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Neural Signal Sampling via the Low Power Wireless Pico System

Grzegorz Cieslewski, David Cheney, Karl Gugel, Justin C. Sanchez and Jose C. Principe

Abstract—**This paper presents a powerful new low power wireless system for sampling multiple channels of neural activity based on Texas Instruments MSP430 microprocessors and Nordic Semiconductor's ultra low power high bandwidth RF transmitters and receivers. The system's development process, component selection, features and test methodology are presented.**

I. INTRODUCTION

A fundamental challenge in Brain Machine Interface (BMI) multiarray electrophysiology experiments is instrumenting behaving animals with hardware for data transmission and collection. Traditional BMI bench designs use commutators and complex cabling that tethers the subject and impede behavior in operant conditioning scenarios. Wired paradigms of this type present a challenge both to the animal and the experimenter. First, the animal must behaviorally contend with the new sensation of being tethered. Typically, it can take an animal several sessions to become acclimated; this is valuable time lost for recordings from chronic microelectrodes. Moreover, as behavioral paradigms become more complicated it becomes difficult to move all of the wired instrumentation along with the animal. Commutators allow 360 degree rotation of the cable and to prevent torque from being applied to the electrode implant and causing it to be torn from the skull. The most advanced minature commutators allow a limit of 36 wires for low torque brush type systems. As we begin to probe in more detail systems of cortical neurons with more microwires, we will eventually reach a fundamental limit in commutator design and fabrication.

The degrees of freedom (materials, electrode design, amplification, A/D, wireless) to accommodate the experimentalist and engineering are enormous, and are visible on the very different engineering solutions proposed and implemented by several research groups [1-11] Other laboratories use wireless links, but a large backpack is still necessary [12-17]. Other wireless systems are underdevelopment but they are still larger and require more power and data bandwidth per channel than our proposed system.

Recording systems require high data rate transmission from an implanted unit to an external device and data bandwidths in excess of 1Mb/s are typically required to monitor neural signal activity from multiple electrodes.

Our goal is to replace the multi-conductor cable with a high bandwidth low power wireless interface to allow the subject more mobility and a more natural response to a given experiment. Moving to wireless interface presents new challenges pertaining to size, weight, and power consumption of the remote device. In order to meet the reduced bandwidth of the wireless link, the remote device must compress data locally. This creates a trade-off between power consumption and processing power. To address this trade-off we chose all off-the-shelf components and specifically selected the MSP430F1611 as the micro-controller. This device only consumes a few milli-Watts of power for 8 MIPs of processing and has the added benefit of conserving space by integrating a UART and multi-channel 12 bit A/D converter all in one small package.

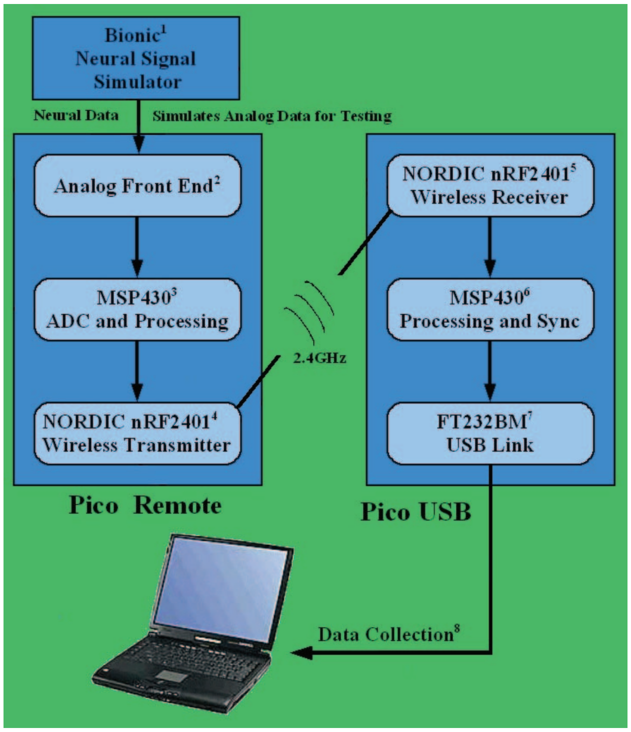

Figure 1. Neural Data Collection via Pico Remote & Pico USB

II. FUNCTIONAL DESCRIPTION

The basic Pico data collection system is comprised of two main components, a smart transmitter and USB enabled receiver. The transmitter is known as Pico Remote and the

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Grzegorz Cieslewski is a PhD student in Electrical Engineering at the University of Florida, Gainesville, FL 32611 USA (email: grzegorz@ufl.edu).

