Inter-Sensor Delay

Many EMG studies are tasked with assessing the behavior of multiple muscles during complex, dynamic movements. In these cases, the synchronization of all recording sensors is of critical importance. Delays of even a few milliseconds between recording sensors can skew results and lead to incorrect physiological interpretations as illustrated in Figure 1. Perfect sensor synchronization is easily achieved in tethered systems because of the direct electrical connections involved. It cannot be assumed however, that all wireless sensors achieve this same level of performance. The Trigno EMG Sensors and Systems have been specifically designed to achieve perfect inter-sensor synchronization, so that their performance is equivalent to that of tethered systems. This achievement requires the construction of a specialized RF communication protocol. It cannot be easily achieved with popular communication schemes such as Bluetooth®, WiFi® and Zigbee® approaches.

Measuring the Trigno Inter-Sensor Delay

In order to measure the actual delay across all 16 sensors in a Trigno network, it is necessary to input the same signal (i.e. from a single source) to all 16 sensors. The delay can then be easily assessed by looking at the 16 recorded outputs. Figure 2 illustrates a test setup which hosts 16 wireless sensors. A common source is connected to all 16 sensors, outputting a series of single square pulses as shown in Figure 3a). Note that the EMG filter of 20-450 Hz is bypassed for this test so that a square signal edge can be detected.

The resulting data collected in EMGworks from all 16 sensors sampled at 2000 samples/s are shown in Figure 3. The superposition of these 16 data traces easily shows that the rising edge of the square pulse occurs on the same data sample of all 16 traces.

Figure 1: The effect of inter-sensor time delays may skew the interpretation of the physiological data.

Figure 2: Test fixture illustrating 16 sensors connected to a common source. The 16 transmitted outputs of the common input signal will reveal any inter-sensor delays.
The Trigno wireless sensors, thus, have no inter-sensor delay. The real-time temporal information of the physiological signals is preserved throughout the Trigno Wireless EMG System.

The test can be repeated with the inclusion of the 20-450 Hz bandpass filter on each of the 16 sensors. In this case, the square test signal is distorted by the filter, but the resulting data still shows zero latency across all 16 sensors. Note that the accelerometer data packets are bundled with the EMG data packets, so these inherently also share a zero-latency specification.

Figure 3: Data acquisition of a common pulse sampled by 16 Trigno sensors at 2000 samples/s. The superposition of the 16 traces shows that the pulse’s rising edge occurs at exactly the same time for all sensors, thus illustrating that no inter-sensor delay exists.

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Analog Output Delay

When data from more than one acquisition system must be combined, it is important to account for the delay that may exist between the systems. If this delay is left unconsidered, incorrect data interpretations will likely result. One approach for avoiding this inter-system delay is to use start-triggers for the various acquisition systems. In this fashion, all systems begin sampling at exactly the same point in time, and no inter-system delays result. However, in some cases it is desirable to have only one acquisition system perform all the data collection. For these situations, the Trigno EMG system is equipped with real-time analog outputs that can be sampled by 3rd party A/D devices. The nature of recreating analog signals from data that has been transmitted digitally introduces an inherent system delay. While there are various delay sources in the data path, the net delay is consistent across all channels and can be easily measured.

Figure 4: A 10 ms pulse with a 1-second period is sampled across 16 Trigno Sensors at 2000 samples/s. The pulse is subjected to the internal sensor bandpass filter of 20-450Hz, thus showing the distorted wave shape. A superposition of the 16 sample traces shows that no inter-sensor latency exists.

Figure 5: Typical elements in the wireless EMG data path. The sensor (left side) consists of amplification, signal conditioning and digitization circuitry. The receiving Base Station contains SinX/X correction, a Digital to Analog Converter and Low Pass filtering. Filtering and digital encoding/decoding elements present fixed delays. The total delay path for an EMG analog output channel is 48ms, and can be easily measured.
Measuring the Analog EMG Output Delay

The analog output delay can be measured with a dual channel oscilloscope, by inputting a square wave into a sensor as previously described, and monitoring the square wave source along with the analog output on the oscilloscope. Referring to the block diagram of Figure 5, the following delays are associated with each of the elements: a) Sensor Filter (1.5 ms), b) Digitization Delay (41 ms), c) SinX/X Correction (2 ms), and d) Analog Low Pass Filtering (3.5 ms).

Figure 6 shows the connections of the signal source and the oscilloscope to the Trigno Sensor and the Base Station Analog Output. The callout shows the resulting data on the oscilloscope, which measures an aggregate delay of 48ms as shown by the screen cursors.

Figure 6: Measuring the analog output delay for EMG signals. A square pulse injected in the EMG sensor results in a 48ms delayed output response. The square pulse is distorted because of the filtering present in the signal path. The inset screen capture shows actual data, sourced from an AFG3000B signal generator and measured with an MSO3014 Oscilloscope. Note that the 48 ms delay is consistent for all EMG channels.
Measuring the Analog Accelerometer Output Delay

The analog output accelerometer delay can be measured in a similar fashion as the EMG signal delay described above. The filter characteristics for these signal paths are different than those of the EMG path, and thus incur a different delay. All accelerometer axes operate in a bandwidth of DC-50 Hz. The constituent delay elements in this path are identified as follows: a) Acc Filter (2 ms), b) Digitization Delay (41 ms), c) SinX/X Correction (27 ms), and d) Analog Low Pass Filtering (26 ms). The aggregate delay sums to a total of 96 ms, which can be easily verified in the oscilloscope screenshot shown in Figure 7.

Figure 7: Measuring the analog output delay for Accelerometer signals. A square pulse injected in the accelerometer channel of the sensor results in a 96 ms delayed output response. The square pulse is distorted because of the filtering present in the signal path. The inset screen capture shows actual data, sourced from an AFG3000B signal generator and measured with an MSO3014 Oscilloscope. Note that the 96 ms delay is consistent for all channels.