Real-Time Processing of Electromyograms in an Automated Hand-Forearm Ergometer Data Collection and Analysis System

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***Abstract*—An automated hand-forearm ergometer with real-time data analysis would be a helpful tool to evaluate muscle fatigue mid-experiment, offering insights into changes in electromyogram parameters that can be used to track fatigue in the hand and forearm musculature. This work presents real-time additions to a custom, automated hand-forearm ergometer that will perform mid-experiment signal processing and help to identify fatigue onset and predict task failure.**

***Keywords*—electromyogram, hand-forearm ergometer, handgrip ergometer, LabVIEW, muscle fatigue**

I. Introduction

A hand-forearm (handgrip) ergometer is a useful resource to assess changes in electromyograms (EMGs) acquired from the forearm musculature as a subject reaches fatigue [1-3]. An existing ergometer design at Kansas State University [4-6] helps to automate the data collection procedure, but it does not incorporate mid-experiment signal processing mechanisms that help the researcher identify fatigue onset and predict task failure: two important goals of this NASA-funded work. Such assessments are currently performed with post-processing tools. A sensible next step is therefore to increase the level of ergometer automation by incorporating real-time processing alongside the data collection features, allowing fatigue assessments and predictions to be performed mid-experiment. Such an upgrade could help a researcher visualize fatigue onset, spur ideas for new parameters that indicate fatigue, and lead to strategies for just-in-time adjustments to workload or rate that could avoid a pending task failure.

II. Methodology

A. Previous Handgrip Ergometer

The previous automated handgrip ergometer is depicted in Fig. 1. A trial consists of the subject squeezing the two bars of the ergometer together at a controlled pace until the subject's hands and forearms reach the point of fatigue. The force, displacement, and EMG data are concurrently recorded and displayed by a LabVIEW virtual instrument (VI) for the researcher to view as the trial progresses. The subject is paced through the squeeze-hold-release process using the subject interface depicted in Fig. 2. Once the trial ends, the data are saved to Excel spreadsheets to undergo post-processing. Post-processing consists of running these data through multiple MATLAB scripts to calculate the work, power, and frequency spectrum affiliated with each EMG burst. These parameters are then graphed and analyzed to obtain a post-experiment assessment of fatigue onset and the trajectories of these parameters as task failure approaches. The flow diagram that represents these system-level interactions is noted in Fig. 3.

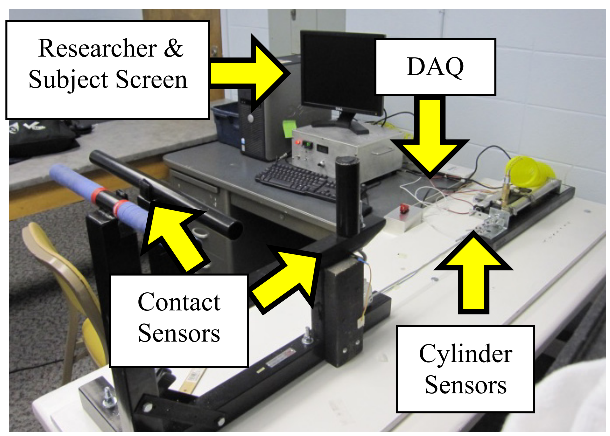

Fig. 1. Previous handgrip ergometer.

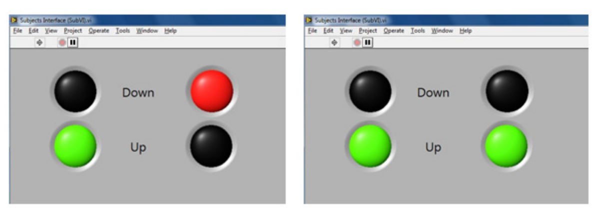

Fig. 2. Subject interface.