David Cheney is an electrical engineer working as a consultant for CNEL at the University of Florida, Gainesville, FL 32611 USA (email: djcheney@ufl.edu).

Karl Gugel is a lecturer and researcher in Electrical Engineering at the University of Florida, Gainesville, FL 32611 USA (email: gugel@ecel.ufl.edu).

Justin C. Sanchez is with the Department of Pediatrics, Division of Neurology, University of Florida, Gainesville, FL 32611 USA (email: jcs77@ufl.edu).

Jose C. Principe is a distinguished professor in Electrical Engineering at the University of Florida, Gainesville, FL 32611 USA (email: principe@cnel.ufl.edu)

receiver is termed Pico USB. See Figure 1. Simulated neural pulses from a Bionic Neural Simulator[1], which are presumed to be of similar voltage levels and spike shapes as actual data sampled from neural probes, are sent to an analog front end[2] on the Pico Remote. The signal is amplified and fed to one of eight 12 bit A/D channels[3] on the MSP430.The MSP430 is then used to perform spike detection through traditional threshold schemes. Spikes are time stamped and sent out the Nordic transmitter[4] for reception by Pico USB.

The Nordic receiver[5] is capable of 1Mbit/sec sustained data transfer and is again fed to another MSP430 processor[6] for buffering/formatting and eventual pass through to a USB FT232BM bridge[7].

The Pico Remote has evolved from several early designs whereby one of the first designs consisted of several boards connected together using male headers and female receptacles and a cable-like interface for the analog front end. See Figure 2.

Presently all the main subsections have been integrated into one 1.35” by 2.8” board and it supports 8 channels of sampling on a single side with future plans to put circuitry for another 8 channels of sampling/processing/transmission on the other side. See Figure 3.

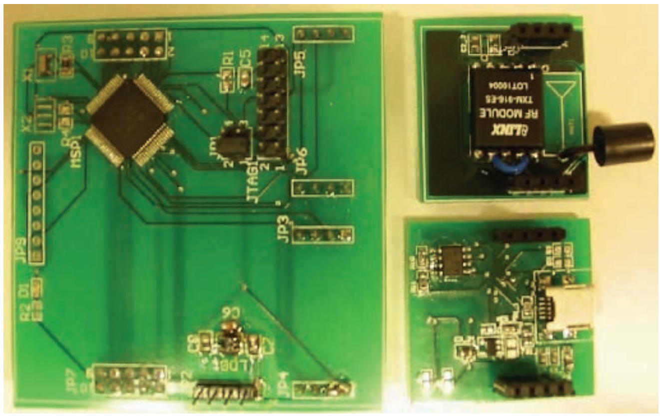


Figure 2. MSP430F1611 Controller Board, RF Tx Board and Optional USB Interface Board

In the current Pico Remote shown in Figure 3, there are eight analog amplifiers are on the left side of the board. The larger chip in the middle is the MSP430F1611 and on the far right is the wireless Nordic interface. Just above and below the wireless interface are ultra miniature connectors used to expand the number of channels by stacking boards immediately above and below.

Each analog amplifier consists of two stages. The first stage (INA118) amplifies the signal by 60dB, removes the common mode, and performs a high pass filter. The second stage (LMV821) increases the gain to 79.5dB and performs a low pass filter. Overall, the bandwidth of the amplifier is 340 Hz to 5.21 kHz.

