Wireless Doppler Ultrasound Instrument for Quantifying Muscle Kinematics

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Introduction: Tracking muscle movement can be very useful in diagnosis and rehabilitation of patients with neuromuscular disorders. Doppler ultrasound is well suited for analysis of musculoskeletal movement, but conventional ultrasound systems are bulky and not suitable for monitoring patients during ambulatory gait. A wireless Doppler ultrasound system can allow for direct measurement of muscular velocity during dynamic gait studies. Using a continuous-wave vascular Doppler and a custom wireless transmission unit, we have developed a wearable system that can record Doppler shifts and send them to a local computer for analysis.

Materials and Methods: An 8MHz continuous-wave vascular Doppler probe (Bistos Co., Ltd, Seongnam, Republic of Korea) was used. The received modulated RF signal was fed into a custom built I/Q demodulator circuit to detect positive and negative phase Doppler shifts. The output of the demodulator was sampled using an Atmel Atmega128rfa1 microcontroller and the data were sent wirelessly to a local host computer hooked up to a receiving microcontroller unit. The receiving microcontroller communicates with MATLAB on the host computer via an RS232 serial connection and transfers recorded data in real time. The Doppler probe and demodulator unit were tested on an experimental Doppler phantom (JJ&A Instruments, Duvall, WA) consisting of a string moving at calibrated velocities. The recorded Doppler shift was extracted at 4 different string speeds. A spectrogram of the received Doppler signal was computed on MATLAB to test the accuracy of the recordings. This system can be extended to include multiple Doppler probes for multi-dimensional velocity estimation. Two Doppler probes were separately housed on a wearable cuff (as seen in Fig 1D) for preliminary in vivo experiments.

Results and Discussion: The accuracy of the wireless unit is dependent on the distance between the two MCUs. The data transmission error was <5% for a distance of 5ft. In the string Phantom tests, Doppler shifts were visible in both the forward and reverse string directions. For low string speeds of 10cm/s, corresponding to typical muscle contraction velocities, the measurement error was less than 10%, and rose to 20% for faster spring speeds of 25cm/s. Extractions of Doppler shifts from the *flexor digitorum profundus* muscle were successfully obtained during a finger extension and contraction test (as shown in Fig 1E & F).

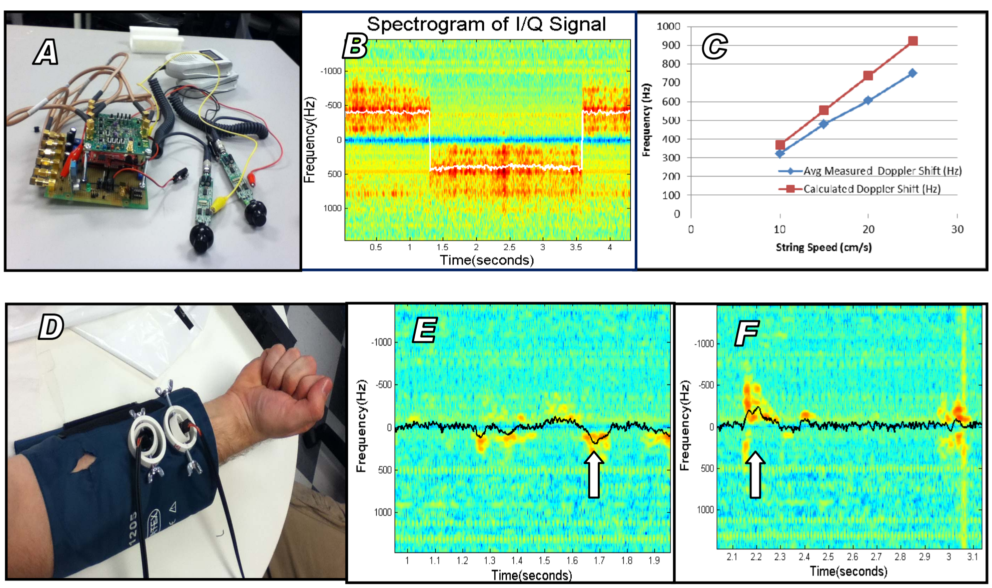

Figure 1: Panel A shows the entire system with 2 Doppler probes. Panel B shows a spectrogram of a recorded Doppler Shift from the I/Q demodulator. The white line is the average frequency of the measured Doppler shifts. Panel C shows the comparison between the measured and theoretical Doppler shifts in the string phantom. Panel D shows the wearable cuff for positioning transducers. Panel E and F show the Doppler shifts generated by contraction and relaxation of the *flexor digitorum profundus* muscle respectively. The black line is the average frequency of measured Doppler shifts.

Conclusions: Preliminary results show that the wireless Doppler ultrasound unit can be used to record and transmit Doppler shifts of the string phantom. Further studies are currently underway to test this system on in vivo muscle contraction. This system can be expanded in the future with multiple probes for velocity vector computations and also to incorporate pulsed wave Doppler capability.