B. Hardware System Architecture and Information Flow

Two FSR402 0.5" Flex sensors, labeled as contact sensors in Fig. 1, are mounted between the two bars of the ergometer and between the rear portion of the ergometer and the support block. The output data streams from the sensors are passed through gain stages and input into LabVIEW via two channels of a National Instruments USB-6211 data acquisition (DAQ) card that offers sixteen 16-bit input channels. The resulting binary data streams carry with them

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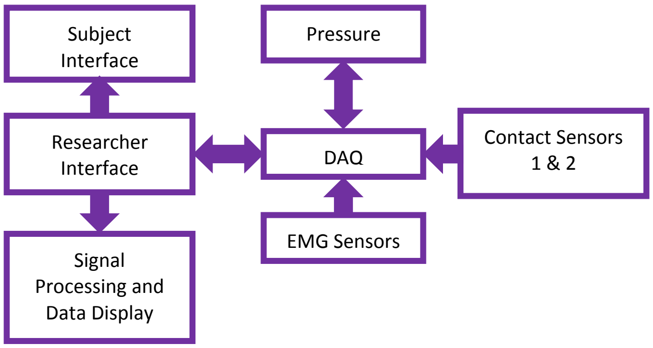

Fig. 3. Updated data flow diagram.

the contact status of the ergometer during the subject trial. The contact/noncontact positions represented by the data streams are presented to both the subject and researcher as green, red, and black indicators within the respective LabVIEW interfaces (e.g., the subject interface in Fig. 2). OMEGA LP801 linear potentiometers and a miniature tension/compression load cell (0 to 300 lbs; 0 to 1500 N) are contained inside the pressure cylinder system to collect force and displacement data, respectively. As the subject squeezes the bars together, the tension in the cord between the ergometer and the pressure cylinder increases, and that signal is captured by the load cell. These force and displacement data are digitized via two additional channels on the USB-6211 DAQ card and sent to the researcher LabVIEW interface, where they are displayed, processed, and stored in Excel files. One Delsys Trigno Wireless EMG sensor is placed on the left forearm and transmits a 16-bit signal into the Delsys docking system, where the Delsys system converts that digital signal into an analog voltage signal that is then digitized by the USB-6211 DAQ card and moved into LabVIEW for processing.

C. Data Acquisition and Data Processing Updates

System improvements focused on embedding the formerly post-processing MATLAB scripts into the LabVIEW researcher interface. This upgrade required the redesign of the researcher interface and the creation of new LabVIEW virtual instruments (VIs) which utilize a producer and consumer loop to maximize the process efficiency.

A typical LabVIEW producer/consumer system consists of two while loops that share information through a FIFO queuing system. The producer loop generates data and inserts them into a queue for the consumer to process. Once data are loaded into the queue, the consumer loop removes these data from the buffer only if the consumer loop is idle. This allows the producer loop to continuously generate data without the delays associated with the processing portion of the program. The program will allocate computational power to process these data only after they have been placed into the consumer loop.

Typically, a producer loop does not process data so as to attain the highest possible data-acquisition rate. However, the producer loop employed here collects data from the sensors through the DAQ unit, finds and removes the baseline noise component of the EMG signal, and then finds the start/stop times for each EMG burst. After each burst has been identified, these individual-burst data are placed in a queue until the consumer loop is available to process them. The consumer loop then processes the burst data in the same fashion as the MATLAB scripts from the previous ergometer system: it calculates the FFT, mean power frequency (MPF), median power frequency (MDF), work done, and power of the burst, and then it displays this information on the researcher interface. The VI then saves these data to Excel files for further analyses.

D. Researcher Interface Updates

The researcher interface will be a control, acquisition, and analysis interface that will allow a researcher to perform any number of hand-forearm ergometer protocols. At present, the researcher interface controls subject stimuli and collects, displays, analyzes, and stores data from the current array of sensors. It has been reorganized to exhibit a more natural information flow and to present new graphs that contain subject response data (see Fig. 4).

The upper three graphs on the researcher interface display raw force, displacement, and EMG data, respectively. The lower half of the researcher interface displays VI calculation results: the MPF trend, the MDF trend, and the raw time-domain data and frequency spectrum for the previous burst. The MDF and MPF are updated after each EMG burst is processed and allow the researcher to track changes in these parameters. In the original automated ergometer system, only the contact-sensor timing data were available to provide alerts for impending subject fatigue. With this upgrade, the researcher can get a better sense of the fatigue trajectory.

