Rowing Exercise Data Collection
-Report-

Human Motion and Control Lab
Control, Robotics and Mechatronics Lab

1 Objective

The objective was to collect extensive data concerning the rowing exercise, accounting for both machine and human variables. This effort is part of a research project funded by NSF aiming at the development of advanced exercise and rehabilitation machines. Data collected from the experiments described here will be used as the basis to design a motorized rowing machine and its control system. The same data will be used to conduct system identification studies of human dynamics during exercise.

2 Experiment Design and Setup

A conventional air resistance gym rower was used, namely the Concept2 machine. The machine consists of a pull chain used to propel a flywheel and fan in only one direction, during the pull phase of the exercise. A freewheeling clutch decouples the chain sprocket from the flywheel, allowing an independent return phase with chain recoil. An elastic shock cord facilitates recoil, and produces a small tension during the return. Thus, there are two relevant angular speeds in the rowing machine, corresponding to the chain sprocket and the flywheel. These velocities coincide during the pull phase. Two optical incremental encoders were installed on the machine to measure these velocities.
The following variables were selected for measurement:

Rowing Machine

1. Chain sprocket angular position, measured with a 256-line optical encoder. Online numerical differentiation was used to compute angular velocity. The pitch radius of the sprocket is 1.35 cm, and it can be used to calculate tangential velocity (linear velocity magnitude of the pull chain) during pull and return phases.

2. Flywheel angular position, measured with a 256-line optical encoder. Online numerical differentiation was used to compute angular velocity.

3. Tension force on the pull chain, measured with a 500-lbf load cell installed between the handle and the chain.

The above variables were measured using a dSPACE MicroLabBox system with a sampling interval of 1 ms.

Human Motion and EMG

1. Human kinematics were measured with an Osprey 10-camera motion capture system paired with the Cortex 3.1.1.1290 software. Markers were attached in 26 different locations (see Table 1).

2. Electromyography signals were recorded at 13 locations using a Delsys wireless system (see Table 2 and Fig. 1).

Marker Number	Marker Name	Anatomical Position
1	LMT5	Left 5th meta tarsal bone on foot
2	LHEE	Left center of heel
3	LLM	Left lateral malleolus of ankle
4	LATI	Left tibia between LLEK and LLM
5	LLEK	Left lateral epicondyle of knee
6	LGTRO	Left greater trochanter of femur
7	RMT5	Right 5th meta tarsal bone on foot
8	RHEE	Right center of heel
9	RLM	Right lateral malleolus of ankle
10	RATI	Right tibia between RLEK and RLM
11	RLEK	Right lateral epicondyle of knee
12	FRTHI	Right thigh between RGTRO and RLEK
13	RGTRO	Right greater trochanter of femur
14	T10	10th thoracic vertebra
15	C7	7th cervical vertebra
16	BBAC	Right scapula
17	LSHO	Left acromion of shoulder
18	LLEE	Left lateral elbow
19	LLW	Left lateral wrist
20	LFRM	Left forearm
21	RSHO	Right acromion of shoulder
22	RLEE	Right lateral elbow
23	RLW	Right lateral wrist
24	RDELT	Right deltoid muscle
25	HAND	Rowing machine handle
26	CABL	Rowing machine cable

Table 1: Anatomical location of optical markers for motion capture.

Marker data and EMG signals were recorded by a Cortex system, with a sampling interval of 1 ms. Because the timebases of the dSPACE system and Cortex systems were separate, one EMG channel was also captured in the dSPACE system. A correlation algorithm was used after data collection for synchronization.

Human Metabolism: A wireless Cosmed K4b2 unit was used to monitor heart rate and oxygen consumption at each exercise intensity setting.

Figure 2 shows a test subject wearing the metabolic unit prior to the exercise and Fig. 3 shows the subject performing the exercise during a data capture session.

2.1 Protocol and Data Set Organization

The subject was instructed to perform warm-up strokes for 10 minutes. A total of nine workouts were performed, corresponding to combinations of air resistance (set by opening or closing machine vents), cadence (in strokes per minute). Each workout lasted for two minutes. Three levels of air resistance were used, each with three different cadence levels. Table 3 organizes these combinations by trial number, and should be consulted when working with the data.

