GRIP ANALYSIS: DAILY ACTIVITIES OF YOUNG ADULTS

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INTRODUCTION

Advances in low power digital devices have initiated a new era of portable instrumentation for medical diagnostics and research. One important application for wearable devices is the characterization of hand forces in activities of daily living as relevant to prosthesis design, occupational risk assessment, and upper limb rehabilitation and diagnoses.

Past research in this area has been largely limited to in-clinic analyses of specific grip types or activities as opposed to those encountered in daily living [1,2]. Measurement techniques as applied to grip characterization can be categorized as follows:

(1) Dynamometers. Subjects are asked to reproduce the grip force used for a specific activity on a dynamometer [1,3]. The reliability and accuracy of this method has been questioned [3].

(2) Instrumented objects. Subjects perform a specific task using an object fitted with sensors for measurement of applied forces [2,4]. This technique enables accurate characterization of isolated grips and activities.

(3) Sensor Gloves. Subjects perform a range of activities while wearing gloves which may be instrumented with a number of sensor technologies including force resistive sensors [5], fibre optics, and conductive polymers. The affect of glove thickness on force application is one limitation of this technique [6].

(4) Wearable sensors. Subjects perform a range of activities while wearing an array of force sensors affixed directly to the hand. This technique was first proposed by Nikonovas et al. [7] and offers advantages in reliability and versatility.

In this study, we adopt the latter approach and have developed a device with enhanced portability and versatility enabling grip characterization outside of the clinic environment. This paper describes the design of a fully portable, wearable system that is capable of monitoring (1) the forces experienced, and (2) the types of grips used by the hand continuously over a six-hour period.

SYSTEM DESCRIPTION

System components were selected to minimize interference with hand function in activities of daily living. The following will discuss the selection and operation of each system component.

<u>Sensors</u>

Tekscan Flexiforce A201 sensors were selected for this application. With dimensions of 0.208mm in thickness, 12mm in width, and variable length, these sensors comply with the physical constraints of the system. The sensors are force resistive with a range of 10-20MΩ unloaded to 20kΩ at max load. The model used

Figure 1 Sensor arrangement on the hand

has a load range of 0–11kg with the manufacturer's claim of <±2.5% repeatability and <±5% linearity error. The sensors were placed in a voltage divider with a fixed 100kΩ resistor, and when calibrated, the relationship between force and voltage was shown to be exponential with an R-squared value greater than 0.99. Force readings on the curved finger surface are expected to be within ±6% of those obtained on a flat surface, as demonstrated by Nikonovas et al. [7]. Eighteen sensors were attached to the hand using 3M Tegaderm transparent dressing with their locations shown in Figure 1. The sensors were positioned in critical areas of the hand involved in different grip configurations (i.e. pinch, palmer, lateral, cylindrical, spherical, and hook) and were chosen to maximize user comfort and grip recognition ability.

Sampling and Signal Conditioning

To realize system portability, a light, compact personal digital assistant (PDA) fitted with a National Instruments CF-6004 compact flash card was used for data acquisition. A sampling rate of 1800 samples per second was selected to ensure long-term stability within the processing power constraints of the PDA. The PDA and data acquisition card were interfaced through Labview.

The signals from all eighteen sensors were converted into a single, multiplexed input acquired by the compact flash card. The rate of multiplexing (as controlled by an Atmel ATtiny13 microprocessor) and the data acquisition rate (as controlled by the CF-6004 compact flash card) were asynchronous. Therefore, a system was needed to distinguish between the different sensor inputs on the multiplexed signal. To accomplish this, a resistor of known value was sampled following each sensor sample to provide a marker by which the signals could be reliably separated. Each sensor was sampled 3 times consecutively to ensure acquisition accuracy. As a result, the effective sampling rate of each sensor was approximately 16Hz, adequate for the capture of quick impact forces. The PDA, control circuitry and batteries were packaged in a waist pack worn by the subject, as seen in Figure 2.