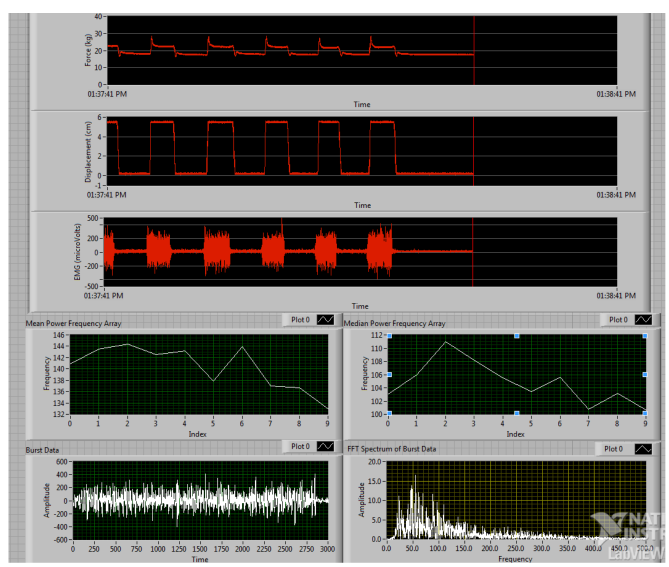

Fig. 4. Updated researcher interface.

III. Calculations and Sample Results

A. Cylinder: Force, Displacement, & Work Data

Fig. 5 depicts a subject operating the ergometer. As the subject begins the experiment, the raw pressure cylinder data are acquired by the LabVIEW program, where they are converted into force and displacement and displayed on the researcher interface. The work done by the subject is computed for each EMG burst using the expression

$$Work = \Sigma\ Force(t) \cdot Distance(t) \qquad (1)$$

where *Force(t)* is the force measured at time t and *Distance(t)* is the distance traveled during the discrete time slot that ends at time t. The time interval of interest (overall burst interval) is determined using the start and stop points of the burst as discussed in *Section II.C.* Average power is then calculated for each burst using the equation

$$Average\ Power = Work\ /\ Duration \qquad (2)$$

where *Work* is the total work done over the burst duration and *Duration* is the burst length. Fig. 6 depicts a post-processing graph for the work done by the subject. Incoming data sets will be input to post-processing scripts to verify the validity of the real-time processing system.

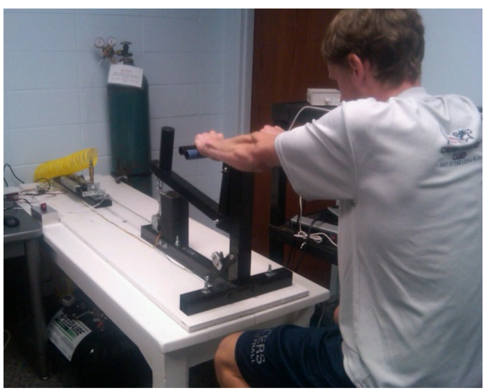

Fig. 5. Typical setup for a subject trial.

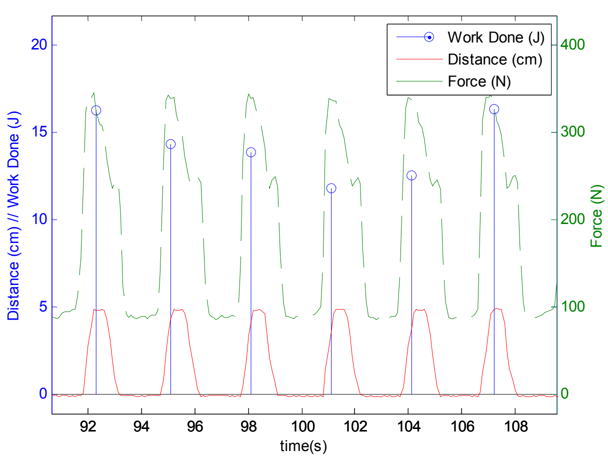

Fig. 6. Example MATLAB analysis for a constant-force experiment. This example illustrates what the graphed output of the LabVIEW program will look like during subject trials.

B. Delsys Sensors: EMG Data

After determining where a current burst starts and stops, the program sends the raw EMG burst data into an FFT VI, where the magnitudes of the frequency components are obtained. The consumer loop then calculates the MPF using the formula

$$MPF = (f_0{*}P_0 + f_1{*}P_1 + \ldots + f_N{*}P_N)\ / \\ (P_0 + P_1 + \ldots + P_N) \qquad (3)$$

where f_N is an individual frequency and P_N is the power (squared magnitude of the FFT coefficient) at f_N. The MDF is calculated by taking the numerator of the MPF and finding the frequency where the resulting summation reaches half of the total burst power (starting at f_0).