File name convention

Filenames containing synchronous data (human kinematics, EMG and machine mechanical variables) are `data1.mat`, `data2.mat`,..`data9.mat`. The files are in Matlab version 7 binary format, and should be readable in any recent Matlab version.

Sensor Number	Muscle Surface
1	Tibialis anterior
2	Gastrocnemius medialis
3	Soleus
4	Vastus lateralis
5	Rectus femoris
6	Semitendinosus
7	Latissimus dorsi
8	Trapezius (middle part)
9	Deltoid (scapular head)
10	Biceps brachii
11	Triceps brachii
12	Rectus abdominis
13	Erector Spinae

Table 2: Anatomical location of EMG sensors.

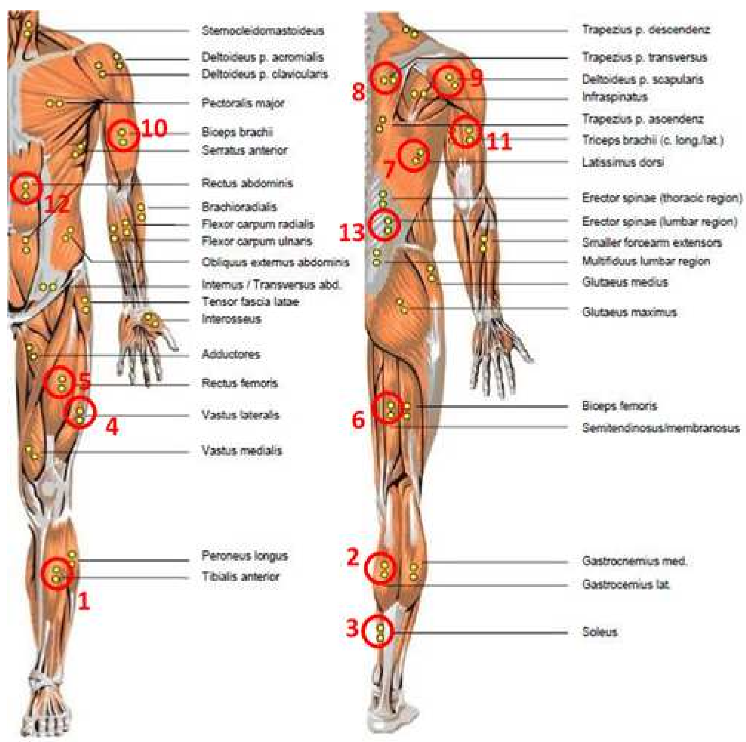

Figure 1: Anatomical location of EMG sensors.

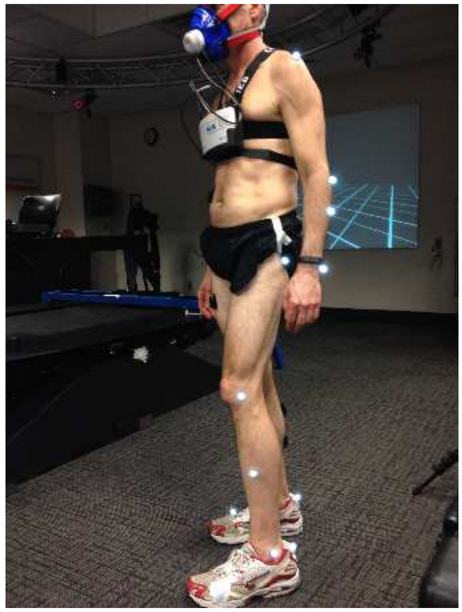

Figure 2: Subject ready for test, wearing the Cosmed metabolic unit and fitted with 16 EMG sensors and 26 motion capture markers.

Figure 3: Subject performing a test during a data capture session. A separate marker was placed on the handle to track velocity.

