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Automated Hand-Forearm Ergometer Data Collection System

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***Abstract*—Handgrip contractions are a standard exercise modality to evaluate cardiovascular system performance. Most conventional ergometer systems of this nature are manually controlled, placing a burden on the researcher to guide subject activity while recording the resultant data. This paper presents updates to a hand-forearm ergometer system that automate the control and data-acquisition processes. A LabVIEW virtual instrument serves as the centerpiece for the system, providing the subject/researcher interfaces as well as coordinating data acquisition from both traditional and new sensors. Initial data indicate the viability of the system with regard to its ability to obtain consistent and physiologically meaningful data.**

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

I. Motivation

DYNAMIC handgrip contractions are a standard exercise modality to evaluate the intact cardiovascular system [1,2] and mechanisms of fatigue [3]. This type of exercise allows for simultaneous measurement of limb blood flow through the brachial artery and limb blood gas analysis via vein sampling, enabling the determination of metabolic rate using the direct Fick method. Tissue oxygenation via near-infrared spectroscopy and electromyography applied to the forearm musculature can provide additional information about the working limb. Such measurements can be difficult during other types of exercise (e.g., cycle or treadmill).

Handgrip exercise is usually performed by a single limb, with resistance generated by suspended weights that are adjusted *a priori*, limiting this exercise to a single work rate per session. Certain investigations, however, require ramped exercise, or a progressive increase in work/power, to evaluate physiologic mechanisms like those investigated during cycling and treadmill exercise. However, a ramped or incremental exercise protocol is difficult to achieve with a handgrip ergometer that utilizes suspended weight. A new ergometer design that supports both constant work rate and ramp exercise is desirable. In addition, ergometer data (i.e., work and power) and data from other biomedical devices may need to be integrated into a single time-aligned data array to promote effective evaluations of the physiologic mechanisms of cardiovascular control and fatigue.

Traditionally, hand and forearm ergometer systems rely on the researcher to manually acquire data and identify subject fatigue [4,5]. He or she must also provide continual prompts to the subject. More recent research has employed automated, one-way data collection systems [6-8]. A natural extension to this work would be a fully automated ergometer in terms of session control and data acquisition, which could reduce investigator burden by acquiring, processing, displaying, and storing session data. Such an upgrade would promote consistency in the experimental protocol. Additionally, a subject interface could increase the number and quality of prompts a subject would receive during an experiment, further improving the quality of the data available for post-processing.

This paper presents an update to a hand-forearm, or handgrip, ergometer system that optimizes data collection and offers the opportunity to improve experimental data from ergometer-based studies that focus on hand and forearm musculature.

II. Methodology

A. Original System

The components of the original handgrip ergometer are depicted in Fig. 1. This system would normally be used to perform trials requiring a subject to squeeze the two bars of the ergometer together repeatedly until their hands and forearms reached the point of fatigue. The force required to squeeze the bars equates to the pressure housed in the pressure cylinder – an opposing pressure that can be raised or lowered to increase or decrease fatigue rate. Subject pacing for the squeeze-hold-release process would typically be provided by a digital metronome, and the researcher would use a stop watch to measure time intervals that were then manually recorded.

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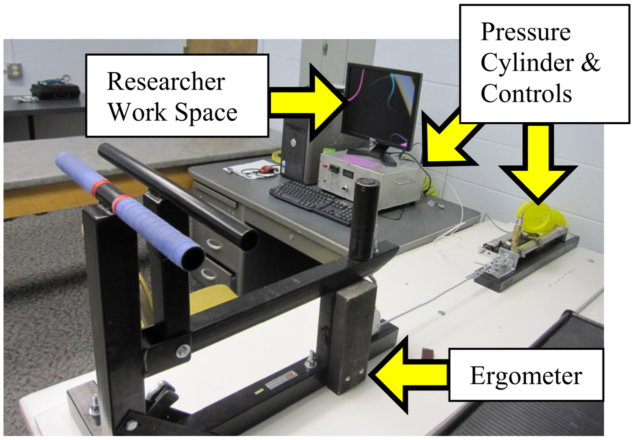

Fig. 1. Original hand-forearm (handgrip) ergometer system.

