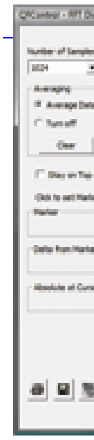
Patient Monitoring via Wireless Sensors: Challenges in Precision Filtering at Minimal Power Levels

Dennis Best, Quickfilter Technologies

Medical Design

Wireless sensors are proliferating across a variety of monitoring applications, from the health of industrial machinery, tire pressure in automobiles, to home security applications. A large growth area for wireless sensors is in healthcare for remote patient monitoring. Many of the largest semiconductor companies have announced



[1]

strategic emphasis on medical electronics, and an Intel led consortium, the Continua Health Alliance, has been formed to &quotestablish an ecosystem of connected personal health and fitness products and services, making it possible for patients, caregivers, and healthcare providers to more proactively address ongoing healthcare needs.&quot (Intel press release: http://www.intel.com/pressroom/archive/releases/20060606corp_a.htm.)

The key to providing the connectivity envisioned is low cost, low power (typically battery operated), easy to use but highly reliable wireless sensors for a wide range of basic healthcare measurements. A typical application consists of one or more wearable or patient located sensors (blood glucose, blood pressure, blood oxygen, heart rate, neurological activity, EKG, etc.) communicating wirelessly with a local Personal Computer (PC) connected to the Internet, or connected to a cell phone with Internet capability. The time-stamped patient measurements must be transmitted to a server that can be interrogated by the patient’s professional healthcare provider, thus providing a more detailed look at patient health than is possible with visits to a doctor’s office.

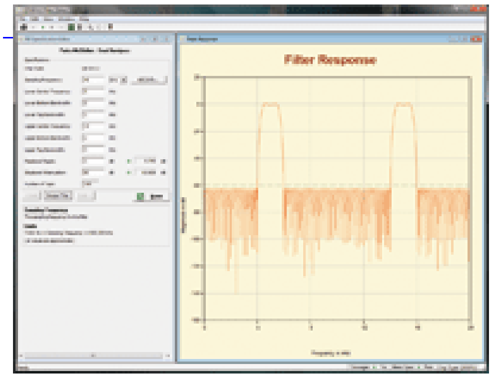
Challenges

There are several architectural and device challenges to implementing the required sensors, but the basic technologies are in place. Architecture trades must consider how much processing must be in the sensor versus the network processors &#151 essentially a trade of local performance versus required communication bandwidth and data—self-test to assure accurate data, ease of use and integrity of the (hopefully non-invasive) connections to the patient, adaptability of the necessary processing and filtering of the sensor data and local or remote storage of the different program files thus required. Implementation trades must consider the power/performance of the sensors, communications, and processing elements, and the power management techniques employed to optimize battery life.

The precision filtering required by these sensors is typically the most computational intensive operation, and thus the most power consuming function, in the wireless sensor. Earlier home use medical sensors often used analog filters, but these devices do not provide the low (battery operated) power, adaptability, precision, and stability needed. Precision digital filtering is required and can help address the quality of measurement and power consumption challenges in wireless medical monitoring devices.

Precision Digital Filtering Options

The most often used filter types for precision digital filters are the Infinite Impulse Response (IIR) and the Finite Impulse Response (FIR). Both methods are implemented by convolving the discrete



[2]

click to enlarge
Figure 2. Filter specification screen illustrating a Dual Band Pass Filter.

samples of an input signal (the output of an Analog to Digital Converter (ADC)) with the filter's impulse response &#151 a sequence of coefficients that represent the response of the filter to an impulse input.

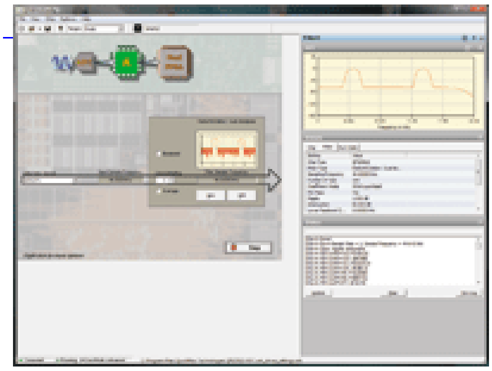
IIR filters are more code and memory efficient for a given filter characteristic (attenuation and slope at the cutoff frequency) than FIR filters since they use feedback in the equation. They are also low latency and thus effective for closed loop control systems. However, they require higher precision arithmetic at higher orders to maintain stability, limiting filter order to a maximum of ~9, and are thus more difficult to implement with fixed point processing. They also exhibit poor phase response, particularly at the transition regions of the filter.

