Engineering 2

[00:00:01.49] Now we're going to review some neural engineering devices that are on the market today. Before we start, a reminder of the parts of a brain computer interface. And remember that not all neural interfaces include all of these components.

[00:00:15.80] But the ones that we're going to talk about all have at least some of these, including sensors to detect information from your own body. Sensors to detect information from the environment, an encoding system-- such as stimulating electrodes-- to deliver feedback and sensory information to the user of the device.

[00:00:35.88] A recording system, such as implanted electrodes, that records information from the user's body in order to send it to an external device. An end effector, which means whatever the user controls. So prosthetic, a wheelchair, or a computer. Whatever it is that the user is controlling.

[00:00:56.69] A processing unit that handles both sensory and motor information, software that encodes or decodes information, a power source, and a case or implant site. And this isn't applicable to all of the devices. We also need to have a method of measuring how useful the device was to the user.

[00:01:21.50] Among the most common neural engineering devices are cochlear implants, which is used for deafness, specifically deafness caused by faulty hair cells. And we'll review that in the next segment of the course. The environmental sensor in this case is a microphone, which is mounted externally on the side of the user's head.

[00:01:41.93] The processor in software translates the microphone's information to a stimulation pattern, which it then delivers to the encoder, electrical stimulation of the spiral ganglia neurons. And this is permanently implanted. And this neural engineering device doesn't have any recording from the user or an end effector. Its power source is embedded inside of the microphone.

[00:02:06.53] And the case includes an internal component that is permanently implanted in the cochlea, to stimulate the spinal ganglia neurons. And the external component-- the microphone and the power source and the processor-- are all a single unit. Attaches via a magnet to the side of the person's head. So there's a magnet implanted under their skin, so they can pop off the external unit when they're in the shower or to replace the battery.

[00:02:37.64] Retinal implant are used for various forms of blindness, most commonly retinitis pigmentosa. And they're still currently in the experimental stage. They're not in widespread use like cochlear implants are. And they are implanted on the retina at the back of the eye. And they include a camera-- which is usually mounted on a pair of glasses-- to record visual information from the environment.

[00:03:03.97] A processing unit also located in that pair of glasses translates the image from the camera to a stimulation pattern, which is then used to provide electrical stimulation to the person's bipolar cells via an array of electrodes-- seen in the upper right photo on this slide-- that is permanently implanted on the person's retina.

[00:03:27.20] And much like cochlear implants, there is no recording from the user's own body or any end effector, anything that the user specifically controls. The internal component of the retinal implant is permanent, or at least more or less permanent. It could be changed out, but it would require significant surgery and could potentially cause damage to the retina. And the external component is located on a pair of glasses that can be swapped out.

[00:03:57.17] Vagus nerve stimulators are used for certain types of epilepsy, most commonly. And they stimulate the left vagus nerve, which is one of the cranial nerves that enters directly into the brain stem and bypasses the spinal cord. They're always used in the left vagus nerve, never the right. Because the right vagus nerve goes to the heart and the left does not.

[00:04:21.53] They can be triggered by a remote control by the user. They don't detect brain activity. They just stimulate continuously at a specific frequency or they can be manually triggered by the user. So the process here is very simple. It either triggers at a set rate every so often or it detects the remote control from the user to tell it when to go. And that's all it does.

[00:04:50.21] And it stimulates the vagus nerve in order to interrupt a seizure. So the vagus nerve travels to the brain stem. And then that information then gets passed on to the cortex. And normally, it carries visceral sensory information from your body. So if you can feel your heart rate or other internal sensation, that comes via the vagus nerve.

[00:05:15.02] And it can cut off a seizure before it starts. And it doesn't work for all types of epilepsy, but for the types where it does-- it is relevant, it can be very effective. And one of the major challenges with the vagus nerve stimulator is its battery life. So the processing unit and the battery are implanted in the person's shoulder.

[00:05:39.77] And the battery life depends on how often the person needs to stimulate. So both the automatic stimulation that just runs on its own at a set rate or the manual activation, the battery can range from 1 to 15 years of life. And if it needs to be replaced, then the person needs to have a relatively minor surgery. But they still need to have surgery in order to get that dealt with.

[00:06:07.17] Deep brain stimulators are also among the most common neural engineering devices that are currently on the market. They're most commonly used for Parkinson's disease and essential tremor, which has similar symptoms to Parkinson's. And occasionally, more rarely, they're used for the treatment of mood disorders, especially obsessive-compulsive disorder.

[00:06:27.99] For the treatment of Parkinson's disease, the implant is placed in the subthalamic nucleus or the globus pallidus, both of which are part of the basal ganglia. And we're going to review basal ganglia anatomy in more depth in a later portion of the course, in the motor anatomy portion of the course.

[00:06:45.87] Deep brain stimulators currently on the market only stimulate the brain at fixed intervals. The frequency of stimulation is not controlled by the user. But there is ongoing research into activity-dependent stimulation that will only turn on the deep brain stimulator when the person is moving, based on recordings from their primary motor areas.

[00:07:06.03] And this would be very useful, because it would save a lot of battery life, among other beneficial effects. So the processing unit of a deep brain stimulator only has to trigger stimulation at a set rate and in a set pattern. So it's a very strict forward processor. And it doesn't record anything from the user's brain in the currently available commercial models. And it stimulates at the selected location, which depends on the individual's specific case.

