Quality of Life Technology Center

a National Science Foundation Engineering Research Center

Classifying Wheelchair Propulsion Patterns with a Wrist Mounted Accelerometer

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Motivation

Manual wheelchair users (MWUs) rely on their upper limbs for mobility

Secondary shoulder injuries are common

Shoulder pain incidence rates range from 31-73%

There is currently little direct evidence to link specific types of activities to incidents of pain and injury

Propulsion pattern executed by MWUs is of interest to researchers because different patterns expose the joints to differing forces

Objectives

To determine the propulsion pattern of a manual wheel chair user by utilizing an accelerometer

Provide feedback to user including proper propulsion technique to minimize forces required to complete tasks and minimize extremes of arm movement in order to reduce risk of elbow and shoulder injury

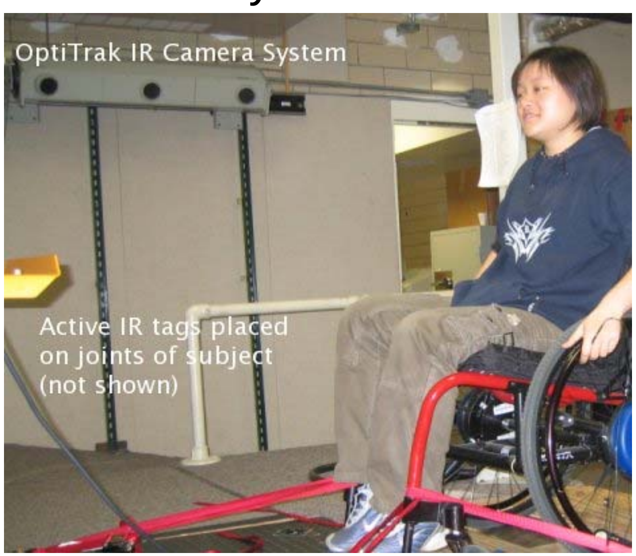
To help understand the cause of upper limb injuries and pain by correlating acceleration data with force data collected via the SmartWheel™

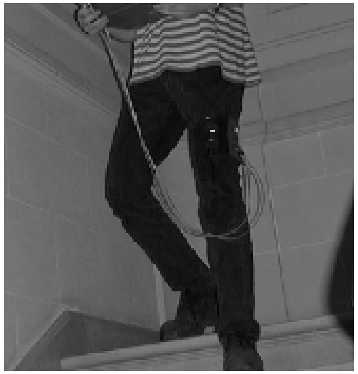
Prior Work

The four propulsion patterns explored in this study were identified by researchers at the Human Engineering Research Laboratory (HERL) at the University of Pittsburgh

- Used a high-frequency infra-red camera with active, IR tags placed on the joints of MWUs (left image)
- Identified four general patterns based on ~30 subjects

Body mounted accelerometers (in different configurations, right images) have been used by a number of researchers to identify a variety of human activities