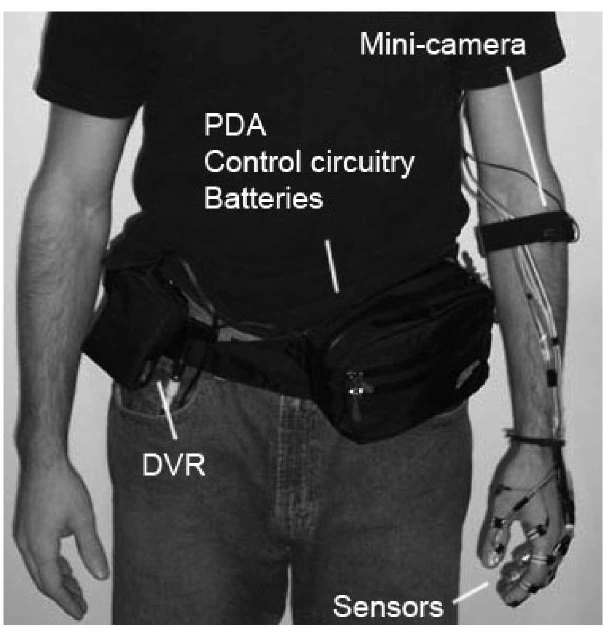

Figure 2 Image of the subject outfitted with the hand characterization system developed.

Data Organization

Upon completion of data acquisition, the multiplexed signal is transferred from the PDA to a personal computer. Using Matlab, the data is de-multiplexed to enable the analysis of force readings from each individual sensor. Measurement errors and/or circuit malfunctions are detected and corrected by comparing each of the three consecutive sensor samples acquired.

Video Recording

In addition to the force measurement components as described above, the system was also outfitted with video capture to aid in the identification of grip types. A mini-camera (Ultra-Mini Cmos Camera) of dimensions 8x8x16 mm and weighing 10 grams, was used for this purpose, along with a digital video recorder (DVR). As can be seen in Figure 2, the mini-camera is mounted on the forearm and secured in a neoprene arm band. The mini-camera is aimed such that it has a view of the hand at all times. For privacy concerns, the focus of the camera is set very close to ensure that objects and people beyond the hand are blurred from recognition. Additionally, subjects may easily disconnect the power source from the mini-camera when additional privacy is desired.

The DVR is located in a second small pouch on the waist opposite from the pack containing the data acquisition system (Figure 2). Utilizing two lithium ion batteries and four gigabytes of flash storage, the DVR can record up to 6.5 hours of video.

Wire Management

To ensure that the sensor and mini-camera wires do not hinder the movement of the subject, the wires are secured close to the skin by a small elastic wristband and a neoprene forearm band as can be seen in Figure 2. The wires then travel up into the shirt through the sleeve of the subject and down the inside to either the waist pack or the DVR pouch. Enough slack is kept in the system to allow for unrestricted movement.

DATA ANALYSIS

Data acquired using the hand characterization system is analyzed using Matlab. For each subject, the following output measures are determined:

(1) A timeline of peak forces, grip types and durations of grip that is sequentially correlated with the video captured.

(2) The frequency with which each of the different types of grips (i.e. hook, platform, push, heavy wrap, circular and prismatic) was used as observed over the entire duration of observation.

(3) The frequency of activation, together with average and peak forces measured at each individual sensor location.

The forces applied to the sensors by the compressive adhesive tape used to secure the system were accounted for by subtracting the sensor signal level measured when the hand is idle. The sensors' voltage readings were converted into force values using the exponential calibration curves developed. An algorithm for grip recognition was constructed based on the location of sensors activated. A sensor was identified as "on" when its value exceeded a specified threshold. Each grip type was associated with a distinct pattern of activated sensors as exhibited in Figure 3.

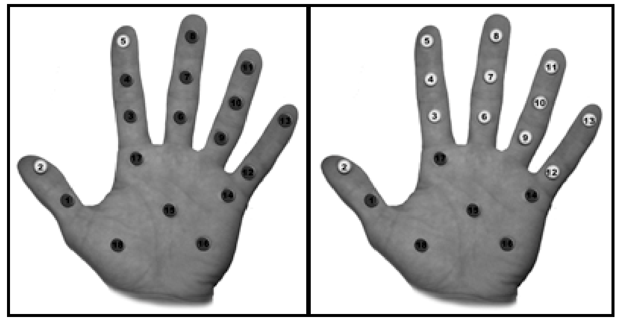

Figure 3 Examples of grip patterns for activated sensors. Two finger pinch (left), full hand pinch (right)

PRELIMINARY RESULTS

Preliminary analysis has been completed on data collected from the dominant hand of one subject during which the hand was in use (i.e. at least one sensor was activated) for a total of 4.5 hours. Figure 4 displays the peak forces applied to the sensors during the entire trial. For this subject, the highest force exerted was 80.6 N on the thumb metacarpal. All of these peaks occurred while the subject was playing with a dog as discerned from the video captured. Figure 5 depicts the average forces experienced by each sensor when activated (greater than 0.5N of applied force) for the first two hours of the trial, before the subject was playing with the dog. Average forces ranged between 0.47N at the thumb proximal phalange and 1.95N at the small proximal phalange. Lastly, Figure 6 displays the

