to simplify the process by having the user—in this case, me—consciously communicate their intent to perform an action by clenching their jaw. The jaw clenching could be varied in duration, creating a sort of Morse code performed using facial muscles. Instead of trying to analyze what all the EEG activity meant, the software I wrote needed only to detect the occurrence and duration of each jaw-clenching episode.

Next, I created an algorithm that defined what each jaw-clenching signal meant in terms of commands for the robot. Some commands are relatively simple (like "grasp"), while others involve a sequence of actions (like "pour from a grasped cup"). Simple commands can be executed sequentially to perform more complex actions.

Putting it All Together

To test the entire signal generation and processing scheme, I planned to build a life-size humanoid robot capable of object manipulation. I searched online articles and images to develop a basic understanding of design options. I also compiled a list of online stores that offered parts and components for the project.

Eventually, I settled on a skeleton-like design that could be assembled in minutes. To build it, I used readily available lightweight aluminum channels and tubes. To facilitate object manipulation, I gave the upper-body skeleton seven degrees of freedom. Each arm was fitted with three servo gearboxes for moving the shoulder, the elbow, and the wrist. I also placed a servo gearbox at the waist to allow the upper body to turn relative to the lower body, giving the robot the flexibility to reach target objects.

I then implemented an algorithm for calculating the shoulder and elbow servo positions in order to bring the hand near the target object when the user requests it. In this way, the user can focus on higher-level commands like "move the hand forward," while the system automatically performs the lower-level servo calculations using the algorithm.

A Robot is Born

Figuring out a hand design that was functional yet light enough for the arm proved challenging. After a few weeks of experimentation, I decided to construct the hand using styrene, a material that is light, easy to work with, and readily available. The hand consists of four fingers, each having three phalanges. Every finger curls closed when a string attached to it is pulled by a small linear actuator. The four linear actuators, when activated in a coordinated manner, enable the closing and opening of the hand for grabbing and releasing objects. I called my robot ARTIE, for Anthropomorphic Robot Trained vIa Electroencephalogram.

On a late December afternoon, I donned the EEG headset, started running the signal processing and control software, and turned on ARTIE's power switch. He was facing a table that held a few small objects, among them a yellow plastic ball. Clenching my jaw, I instructed ARTIE to raise his right arm, move it forward, turn his palm so as to place his hand over the ball, lower the hand, grab the ball, and then raise the hand up, lifting the ball off the table. At every step, I waited nervously for ARTIE to confirm my intended move via voice feedback before committing to it. My nervousness turned to excitement as he successfully completed move after move, until he had raised the ball in the air and eventually placed it back on the table. I was overwhelmed with a sense of joy and accomplishment.

Ava demonstrates ARTIE's abilities at the 2015 Intel Science and Engineering Fair.

With Dr. Burden's encouragement, I entered my project in my school's science fair, where it received positive reviews from my peers and high marks from the judges. This qualified me for my county's regional fair, where I won numerous awards and qualified for the state science and engineering fair. There, I was thrilled when the judges awarded me Second Grand Prize, a recognition that qualified me for the Intel Science and Engineering Fair (ISEF), where my project was recognized as the Best in Category for Robotics and Intelligent Machines.

I'm currently redesigning my robot to have it walk under the control of my brainwaves, and I've begun experimenting with other signal generation techniques to provide the user with the ability to transform brainwaves into natural language expressions that can be processed and executed by the robot—a system that more closely mimics natural human thought. Long term, I hope to create cost-effective commercial assistive technologies for people with physical disabilities. I look forward to working toward this goal in college and beyond. ■

Ava Lakmazaheri is a senior at Thomas Jefferson High School for Science and Technology in Alexandria, VA. In addition to her academic interests, Ava is a hip hop dancer who enjoys listening to music and performing with friends.