[00:07:40.38] The implanted battery lasts approximately five years, and is included in an integrated processor and battery unit that's implanted in the person's shoulder, much like the vagus nerve stimulator. So again, like the vagus nerve stimulator, replacing the deep brain stimulator's battery requires a minor surgery, but it does require surgery. In addition adjusting the settings of the deep brain stimulator also requires surgery.

[00:08:10.03] Muscle reanimation is a highly experimental technology that's currently only in use in a few individuals. It's used for paralysis due to spinal cord injury. And it requires that the user has functional muscles that can be controlled via electrical stimulation. So in this case, electrodes are placed on the surface of the brain to record-- from either the primary motor area or from the premotor area-- to detect what the user wants to move.

[00:08:42.78] The processor and software decodes the user's movement and tension from that signal recorded from their brain. And it identifies the desired movement for that limb. The end effector in this case, what the user is controlling, is their own body. Electrodes wrapped around the muscles of-- in this case-- his arm stimulate the muscles, based on the signal taken from the brain, and control his own body.

[00:09:12.39] The power source and case and processing unit in this device are all external. And it's very large. And it's not very portable at this stage. But eventually, we would want to have a power source and processing unit that could at least be carried in a backpack, if not be fully implanted.

[00:09:36.18] This user has one of the most advanced prosthetics currently available on the market. It could be used for amputation or congenital lack of a limb. In this case, it was an amputation. The biological recording and interaction is with the surviving nerves in the stump of his arm, where there are embedded sensors that record the neuron activity from those surviving nerves.

[00:10:01.18] There are also sensors in the hand on this prosthetic that can sense what he's touching and provide feedback to the user. Most prosthetics don't currently have that capability, but this particular one does. The processing and software is all embedded in the prosthetic. And it requires calibration every day for the motor decoding and for the sensory system.

[00:10:26.19] So he has an encoder in his shoulder that receives peripheral nerve stimulation based on the feedback of what he's touching with his prosthetic limb. And it records from the motor nerves in his shoulder, in order to control the movement of the prosthetic. More commonly, powered prosthetics record EMG from surviving muscles.

[00:10:52.56] And this particular prosthetic, he can open and close his hand, rotate his wrist, flex and release his elbow, and flex and release his shoulder. So it's not as much as his real arm can do, but it's still pretty good. And the commands of his arm are generated in this case, again, from implanted electrodes that are recording from peripheral nerves. But it could also be recorded directly from the brain, depending on the design of the device.

[00:11:27.06] And the power of this arm needs to be charged every night. So he has to plug his arm into the wall when he goes to bed. And everything is contained inside of this prosthetic unit, so there's no additional hardware besides what you see on his arm.

[00:11:42.46] This is another model of prosthetic arm control, in this case, again, for amputation. And in this user's case, they surgically reorganized surviving nerves in his deltoid muscles in his upper chest. And installed temporary electrodes that have to be replaced and recalibrated every day, in order to record from the surviving nerves.

[00:12:10.05] He was then retrained, through significant practice, to control both arms. So he can control both arms simultaneously, but for each arm he can only control one joint at a time-- wrist, elbow, hand, or shoulder. And the power is all integrated into the arm. And again, it has to be charged nightly. And the processor is permanently encased inside of the prosthetic. And the mounting in both of these prosthetics is not permanent. It has to be put on every day.

[00:12:41.25] The major downside of this arm-- relative to the other arm-- is that A, he can only control one joint at a time; and B, that he had to undergo significant behavioral training in order to learn how to use the reorganized surviving nerves in muscles that were not originally meant to control the arm. So the nerves ave been repurposed. And that required significant therapy.

[00:13:17.91] Besides controlling prosthetics, users can also control an external effector. Here, a robotic arm. This is primarily used for individuals who are paralyzed and currently only for those who have complete tetraplegia. So this woman has a degenerative disease and has no motor control over her body-- except for her face-- at all.

[00:13:39.00] She has installed cortical recording electrodes. And currently, this system does not provide any sensory stimulation to give her feedback of what she's touching. So she can control what she is looking at, but she doesn't actually feel anything. And it decodes what she's trying to do from electrodes that are placed over her primary motor cortex. And it transforms that into a movement for the robotic arm.

[00:14:06.39] You can also record from the premotor cortex, but this particular device reports from primary motor cortex. It controls this robotic arm. It could also be used to control a computer cursor or a wheelchair or anything else that she wanted to move. And everything in this case is external. The processing unit, the computer that does all of the recordings and decodings, and the power source are all not implanted in her body.

[00:14:34.36] So you can see, the researcher in the background of this is sitting at the computer that is decoding her motor signals from her brain. It's not part of her wheelchair. It's not implanted in her body. It's a standard desktop computer.

[00:14:51.24] Finally, orthotics and exoskeletons can be used for weakness, instability, or inappropriate range of motion in a limb. Either a limb that can move too far, that the joint is not stable enough to stay within the typical range of motion, or to help extend a range of motion that is not otherwise normally present. And it's usually just superficially attached to the limb. It wraps around.

[00:15:15.24] You have almost certainly used a very simple orthotic in your life when you have sprained an ankle or a wrist or sustained some other injury that a standard brace is considered a type of orthotic. Most common types of orthotics do not have any software or any power. They just wrap around the limb and mechanically induce the changes to stability or strength through a mechanical process.

[00:15:41.22] But there are powered versions that can detect the intended magnitude of the movement, usually through EMG, and provide additional strength or stability based on that intended signal. So this would be used in instances where a person has reduced strength or stability but can still control their limb.