Propulsion Patterns

A. Semi-circular (SC)

B. Single Loop Over Propulsion (SLOP)

C. Double Loop Over Propulsion (DLOP)

D. Arc

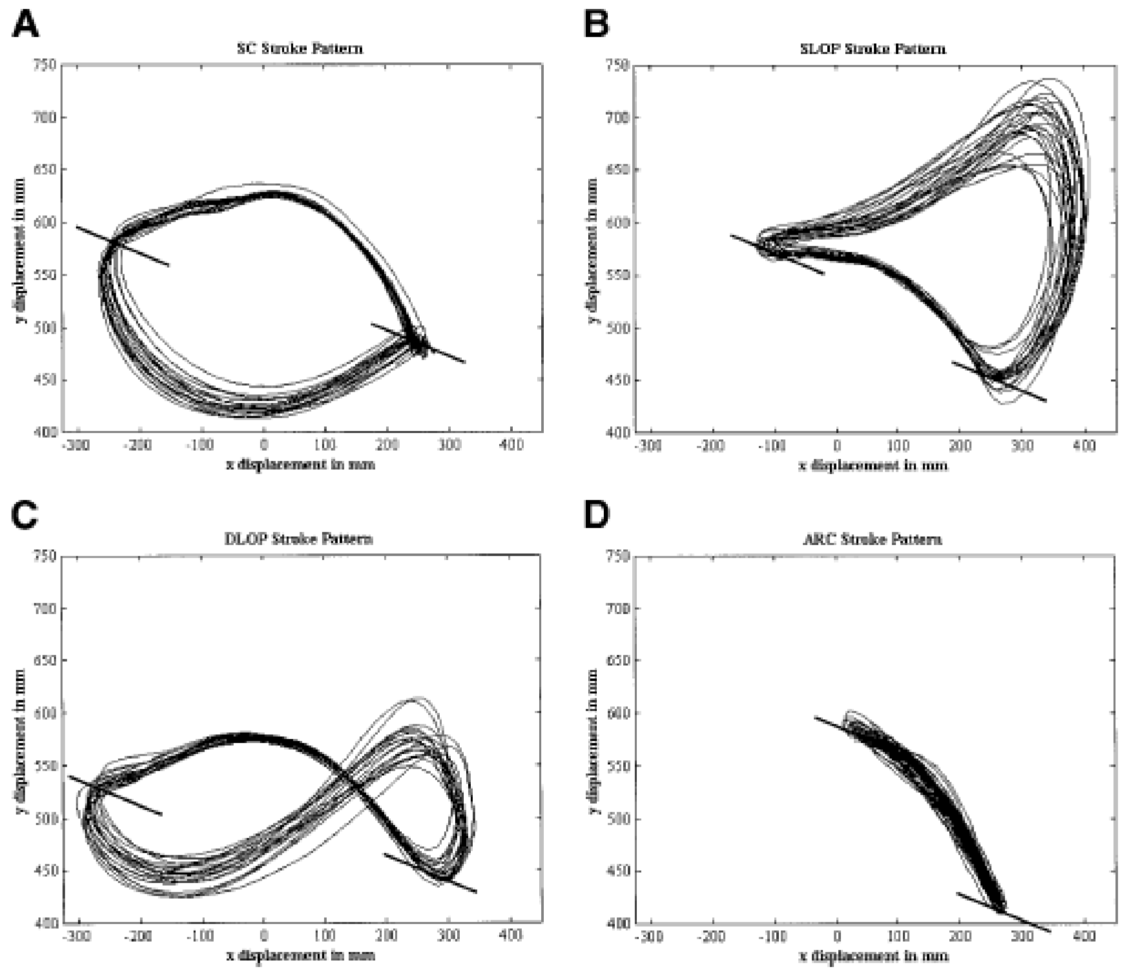
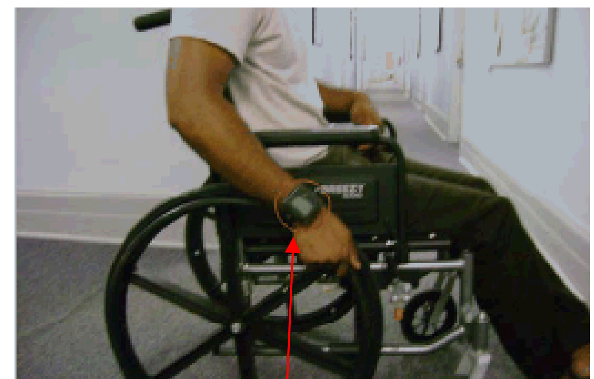


Fig 2. Propulsion patterns. Four classic propulsive strokes are shown: (A) semicircular (SC); (B) SLOP; (C) DLOP; and (D) arcing (ARC). The dark bars to the right of each pattern represent the beginning of the propulsive stroke. The dark bars to the left of each pattern represent the end of the propulsive stroke and the beginning of recovery.