The MSP430F1611 processor samples each analog channel at 20kHz with a 12 bit A/D converter. The wireless link consists of a small Nordic nRF2401 transceiver IC and has a small surface mount antenna. The link has been shown to have error-free transmission up to six feet line-of-sight. We have seen 75 ft. line of site transmission when using the Nordic development boards and feel we can match these results if better impedance matching antenna circuits are used. We opted to use the Nordics low-power mode, capable of up to 30KB/s (240Kbit/s), instead of the higher speed 1M bit/sec mode to reduce the power consumption initially. The lower power mode consumes roughly 8-10mA for data transmission and is roughly double these numbers for the higher data rate.

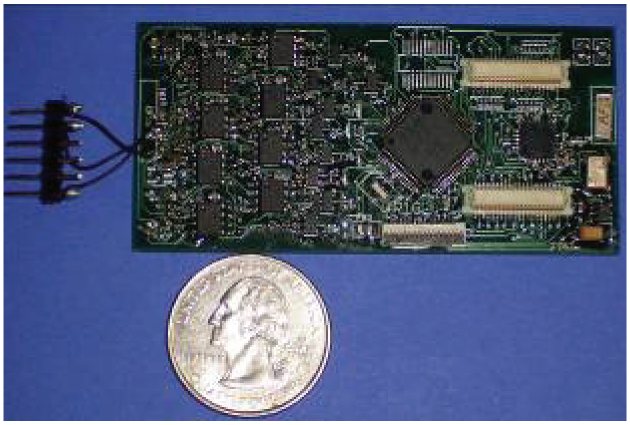


Figure 3. Current Pico Remote

As previously mentioned, the connectors on the right of the board allow the connection of multiple boards directly on top of each other to dynamically add additional channels. Future designs of the PICO stack could allow as many as eight boards with 16 channels each, along with a DSP layer that will process the entire stack to assist in performing data acquisition, wireless transmission of data, and LMS processing. See Figure 4. The DSP layer is based on the TI TMS320VC33 and is presently under development.

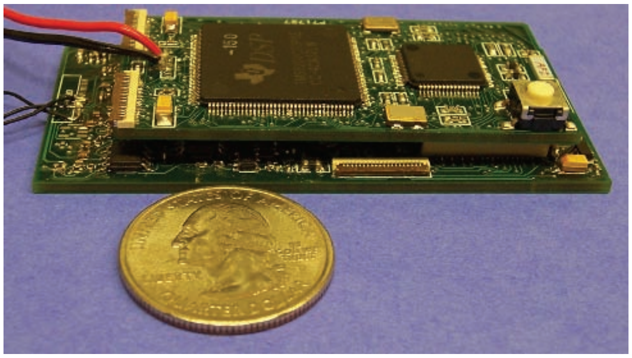


Figure 4. Example stack consisting of a PICO Remote (bottom) and a TMS320VC33 DSP (top)

On the receiving side of the RF link data is collected via a Nordic nRF2401 receiver on Pico USB. The RF link is controlled by another MSP430F1611 microcontroller and results are passed on to the PC (laptop) via a USB bridge (FT232-BM from FTDI). The maximum theoretical throughput of the USB bridge is 3M bits/sec.

III. User Software & Functional Testing

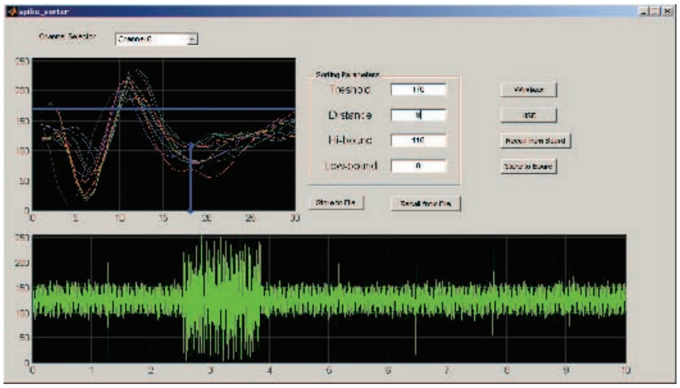
Since invasive microwire recording technologies are targeting single unit neuronal activity, we will use the action potential (spike) as our standard for evaluation of data collected from the neural probes [18]. To configure the spike detector used on the Pico Remote, a user interface on the receiving laptop was needed. This interface was created with a Matlab GUI and functions written in C. This interface is divided into two pieces:

1. Spike Detection Parameter Initialization
2. Binned Spike Data (firing rate) Display

A. Spike Detection Initialization

Beginning with spike detection parameter initialization, the top left window is used to perform spike sort whereby two sets of threshold parameters can be entered for a 30 sample window. See Figure 5. This information is then downloaded to the Pico Remote for real-time spike detection and transmission. The spike sorting algorithm is the typical neural sorter where a threshold, upper and lower bounds interval are employed.

