Wireless systems could improve neural prostheses

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Wireless systems could improve neural prostheses

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A wireless address event representation protocol could find use as a low-power, asynchronous system to record neural activity and act as an interface between prosthetic devices and the brain.

In the past, doctors usually treated disorders of the nervous system by substitution instead of correction, including wheelchairs for walking, braille for text, and sign language for speech. However, as our understanding of the nervous system increases, so does our ability to treat its disorders with neural prostheses that directly stimulate the nervous system. Cochlear implants are one example of neural prostheses. Control of such prosthetics with brain-derived electrical signals is now possible due to the development of microelectrode arrays such as the Utah Intracortical Electrode Array (UIEA), the University of Florida flexible substrate microelectrode array, and others.[1–3] A large number of microelectrodes are typically needed, especially when interfacing with the central nervous system to restore a sensory function such as vision or hearing, because the quality of perception increases with the number of stimulated sites and the stimulation rate.[4–6]

On the other hand, using a large bundle of ultra-thin wires that pass through the skin to record neural activity from implanted microelectrode arrays introduces significant technological hurdles for the development of practical prosthetic devices. Communication with implanted microelectrodes is better accomplished wirelessly. The Interstim-3 and the UIEA-based telemetry circuit are the state of the art in microelectrode arrays with wireless transmitters mounted on them.[7,8] Both systems face major challenges, however, including crosstalk and digital interference. An additional limitation is that data transmission in these systems is based on fixed data rates and synchronous protocols, in which actions occur at specific times. An asynchronous scheme, in which actions occur in response to a signal, would provide more flexibility and adaptability to different environments.

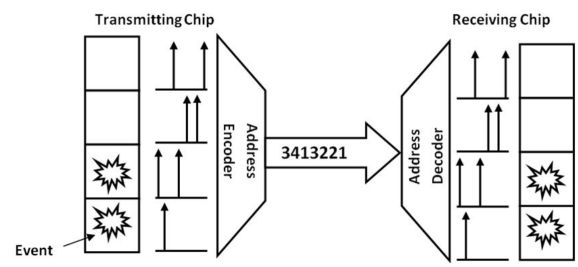

Figure 1. *Standard address event representation (AER) protocol. The address of the spiking neuron is encoded as a unique binary address, which is broadcasted on a digital bus. The decoder on the receiver decodes the address and directs the signal to the appropriate location. The diagram is modified from another paper.*[9]

Address event representation (AER) is such a protocol, and one that has been used to transmit neural signals. As a data-driven digital multiplexing protocol, it provides a more life-like method for transmitting many impulses down a single wire/channel. Figure 1 illustrates the standard (wired) AER protocol. We are developing a system that transfers the AER protocol from the wired to the wireless domain. Such a system will provide both asynchronous stimulation and recording of neural activity.

Wireless address event representation system

Our wireless AER system enriches the standard AER protocol by encoding both the neuron's address and the data in every spike. Event generation here is similar to that in the standard AER protocol. Each neuron on the transmitting chip generates a unique pseudorandom (PRN) code with sensor data encoded as a delay in the code transmitted to the receiving chip. The codes from all the neurons are combined to create the signal that is sent to the receiver. At the receiver, each decoder block generates a reference code, namely the same PRN code as its complementary transmitting neuron. This reference code is correlated with the received signal to extract the component that corresponds to the

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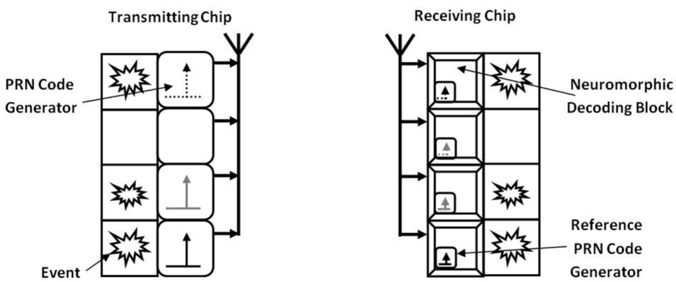

Figure 2. *Our wireless AER scheme. Neurons in the transmitting chip generate unique PRN codes and send data as a delay in their unique code sequence. At the receiver, each decoding block generates the same PRN code as its complementary neuron and correlates it with the received signal to extract its component of the received signal.*

signal transmitted by the complementary neuron, as illustrated in Figure 2.[10,11]