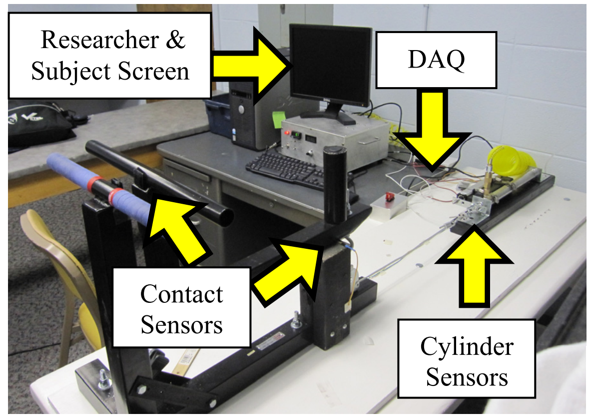

Fig. 2. Updates to the original system.

B. *General Upgrades*

Overall system improvements focused on consolidating system needs, automating the data acquisition process, and storing the resultant data electronically. These broad updates include the creation of LabVIEW-based subject/researcher interfaces (a.k.a., virtual instruments (VIs)), automatic streaming of pressure cylinder data into the researcher interface, the addition of contact sensors whose data are also streamed into the researcher interface, and the capability to receive data from additional sensors customized to the needs of the data collection protocol (e.g., additional electromyogram (EMG) sensors attached to user forearms). All data are time-aligned and stored to Excel spreadsheets for post-processing.

C. *Sensors and Information Flow*

Several sensors were added to the system in order to improve the information available to the investigator (see Fig. 2). First, two FSR402 0.5" Flex Sensors were mounted to the hand ergometer: one between the two hand bars and the other between the support block and the lower bar. The output voltages from their circuitry are monitored by two channels of a National Instruments USB-6211 data acquisition (DAQ) card that offers sixteen 16-bit input channels. The result is a set of data streams whose binary nature indicates contact and non-contact status during the squeeze-hold-release process embodied in a typical handgrip ergometer experiment. The on/off status of these binary streams is presented to the user and researcher as green, red, and black indicators within the respective LabVIEW interfaces. OMEGA LP801 linear potentiometers and a miniature tension/compression load cell (0 to 300 lbs; 0 to 1500 N) were also added to the pressure cylinder system to track force and displacement. These signals are digitized by two additional channels on the USB-6211 DAQ and sent to the researcher LabVIEW interface, where they are displayed and then stored in Excel files for offline power calculations. Fig. 3 depicts the overall information flow in the system.

D. *Subject Interface*

The subject interface (see Fig. 4) provides visual and audible prompts to the subject and is fully controlled by the researcher interface. The interface contains two columns of indicator lights. The lights in the left column prompt the user to either squeeze or release the ergometer bar. State changes in this column are accompanied by an audible sound, much like a metronome. The lights in the right column provide feedback regarding the actual movement performed by the subject. A red light indicates that the subject has released the bar: the ergometer is in the 'Down' position. A green light indicates that the subject is squeezing the ergometer handles: the ergometer is in the 'Up' position. This feedback helps the subject synchronize their movements with the cadence set by the researcher via the left column of lights.

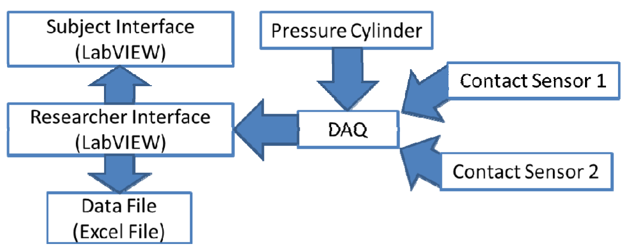

Fig. 3. Handgrip ergometer data flow diagram.

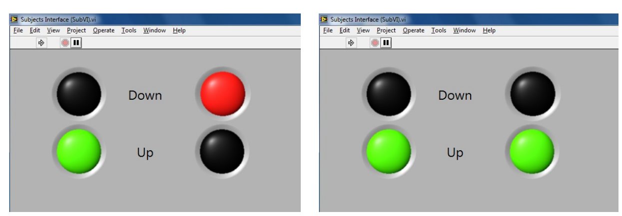

Fig. 4. Subject interface. The left image depicts incorrect subject movement, whereas the right image depicts correct subject movement.

E. *Researcher Interface*

The researcher interface (see Fig. 5) is the central location for sending subject prompts and receiving sensor data. Its long term role will be to provide a complete control, acquisition, and analysis interface that will allow a researcher to perform any number of hand-forearm ergometer protocols. At present, this interface controls the audiovisual prompts for the user while it collects, displays, and stores the data from the current sensor set.