FIR filters are inherently stable, can be designed with linear phase response, and the performance can be improved by adding additional coefficients or taps. They are easily implemented with fixed point arithmetic. Figure 1 illustrates the precision improvement by adding taps to an FIR filter by comparing a 43 tap to a 407 tap band pass filter. The downside of added taps is increased latency.

Filter Hardware Options

The compute hardware available for filter processing includes microcontrollers (&#181Cs) and digital signal processors (DSPs), which are software programmable, and field programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), and application specific standard products (ASSPs), which are, or can be designed to be, reconfigurable.

Wireless sensors will, at a minimum, have a microcontroller to detect the signal of interest from the appropriate sensor, determine the &quotreading&quot, place a time and date stamp on the collected data, and communicate the result via the wireless interface. Very low power microcontrollers that work across a battery range of 3.6 to 1.2 V, with very low leakage currents, are available. Many include integrated ADCs, and effective power management



[3]

hardware, and will shortly be available with integrated short range radio functions. These microcontrollers may offer the total solution for sensors with low bandwidth (low sample rate) filter requirements. As an example, a TI MSP430 could execute a 50 tap FIR filter up to sample rates of 3 kHz using about 15% of its total available compute power. In general, a microcontroller can be used to perform the filtering if the sample rate is low, and the filter specifications are not highly stringent in either frequency selectivity or attenuation.

If a higher sample rate or a higher precision filter is required (more taps), A DSP could be added to the design. DSP’s typically offer 4x to 10x the performance of microcontrollers on filter calculations at the same power levels. However, there are currently few DSPs designed for battery operation. A TI TMS320C55 can perform 500 tap FIR filters at sample rates of 100’s of KHz sample rates, but the power would be above 60 MW during execution.

The lower cost, lower power FPGAs can be used for filter functions, but typically require more power than other solutions for the same compute performance, and require a more complex design cycle to provide the needed reconfiguration capability. ASICs are not typically used for these low cost requirements because of design time and unit cost considerations.

There are now ASSPs on the market dedicated to filtering or other signal processing functions, and the value of growing wireless sensor markets will promote the development of more of this class of device. And they are very effective when attached to a microcontroller to provide filter processing. An example is the QF1D512 SavFIRe&#153 device from Quickfilter Technologies, Inc. This device comes in a 3 &#215 3 mm, 16-pin QFN package, and can be configured to execute FIR filters of up to 512 taps at sample rates from 10 sps to 500 ks/s. The device is clocked only when calculating filter samples, and is thus very power efficient &#151 it consumes less than 1 mw for 512 taps at a 1000 Hz sample rate. It is easy to interface to serial ADCs and microcontrollers via programmable SPI ports, and it can be used as a coprocessor for microcontrollers with embedded ADCs. It also comes with a development board and easy to use software for automatically creating the configuration of the chip from user defined FIR filter specifications. Figure 2 shows the input screen used to design a dual band pass filter, and Figure 3 illustrates the filter running in the development kit.

The use of very low power microcontrollers with attached ASSPs for the compute intensive signal processing functions appears to be the appropriate architecture for battery-operated wireless sensors. Currently the radio would be a discrete device, but new products are in development with integrated radios. The devices mentioned in this article are used as examples &#151 other manufacturers have similar products. The wireless sensor product developer must make the final trades based on required cost, functionality and desired battery life, but certainly the semiconductor technology is available. Dennis Best is vice president of engineering and CTO for Quickfilter Technologies, Inc., 1024 S. Greenville Ave., Ste. 100, Allen, TX; (214) 547-0460; www.quickfiltertech.com.

Links:
[1] http://www.wirelessdesignmag.com/sites/wirelessdesignmag.com/files/legacyimages/0706/medsup1_1_lrg.gif
[2] http://www.wirelessdesignmag.com/sites/wirelessdesignmag.com/files/legacyimages/0706/medsup1_2_lrg.gif
[3] http://www.wirelessdesignmag.com/sites/wirelessdesignmag.com/files/legacyimages/0706/medsup1_3_lrg.gif