Trial #	Vent setting*	Cadence (strokes/min)
1	10	20
2	10	30
3	10	40
4	5	20
5	5	30
6	5	40
7	1	20
8	1	30
9	1	40

Table 3: Numbering and description of the 9 workout trials. A resistance setting of 10 corresponds to a fully-open air vent (maximum load).

Each file contains a variable named `DATA`. The variable is a matrix with 21 columns. The data has been truncated to 60,000 samples, that is, 1 minute of activity. Since the minimum cadence was 20 strokes per minute, the record contains tens of cycles, from which portions can be selected for analysis. Longer data records, up to approximately 150 seconds, can be obtained by contacting Hanz Richter.

Column organization Table 4 summarizes the contents of each column.

Column	Variable	Units
1	time	s
2-17	EMG channels 1-16	normalized*
18	Chain sprocket angular speed	rad s^{-1}
19	Flywheel angular speed	rad s^{-1}
20	Force along chain	N
21	Tangential velocity of chain (at handle)	m s^{-1}

Table 4: Column organization of each trial matrix. See next section for EMG normalization description

2.2 Marker Data

As of this revision (Aug. 1, 2016), marker data is supplied as nine separate files corresponding to each trial. File names are `Mdata1.mat`, `Mdata2.mat`,..`Mdata9.mat`. The files are in Matlab version 7 binary format. Each file contains a variable named `MDATA`, a matrix with 79 columns. The first column is time, while the remaining 78 are the X,Y and Z positions of the 26 markers, ordered following Table 1. More precisely, the X, Y and Z positions of marker number i from the table are stored in columns $2+3(i-1)$, $3+3(i-1)$ and $4+3(i-1)$, respectively, for $i = 1, 2....26$.

3 Data Processing

The dSPACE MicroLabBox and the Cortex system sampled data at the same rate of 1kHz, however their time bases were independent. Operators on each device did not start the capture at exactly the same time. Foreseeing this problem, the team decided to record one EMG channel in dSPACE as well as in the Cortex system, which recorded all 16 channels. EMG1 data could then be used with an autocorrelation algorithm to find the relative delay and perform the synchronization.
Also, the dSPACE and Cortex system read the EMG channel with different gains and cabling effects introduced a small relative bias. A normalization procedure was required before correlation analysis. To normalize the EMG signals, means were removed, followed by division by the peak absolute value in the record. With this, all EMG traces were contained between -1 and 1.

The correlation algorithm gave near-perfect results. Data accompanying this document reflects normalization and synchronization procedures. An undesired effect of normalization was that some raw EMG channel data displayed large spikes. Normalization resulted in amplitude compression of most of the record, leaving only a few spikes to reach the -1 or 1 limits. This must be resolved manually, by performing additional processing.

Marker data was sampled at 100 Hz, and contained small sections of missing marker data. Marker data was subsequently resampled at 10x to match the sampling interval of all other data. The resampling process also removed missing data segments, replacing them with linear interpolation. Marker data being released incorporates these corrections, and is also limited to 60,000 samples.

3.1 Calculated Data

Handle velocity (pull chain tangential velocity) was calculated by multiplying the angular speed of the chain sprocket by its pitch radius of 1.35 cm.

Multiplication of handle velocity by force gives instantaneous power. Because the return phase involves a small residual tension due to the shock cord, instantaneous power becomes negative in this phase. To validate the data, power was averaged (including the small negative portions) and compared with the value displayed by the Concept2 LCD screen, with very excellent agreement. No data based on power calculations is included in the data accompanying this document.

4 Plotting Script

A simple Matlab plotting script is supplied along with the 9 data files. To use it, place the script and all data files in the same directory and type `>>data=plotfinaldata(trnum);`, where `trnum` is the trial number from 1 to 9. The data matrix will be returned in variable `data`.

4.1 Note

1. The chain sprocket and flywheel angular velocities should coincide during the pull phase. The data shows a small offset. We believe this may be due to the online numerical differentiation or to some slippage of the encoders mounted in the machine. The effect is small and may be safely ignored.

5 Metabolic Data

Metabolic data was collected at a much slower rate, and it does not need to be exactly synchronized to the machine or human kinetic data. An Excel file with self-explanatory labels contains all trials.