The upper left corner of the researcher interface displays a replica of the subject interface. A Cycles/Minute indicator box below these lights allows the investigator to choose the speed of the audiovisual prompts. This value is purposefully hidden from the subject. An additional value box allows the researcher to choose the sound file for the metronome, since different subjects hear different types of sounds with variable clarity. The data acquired from the force and displacement sensors on the pressure cylinder are displayed in the graphs on the right side of the interface. Note that this system also allows an investigator to see when the subject starts to fail (i.e., the pull sensor no longer experiences contact) because the contact sensor data and the associated indicator lights provide information that is contradictory to the prompts and possibly to the data provided by the pressure cylinder (e.g., the subject might squeeze and generate a displacement signal but not achieve full sensor contact). In the original, manually controlled ergometer, this type of information would be difficult to gather.

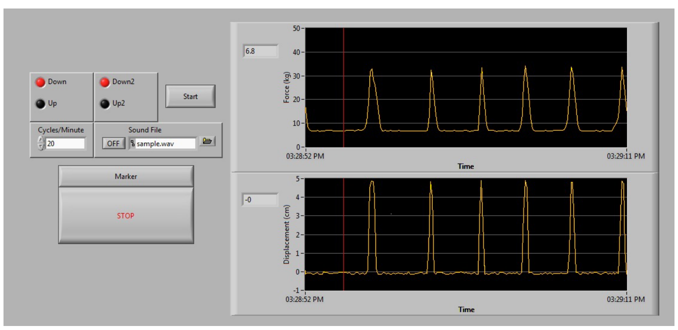

Fig. 5. Researcher interface.

III. Results and Discussion

A. Cylinder: Force, Displacement, & Power Data

Fig. 6 illustrates a subject engaging with the hand-forearm ergometer system. As the experiment commences, the raw force and displacement sensor data from the pressure cylinder are digitized and then acquired by the LabVIEW researcher interface as noted earlier. Prior to display, the LabVIEW VI converts these data into force and displacement, and then it displays the data and saves them in an Excel file. Representative force and displacement data for constant-force and increasing-force experiments are depicted in Figs. 7 and 8, respectively.

Force and displacement data are converted to work done by the subject using the relationship

$$Work = Force\ Measured \cdot T \cdot v,$$

where T is the effective duration of each stroke (determined by MATLAB with the help of a peak-detection algorithm), and v represents the instantaneous speed determined as the first-order derivative of the displacement, D, in relation to the sampling interval, T_S:

$$v = \frac{D(i) - D(i-1)}{T_s}$$

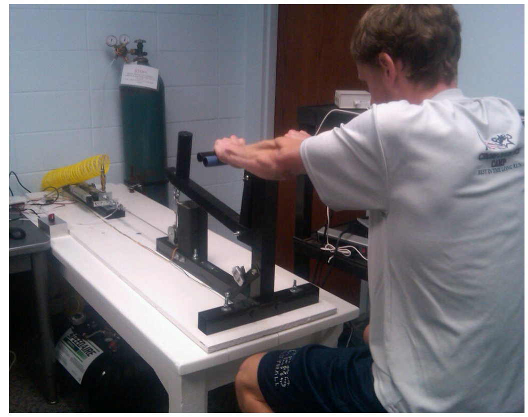

Fig. 6. Demonstration of the hand-forearm ergometer.

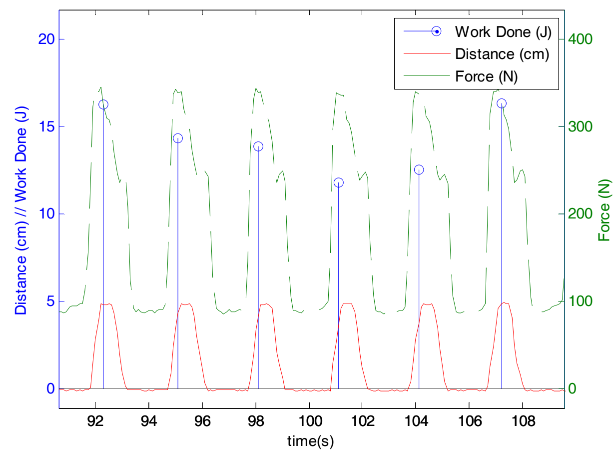

Fig. 7. Example MATLAB analysis for a constant-force experiment. This example illustrates that the work done for each compression can be variable.