Neuromorphic cross-correlation decoder

The received signal is a mixture of the PRN codes transmitted by the neurons on the transmitting chip. To extract the delay corresponding to a particular neuron, the received signal is correlated with a synchronized replica of the PRN code (the reference signal) for that particular neuron. This decoding mechanism uses integrate-and-fire neurons for its correlation operations as a low-power alternative to mathematical computations.[10,11]

The neural decoder consists of two integrate-and-fire neurons, a counter and an interspike interval histogram (ISIH) accumulator. The received signal is the input to one neuron while the reference signal is the input to the other. Initially, one neuron is integrating while the other is in an inhibited state. When the integrating neuron fires, it both inhibits itself and disinhibits the other neuron, resulting in alternate integrate-and-fire periods for the neurons (see Figure 3).

Results and Discussion

We implemented this system in MATLAB to explore the functionality and limitations of the approach. Each sensor transmits a unique phase-delayed PRN code with the phase delay corresponding to the sensor data. The codes from multiple sensors are added together and ‘transmitted’ to simulate the combined received wireless signal. At the receiver, each decoder block generates the PRN code of its corresponding sensor as its reference signal. The reference signals are correlated with the received signal using the neural correlation decoder, and the sensor data corresponding to each sensor is extracted from the ISIH output of the accumulator. Figure 4 shows the ISIH output of a single neu-

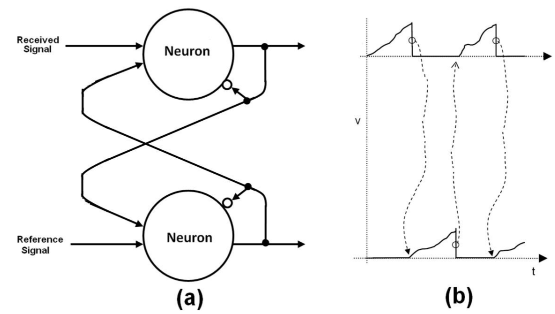

Figure 3. *(a) Neural circuit showing the coupling of the two integrate-and-fire neurons in the neural decoder. (b) Simple plot demonstrating the alternating integration periods for the neurons.*

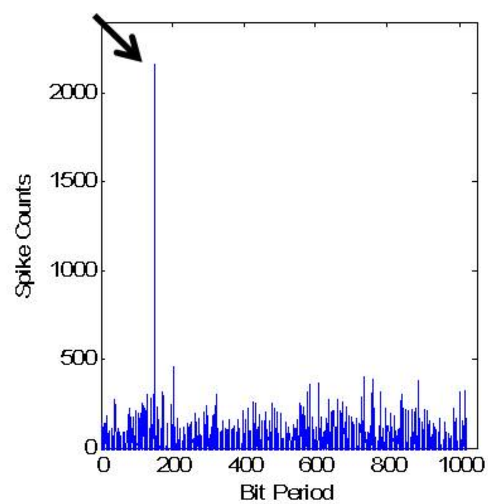

Figure 4. *The output of the interspike interval histogram (ISIH) accumulator when a single neuron is transmitting a 150bit phase-delayed version of its PRN code.*

ral decoder block when a single neuron in the wireless AER system is transmitting a phase shifted form of its PRN code. The decoder is able to find correlated terms and extract the delays from a signal containing a mixture of six distinct PRN codes.

The system requires the whole PRN code to cycle through the correlator multiple times in order to extract correlated terms using a single decoder block. Using multiple parallel decoder blocks reduces the number of cycles necessary. The need for multiple cycles or larger parallel circuits makes it difficult for the system to replace the standard AER scheme in all situations, but it would be beneficial in situations in which using wires would be difficult.

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Conclusion

We have introduced a wireless address event representation based system with a potential application in stimulating and recording neural activity in the brain. Both the address of and the data from spiking neurons are encoded in each spike. A low power neural cross-correlation decoder is utilized to extract this information from the transmitted signal. This improves the current AER methodology by allowing simultaneous transmission of multiple signals. However, the capacity and bandwidth of this system must be increased for practical use. This is the subject of ongoing work.

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