A raw sample neural channel is also displayed in this window and the system presently can transmit only one channels of raw data (20K Hz 12 bit sampling) per Pico Remote. See the lower window in Figure 5. The bottom graph shows collected spikes versus time over the past 10 seconds of analog activity on the channel and is simply used to display the spike congestion in a real-time manner. Each of the eight channels can be configured and viewed one at a time. Two pair of individual threshold parameters can be set for each channel. After configuring a channel, you transmit a change channel command back to the remote to select the next channel for configuration.



Treshold 170
Distance 8
Hi-bound 110
Low-bound 0

Figure 5 Spike Threshold Config Window
(Pico USB Laptop Software Interface)

B. Binned Spike Data Display

Binned spike data can be displayed in the "run mode" after the channels have had their thresholds configured. See Figure 6. The Y axis is the number of spikes and the X axis is a 100mSec bin, spanning the past 10 seconds of binned data which equates to (100) 100mSec bins.

C. Bionic Simulator Functional Testing

The Bionic Neural Simulator was used to test the analog front end. This unit was employed to create simulated neural signals consisting of spikes, noise and other interference and this signal was input to the PICO Remote. The raw analog signal was then wirelessly transmitted to the PICO Receiver for analysis with our custom software as well as to file for viewing in Matlab. Figure 7 and 8 are Matlab snapshots of unprocessed analog neural data. Figure 7 displays a window of 3,500 samples while Figure 8 displays a zoom in of a single spike in a 160 sample width window.

IV. RESULTS RELATING TO SPECIFICATIONS

Power consumption of the PICO Remote has been measured to be approximately 106mW. However this measurement was done during the continuous transmission of raw analog data and therefore should significantly decrease for transmission of bin data and/or time stamped windows of detected spikes. We are presently developing this software and will present more power consumption numbers at a later date.

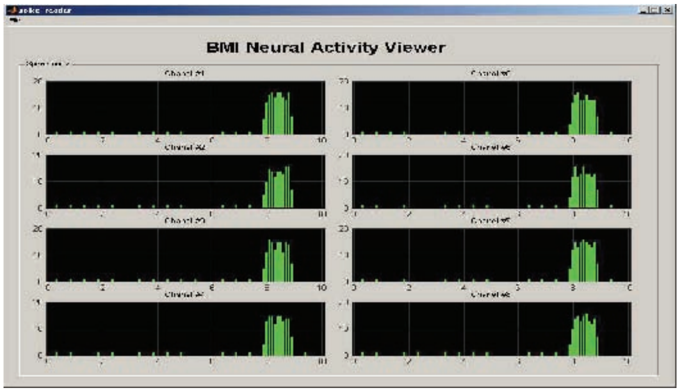


Figure 6. Real-time Binned Data Display
(Pico USB Laptop Interface)

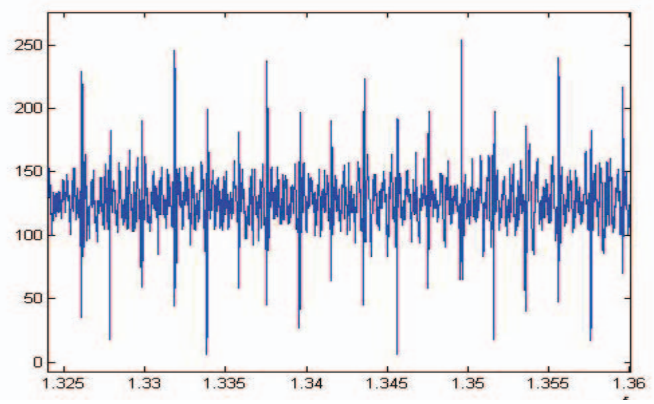


Figure 7. Real-time Raw Bionic Neural Data (Matlab Display of 3,500 Samples)