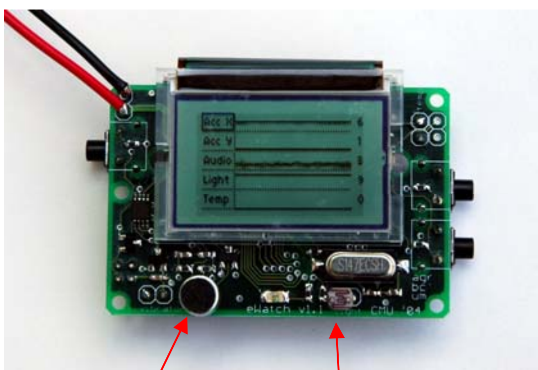
Data Collection Platform

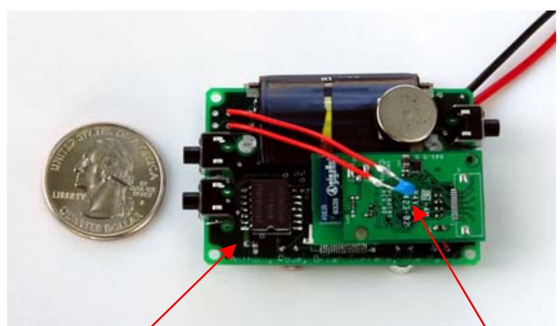
Used 2D accelerometer on the eWatch wearable, context aware computing platform

- Sampled continuously at 20Hz
- Mounted eWatch on dominant wrist



Mount Location





Audio Light Accelerometer Temperature

Data Collection Methodology

Used one propulsion pattern for a distance of 30 yards (1 trial)

- Approximately equal velocities for each pattern
- Cycled through each pattern per round of collection
- Collected multiple rounds over a period of several weeks

Inserted time stamp into eWatch log at the beginning and end of each trial

Surfaces: dynamometer, medium pile carpet, low pile carpet, tile, and asphalt

Trial Separation

Ignored first three seconds and last five seconds of each trial

- The patterns vary during acceleration and deceleration during each run
- We were interested only in steady-state patterns

Partitioned the remaining data into individual samples

- Non-overlapping 3 second windows
- Window size was chosen through cross validation
  - Intuitively, this is the smallest window size that ensures at least one complete cycle of each pattern has taken place

Computed a set of statistical features on each window

Data Sample Features

Acceleration features calculated for both X and Y axes

- Mean
- Standard Deviation
- Root Mean Square
- Median Absolute Deviation (MAD)
- Zero Crossing Rate
- Mean Crossing Rate
- Fluctuation in Amplitude
- Energy
- Entropy

Features were chosen based on prior experience classifying accelerometer data

Analysis

Used two standard machine learning algorithms to classify propulsion patterns based on acceleration features

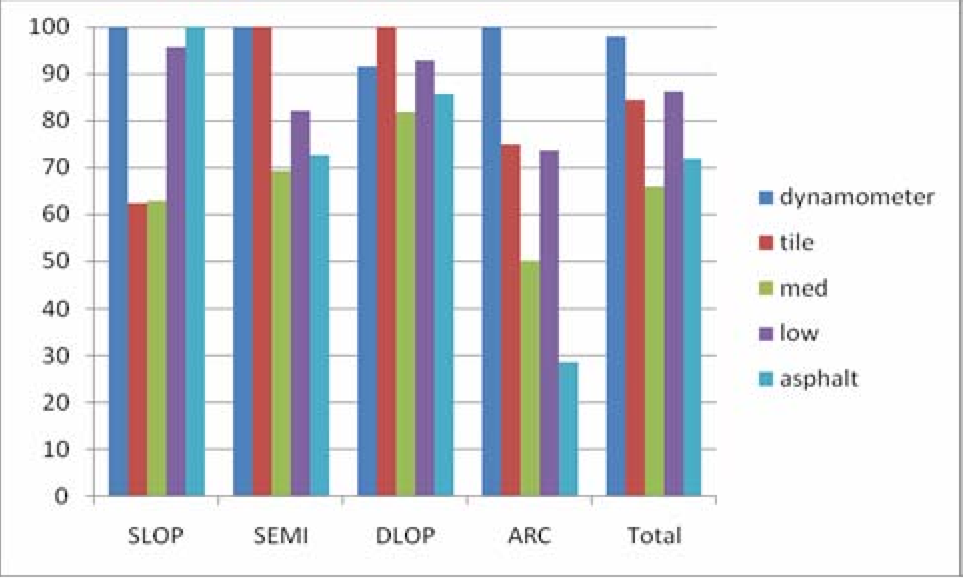
- Support Vector Machines (SVMs) with radial basis function kernel
- k-Nearest Neighbor (kNN)
- Used MATLABArsenal implementation of kNN and SVMLight implementation of SVMs