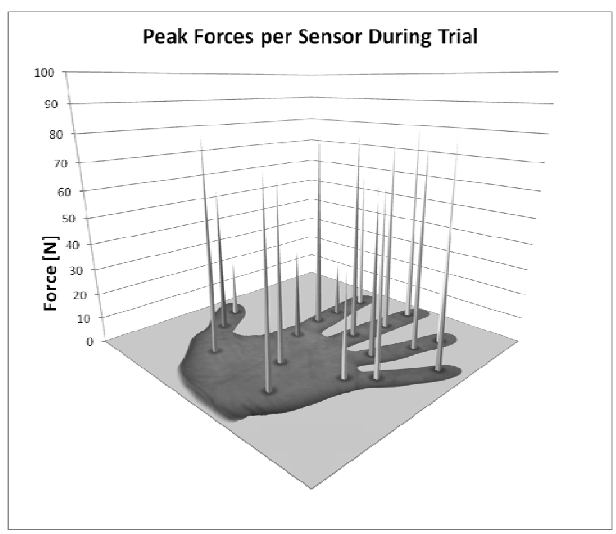

Figure 4 Peak forces recorded during trial. Peak of 80.6N recorded on the thumb metacarpal

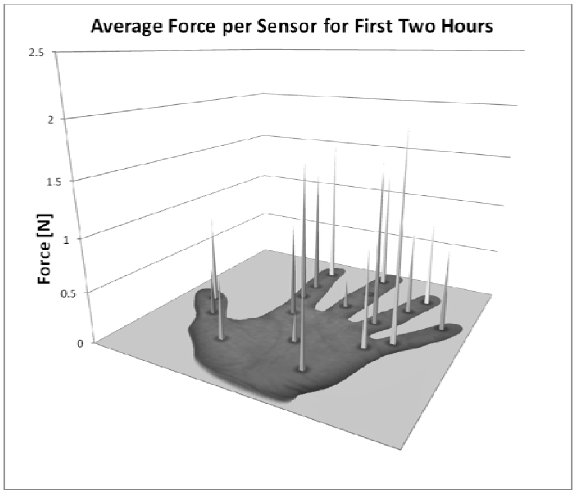

Figure 5 The average force over 0.5N applied to sensors during the first two hours of the trial

cumulative time that each sensor was activated. From this graph, it is evident that the sensor at the base of the small metacarpal was activated for the longest duration. By reviewing the captured video, it was determined that the subject had been using that part of their palm for balance while riding the subway. This demonstrates the potential of the developed system for realistically capturing the functional role of the hand in a variety of activities of daily living.

Additional development of the system will be carried out to increase the number of recognizable grips. The potential of non-binary based algorithms for improved grip recognition will be explored to distinguish between similar grips (i.e. 5 finger circular precision grasp and 5 fingertip non-prehensile power push).

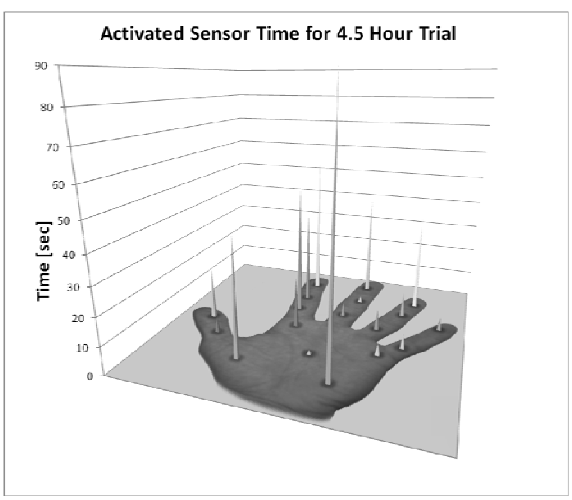

Figure 6 Cumulative time over trial for sensors with greater than 0.5N of force applied

CONCLUSION

This paper outlines the design of a portable hand characterization system to be used for force and grip analyses. This system offers several advantages in terms of portability and versatility. The hand characterization system developed can be used to explore the functional needs of an individual during a typical day or those needed to perform a specific activity depending on the structure of the experiment design. The system will be used in the future for both purposes in order to quantify the functional roles of the hand

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