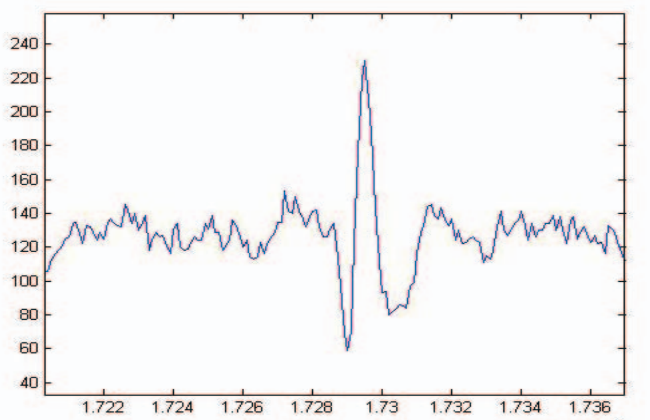


Figure 8. Real-time Raw Bionic Neural Data (Matlab Display 160 Samples)

Because the microcontroller is being clocked at 8 MHz, it has a theoretical peak performance of 8 MIPs. This speed supports spike threshold detection for two pairs of thresholds on eight analog channels. Recently, TI has released a new ultra low power family of MSP430F2XX microcontrollers which can be clocked at 16 MHz and thus these numbers can theoretically be doubled. The 250K bit/sec wireless link easily supports transmission of 8 channels of binned spike data. However this rate is barely fast enough for the single raw data transmission. It also is not fast enough for transmission of 30 samples per spike (spike window) on spikes occurring often on the eight channels. Hence we have plans to move from our very small lithium ion watch button battery power supply to a much larger lithium ion camera battery. This will enable us to increase the transmission rate to the Nordic's fastest 1M bit/sec rate.

V. CONCLUSIONS & FUTURE WORK

The accomplished goals to this point were to design, develop, and functionally verify the Stackable PICO Remote and PICO USB hardware. The wireless link is fully operational and working for full analog data or binned data.

There is still additional work to be done on the analog amplifiers to reduce input noise and on the number of bins per channel transmitted. We also would like to be able to transmit a time stamped spike for at least 3-4 sets of threshold parameters.

To address these issues, a custom analog amplifier is under design that will require less power and consume less board area. This amplifier is being designed by the analog IC designers in the Computational NeuroEngineering Lab under the guidance of Dr. J. Harris and will contain eight channels of amplification in a single chip. As an interim fix, we are going to use the head-stage pre-amplifier available from Tucker Davis Technologies. We are confident that with this neural probe impedance matching front-end, we can acquire low-noise signals with our existing analog front-end.

It is also planned to migrate to the faster MSP430 device which can execute at 16 MIPs and greatly increasing the stored power with newer slightly larger lithium ion batteries. We are also considering piggy backing a small TI TMS3202X DSP to act as a co-processor for threshold detection, bin counting and data compression.

With respect to the wireless link we have found blind spots when the Pico Remote is turned in a particular direction away from Pico USB. To address this and greatly improve the reception, we are working on adding additional receivers connected to Pico USB through RS485. We have found that the Nordic device has a very nice feature in that multiple receivers can be used in parallel and polled to see who has received the current packet error free.

Our present software on the Pico Remote is also being optimized to allow for more threshold computations per channel and to connect data as packets of 100ms bins instead of the current protocol where individual packets are sent as ten 10ms packets. This will free up time on the transmission of the data because while the overhead per packet does not change, the actual useable data in the packet is being increased ten times.

With respect to the MatLab GUI, it is fully operational; however, it takes up a large amount of resources and is complex. Development has started on a new configuration application, designed as stand alone 'C' windows application. The real-time binned data application will remain in MatLab, but development of more functions that are MatLab compatible will be developed, giving the end-user all the flexibility that comes with MatLab.

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