Puggle: a miniature, real-time data acquisition and processing system for closed-loop electrophysiology

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***Abstract*—Puggle is an ARM®-based, real-time data acquisition and processing tool. It is designed to sense, process, and react to analog input signals in hard real-time. Puggle encompasses a set of hardware and software modules that (1) provides hard real-time, unbuffered data acquisition from up to thirty-two ±5 mV and/or four ±4 V, 16-bit inputs, (2) provides signal generation from four ±4 V 16-bit outputs, (3) allows easy reconfiguration, and (4) is low cost. To meet these goals, Puggle has leveraged the growth of the mobile computing industry and recently available integrated circuit solutions for multichannel bio-signal amplification, filtering, and digitization.**

There are currently more than 1 billion smartphones in use around the world. The explosive growth of mobile computing has driven the development of powerful, low-cost chipsets for embedded processing. Simultaneously, recent studies have begun to demonstrate the power of a closed-loop approach for dissecting neural function and improving sensory prostheses [1], [2]. The ARM® architecture encompasses a family of reduced instruction set processor designs that are low-cost, high-performance, and intended for high-speed peripheral interfacing. This makes them well suited for real-time data acquisition and processing in neuroscience research.

Here we describe a miniature data-acquisition system capable of hard real-time interaction with neural tissue, called Puggle (http://www.puggleboard.com). Puggle encompasses a set of hardware and software modules built around the BeagleBone Black, a 45 USD, credit card-sized, AM335x 1 GHz ARM Cortex A8-based Linux computer produced by Texas Instruments (Fig. 1(b), www.beagleboard.org). Puggle's hardware and software modules are as follows:

- **PuggleBoard** Expansion board for the BeagleBone offering four channels of ±4.096V 16-bit analog I/O and 8-bits of GPIO (Fig. 1(a))
- **PuggleBOBs** Break-out boards (BOBs) offering passive BNC connectivity, CMOS-to-TTL conversion, and low-voltage differential signal conversion to communicate with Intan chips (http://www.intantech.com/)
- **Puggle Drivers** Driver set which uses the AM335x's integrated programmable real-time co-processor
- **Puggle API** Programming interface for designing custom real-time protocols to run on the ARM processor
- **Puggle Linux** RTLinux variant that combines the lightweight Angstrom distribution with the Xenomai real-time development framework (www.xenomai.org)
- **Puggle Streaming Modules** Kernel modules for streaming data to host applications. e.g., Real-Time eXperiment Interface (Fig. 1(c), RTXI, www.rtxi.org)

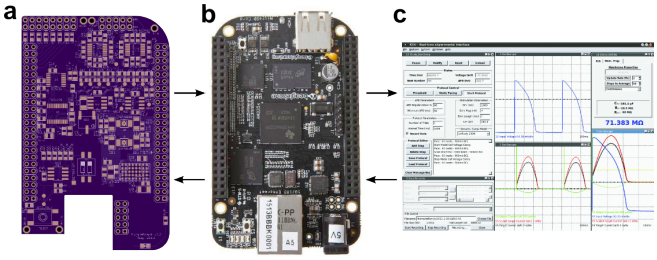

Fig. 1. **Puggle integrates with existing open-content hardware and software to provide a low-cost, hard real-time data acquisition and processing. (a)** The PuggleBoard. **(b)** The BeagleBone Black (www.beagleboard.org). **(c)** Screenshot of the RTXI user interface.

Because Puggle's embedded processor runs RTLinux, it is highly configurable and can stream data to a number of host applications using standard function calls. This makes Puggle useful for established forms of real-time electrophysiology, such as dynamic clamp, and for emerging technologies that require real-time processing of multielectrode data [1], [2]. The PuggleBoard is capable of unbuffered acquisition and processing from four 16-bit analog inputs and up to 8 single-ended digital input/output lines at 100 kHz/channel. It can generate four channels of 16-bit analog output with worst-case 50 microsecond jitter relative to input samples at 100 kHz/channel. An optional BOB provides 2-bus LVDS conversion for driving two 32-channel Intan bioacquisition chips (http://www.intantech.com/), allowing a total of 36 analog inputs at 25 kHz/channel. The entire system operates from a single 5V DC supply.

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References

[1] J. P. Newman, R. Zeller-Townson, M. f. Fong, S. A. Desai, and S. M. Potter, "Closed-loop, multichannel experimentation using the open-source NeuroRighter electrophysiology platform," *Front. Neural Circuits*, vol. 6, no. 0098, 2013.

[2] D. H. O'Connor, S. A. Hires, Z. V. Guo, N. Li, J. Yu, Q.-Q. Sun, D. Huber, and K. Svoboda, "Neural coding during active somatosensation revealed using illusory touch," *Nat. Neurosci.*, vol. 16, pp. 1–11, 2013.