C. Contact Sensors: Power Data

Data received by the contact (Flex) sensors are also processed alongside the force and displacement data in LabVIEW. Since the data are time-aligned, the consumer loop will be able to (a) consider the desired grip movement of the subject relative to the experimental grip data from the subject and (b) link grip activity, such as rate and duration, to the force, displacement, work, and instantaneous power data. Post-processing data for these sensors are illustrated in Fig. 7 in tandem with the corresponding power calculations. In both data sets (Figs. 7A and 7B), one can see that, at the end of the exercise interval (an approximate range of [140, 160] seconds), the decrease in power in Fig. 7A coincides with delayed subject contractions in Fig. 7B, both of which suggest the onset of fatigue. The MATLAB outputs shown in Figs. 6 and 7 depict what the LabVIEW interface will create in real time once this work in progress is completed.

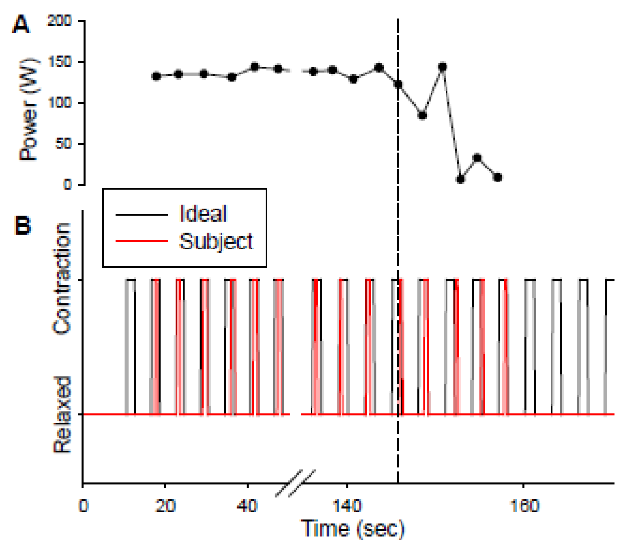

Fig. 7. Subject data acquired during a constant-work-rate handgrip exercise. A. Instantaneous power produced by the subject during the exercise. B. Ideal contractions (black lines) compared to actual contractions (red lines).

IV. Conclusion and Future Work

This paper presented ongoing real-time processing updates to a custom, automated hand-forearm ergometer that will help to streamline the data collection and analysis process, offering mid-experiment insights into changes in EMG parameters that can be used to track fatigue in the hand and forearm musculature and potentially predict task failure. The research and development effort is a work in progress, and experiments that utilize subjects are pending.

Multiple ergometer updates are planned. For example, the authors have considered the addition of active pressure-cylinder control in the researcher interface – a task currently performed manually through a pressure cylinder control box. Other parameters such as the RMS power of each burst and the subject reaction time have been discussed for the purpose of identifying subject fatigue. Fatigue prediction using MPF and MDF trajectories is also planned.

References

[1] Casey,D., M. Joyner, P. Claus, T. Curry, "Hyperbaric hyperoxia reduces exercising forearm blood flow in humans," *Am J Physiol Heart Circ Physiol,* vol. 300, March 2011, pp. H1892–H1897.

[2] MacDonald, M., H. Naylor, M. Tschakovsky, R. Hughson, "Peripheral circulatory factors limit rate of increase in muscle O_2 uptake at onset of heavy exercise," *Am J Physiol Heart Circ Physiol,* vol. 90, 2001, pp.83–89.

[3] Shushakov, V., C. Stubbe, A. Peuckert, V. Endeward, N. Maassen, "The relationships between plasma potassium, muscle excitability and fatigue during voluntary exercise in humans," *Experimental Physiology,* vol. 92, no. 4, 2007, pp. 705–715.

[4] Gude, D., R. Broxterman, C. Ade, T. Barstow, T. Nelson, W. Song, and S. Warren. "Automated Hand-Forearm Ergometer Data Collection System," *HRP 2013,* Feb. 11–14, 2013, Galveston, TX.

[5] Gude, D., R. Broxterman, C. Ade, T. Barstow, T. Nelson, W. Song, and S. Warren. "Automated Hand-Forearm Ergometer Data Collection System," *34th Annual Intl Conf IEEE EMBS,* San Diego, CA, Aug. 28 – Sept. 1, 2012, pp. 2379–2382.

[6] Gude, D. *Automated Hand-Forearm Ergometer Data Acquisition and Analysis System*, Master's Thesis, Kansas State University, Manhattan, KS, August 2013.