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Wireless radio-frequency network of distributed microsensors

Distributed sensing of a dynamic environment is typically characterized by the sparsity of events, such as neuronal firing in the brain. Using the brain as inspiration, an event-driven communication strategy is developed that enables the efficient transmission, accurate retrieval and interpretation of sparse events across a network of thousands of wireless microsensors.

This is a summary of:
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The problem

Electronic sensors are increasingly prevalent in the world around us. For applications such as wearable and implantable biomedical sensors there is a particular need for unobtrusive microdevices that operate autonomously as large ensembles to map physiological activity across a body area of interest. A challenge is how to construct a wireless network whereby aggregate data from a large microsensor population are transmitted, received and decoded, to unpack data from the individual sensors. Similar to a population of radiofrequency (RF) identification tags, the data must be read at once by a single transceiver, but with the major complication that the signals at each sensor location vary both in time and in magnitude.

A brain–computer interface presents a paradigm of such a problem: how to capture neuronal signals at high resolution with a population of autonomous brain-implanted microsensors. Ongoing research in the development of brain–computer interfaces is focused on several schemes through which access to thousands of points in the cortex is sought to translate brain computations into useful electronic commands, such as for intended speech[1,2]. The neurotechnology problem is in fact threefold as it requires the unobtrusive recording of electrical signals from the brain, the wireless transmission of data to a body-external receiver and the decoding of the signals in real time.

The solution

Our work focused on an all-in-one approach to build a large-scale wireless microsensor network. Specifically, we developed an RF transmission scheme whereby an external transceiver collects data while supplying wireless power to the sensors (Fig. 1).

Each sensor is a submillimetre-sized silicon system on chip with custom circuitry designed for event detection, which involves the conversion of time-varying sensor inputs into a series of short 'spikes'. This brain-inspired method of encoding data from sparse events has emerged over the past five years in dynamic vision cameras[3,4]. The spike train data are then converted into digital form on chip and transmitted to a common receiver. As only the event-driven spikes are transmitted through the network, the bandwidth of the communication system can be used very efficiently, enabling a large population of sensors to be incorporated into the network.

Using 78 fabricated microchips, we experimentally characterized the network performance, demonstrating that it achieves a low error rate and efficient, asynchronous spiked-based wireless transmission. Moreover, in silico simulations indicated the extended applicability of the network to thousands of nodes. For example, in a network simulation of 2,000 sensors, we collected approximately 100,000 events per second, achieving an error rate below 10^{-3}.

Importantly, the event-sensing detection and wireless communication approach is suitable for use with neuromorphic computing techniques for analysing multisensory data. This is because the event-detecting microchips output data in the form of spikes, which is the main currency used in neuromorphic computing[5], for which low-power hardware is now available. Demonstrating the scalability of the wireless network, we decoded in silico actual brain data (synthesized elsewhere from primate brain recordings) from a hypothetical implant composed of up to 8,000 microsensors.

Future directions

We have demonstrated a brain-inspired approach for wireless transmission by large ensembles of autonomous event-sensing microsensors. The ability to record data wirelessly from many silicon microchips no bigger than a grain of salt offers opportunities beyond neurotechnology for broader biomedical use.

A general challenge is to meet the regulatory limits on allowable RF exposure from biomedical implants (currently, our wireless transmission operates near 1 GHz); however, through the wireless link between the external RF transceiver and the microchip population, it is possible to take advantage of bidirectional communication for 'smart' management of the RF exposure. Additionally, further optimization is required to reduce the power at each sensor to microwatt levels (from approximately 10 µW currently).

More generally, we believe that this work presents opportunities for the wider sensor community to explore applications in which distributed sensing is important, such as in monitoring any complex dynamic environment and inferring its probable trajectory.

Jihun Lee & Arto Nurmikko
Brown University, Providence, RI, USA.

FROM THE EDITOR

"Wireless communication schemes that work with large networks of autonomous sensors are needed for a range of applications. In this work, the researchers have developed an approach that ensures real-time information can be collected from microchip sensor networks, with spectral efficiency, low error and without the need for complex network synchronization methods." **Stuart Thomas, Senior Editor, *Nature Electronics*.**

FIGURE

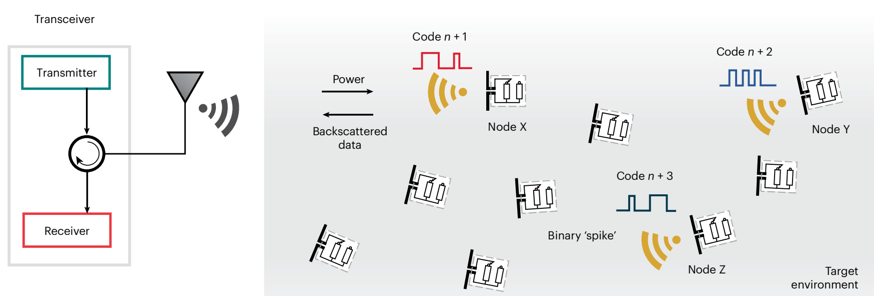

Fig. 1 | An event-driven microsensor communication network. Each node detects sparse binary events and asynchronously transmits these through backscattering of electrical spikes. Data on each chip are encoded with a unique RF identifier sequence (coded as $n + 1$, $n + 2$ and $n + 3$). At the transceiver, data from each sensor can be accurately recovered with minimal error. As the sensors transmit signals only when events are detected, the event-driven communication strategy conserves the RF bandwidth, enabling fast population-level decoding. © 2024, Lee, J. et al.

BEHIND THE PAPER

It is well known in neuroscience that while the brain processes information with astonishing efficiency, the neuronal activity is sparse. Contemporary research into brain–computer interfaces, including work in our laboratory, using microelectrode arrays to record from individual neural cells shows that collecting and extracting spiking data is a resource-intensive and inefficient process. To address the inefficiencies and bandwidth constraints, particularly with an eye towards fully wireless, high-performance brain implants, we drew inspiration from the brain's own mechanisms to develop a wireless sensor network concept, whereby signals are only transmitted when necessary to generate electrical spikes. Beyond contributing to brain–computer interface technology, we hope that this approach can offer a solution to a broader range of applications that require large-scale spatially distributed wireless sensor networks to track and characterize complex and dynamic environments in real time. **J.L. & A.N.**

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