Partitioned the training and test sets based on the day that each trial was collected

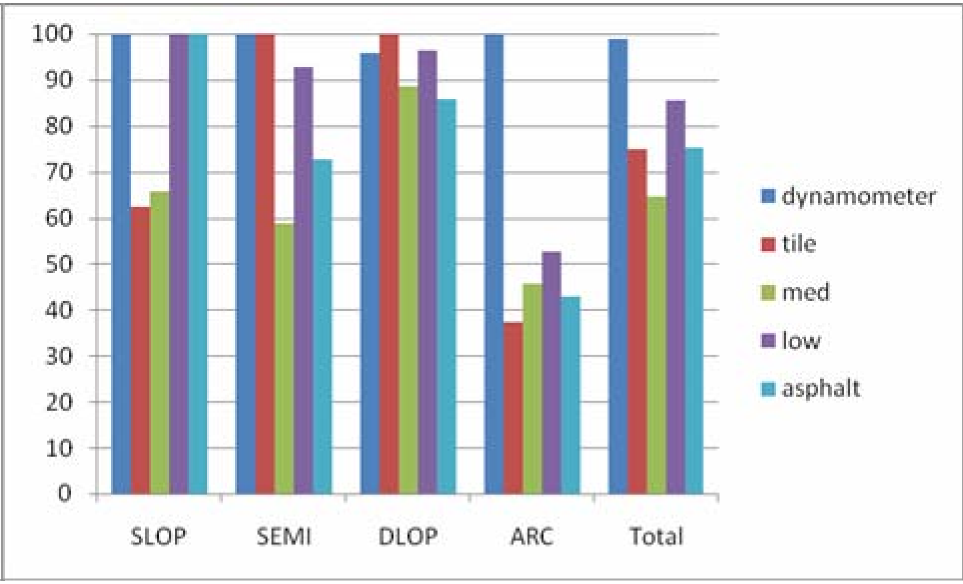
- All data collected on the same day is exclusively placed in training or testing

Average Classification Accuracy by Surface Type

kNN results



SVM results



Generally, high resistance surfaces (dynamometer, carpet) yielded better performance due to reduced freedom of motion in maintaining the constant rate of speed

- Medium carpet and asphalt are worst performing due to an insufficient number of samples
- Arcing is the most difficult to classify being a subset of the other patterns

kNN accuracy ranged from 66-98%, averaging 81% over all surfaces

SVM accuracy ranged from 65-99%, averaging 80% over all surfaces

Misclassification Analysis

In general, kNN confuses each pattern strongly with one other pattern and weakly with a third pattern

SVMs tend to be more confused about ARC than kNN, but demonstrate the same confusion pattern as kNN for SC, SLOP and DLOP

kNN Dynamometer

	true SLOP	true SC	true DLOP	true ARC
predicted SLOP	25	0	1	1
predicted SC	0	35	0	0
predicted DLOP	0	0	47	1
predicted ARC	1	0	0	25

kNN Low Pile

	true SLOP	true SC	true DLOP	true ARC
predicted SLOP	22	1	2	4
predicted SC	0	23	0	1
predicted DLOP	0	0	26	0
predicted ARC	1	4	0	14

kNN Asphalt

	true SLOP	true SC	true DLOP	true ARC
predicted SLOP	7	1	2	4
predicted SC	0	8	0	1
predicted DLOP	0	0	12	0
predicted ARC	0	2	0	2

kNN Tile

	true SLOP	true SC	true DLOP	true ARC
predicted SLOP	23	0	4	9
predicted SC	0	32	0	0
predicted DLOP	3	8	36	1
predicted ARC	4	0	0	14

Conclusions

We have shown that reasonably high accuracy classifiers can be built for these four patterns using a single, wrist-mounted accelerometer

- Surface resistance had the largest impact on classifier accuracy

Continuing work

- Collecting data from a larger population of subjects
- Unexplored classification variations
  - Across subjects, across surfaces, non-static velocities, and distinguishing between propulsion and non-propulsion motions

Thank you