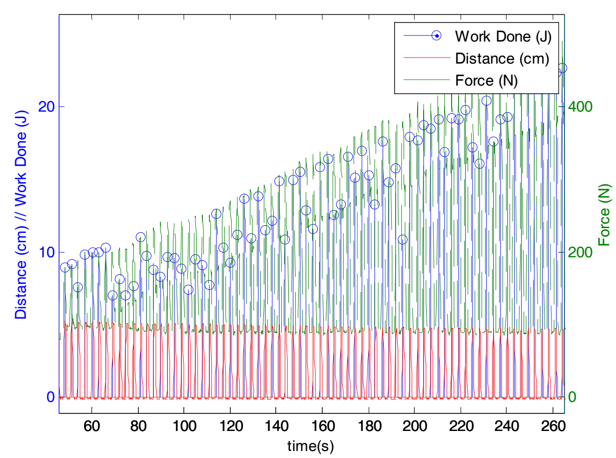

Fig. 8. Example MATLAB analysis for an increasing-force (ramped) experiment, where the work done gradually increases over time.

B. Contact Sensors: Hold & Release Data

Data received by the contact (flex) sensors are also processed in LabVIEW and saved to a separate Excel file. In this Excel file, the time values are aligned with the time values stored in the Excel file that contains the force, displacement, and work data garnered from the pressure cylinder system. This allows post-processing software to (a) compare ideal grip movement to actual grip data and (b) correlate grip activity (e.g. rate and duration) to force, displacement, work, and instantaneous power data. Representative data for these sensors is depicted in Fig. 9 along with a corresponding set of instantaneous power calculations. In both data sets (Figs. 9A and 9B), one can see that, at the end of the exercise interval (an approximate range of [140, 160] seconds), the decrease in power in Fig. 9A coincides with delayed subject contractions in Fig. 9B, both of which suggest the onset of fatigue.

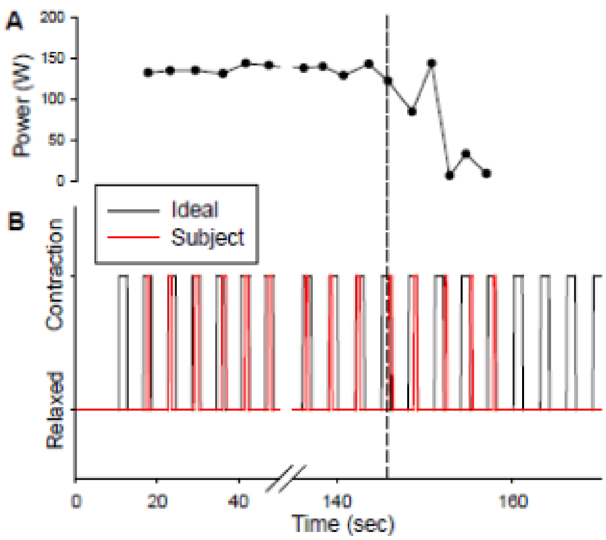

Fig. 9. Subject data acquired during a constant-work-rate handgrip exercise. A. Instantaneous power produced by the subject during the exercise. B. Ideal contractions (black lines) compared to the actual contractions (red lines).

C. Future Work

Numerous improvements are planned for this ergometer design. For example, the use of additional EMG sensors on the subject's forearms will allow the investigative team to track changes in muscle activity prior to, during, and after the onset of fatigue [7]. This will require interface changes and throughput optimization. Real-time calculation and display of work performed and instantaneous power are also planned. Additionally, the authors have considered means to actively control the pressure cylinder from the researcher interface – a task which is currently performed manually through the pressure cylinder control box. This task is currently in the calibration phase and will be part of future experiments. Fig. 10 depicts an updated data flow diagram that maps to these changes.

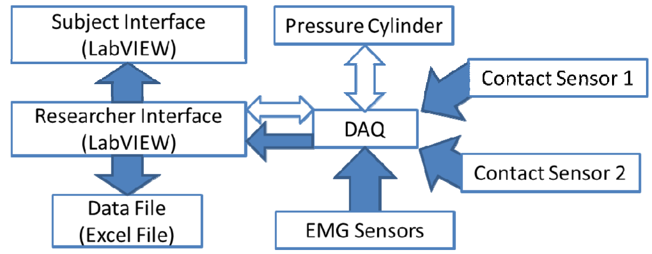

Fig. 10. Further data flow upgrades.

IV. Conclusion

This paper presented a LabVIEW-controlled hand-forearm (handgrip) ergometer that automates tasks which were previously managed manually. Such an upgrade reduces the burden on the researcher and increases the likelihood that experiment-to-experiment data will be consistent. The system has proved effective to date with a limited number of test subjects. Planned functional upgrades will allow researchers to obtain higher-fidelity data regarding the relationships between measured hand/forearm muscle activity and the onset of fatigue.

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