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Measuring Finger Flexion and Activity Trends over a 25 Hour Period using a Low Cost Wireless Device

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Abstract— **The goal of this research was to evaluate the usefulness of a wireless custom monitor in measuring real-time finger posture over an extended period of time as the wearer goes about daily life activities. One individual wore the device for 25 continuous hours in the research facility and at home. Initial data analysis methods have been presented to explore different aspects of hand activity over time. Evaluating mean flexion over five minute intervals reveals common hand postures assumed throughout the day, while total joint excursion over longer intervals highlights periods of inactivity associated with sleep or rest, as well as periods of higher intensity activities that can be used to evaluate compliance with physical therapy and home rehabilitation instructions.**

I. INTRODUCTION

Understanding and measuring improvements in hand function following disease or injury is critical in planning effective treatments and evaluating rehabilitation therapy. However, evaluations performed in the clinic do not always correspond to increased hand use in the home and community. Trends toward wearable measurement devices and home monitoring are opening the door for researchers and clinicians to collect hand posture and movement data as individuals perform daily activities such as eating, dressing, and manipulating everyday objects. This can provide a much clearer picture of true hand usage. Real time finger movement data collected over an extended period of time (e.g., more than 24 hours), can yield valuable objective information about the efficacy of various interventions, including currently unanswered questions regarding the total amount of hand use, recovery of hand and finger speed, compliance with home therapy regimens, and hand postures assumed throughout the circadian cycle.

Currently, commercial gloves exist that can measure finger and joint position in real time; most are based on gloves containing from 5 to more than 22 sensors to measure joint flexion, extension, abduction and adduction, and in some cases, palm flexion. Some commercial gloves include the DataGlove family (Fifth Dimension Technologies (5DT), Irvine, CA), Cyberglove (Immersion Corporation, San Jose, CA), and the Humanglove™ (Humanware S.R.L., Pisa, Italy). Some have wireless capabilities, although the glove must be within a short range of a computer which receives and stores the real time data. This allows local wire-free use but not complete freedom throughout the home and into the community.

Most gloves were developed for the virtual reality market and are too expensive to allow the purchase of sufficient numbers for research studies. More critically, these gloves are typically difficult for individuals with severe restrictions in hand and finger range of motion to don. While some of them can be used to evaluate hand function with disability [1], these devices do not meet our needs for low-cost, longer term monitoring in the home and community for individuals with a wide range of hand dysfunction.

The goals for our research require a very low-cost device for widespread deployment at several research sites. In addition, we wish to avoid necessitating the restriction of common behaviors due to the desire to protect an expensive device from damage. In addition, the device should be easy to put on for all individuals, including those with severe reductions in range of motion, spasticity, or contracture. Finally, the device should be lightweight, unobtrusive, and allow wearers to move about the home and community with ease.

The Shadow Monitor was developed to meet these needs. Measurement repeatability has been established and calibration methods developed [2]. The device has been used to explore activity of the metacarpophalangeal (MCP) joints in healthy individuals and individuals with brain injury during the performance of specific short term tasks. Even looking only at these five joints, characteristics, such as speed and range of motion, of functional tasks show a clear difference with brain injury, prompting us to explore the feasibility of long term trials [2].

Completely portable 24 hour monitoring is not new, but has gained popularity since the invention in 1949 of the

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Holter monitor for portable continuous recording of ECG. Multi-day activity monitoring is possible with lightweight wearable devices, and algorithms have been developed to classify different types of motor activity with movement disorders or diseases such as chronic obstructive pulmonary disease [3],[4]. Wearable devices yield rich data about the type, duration, and intensity of an individual's normal daily activities; information difficult or impossible to capture during a typical clinical or therapy session. In addition, longer term monitoring can reveal unanticipated events (e.g., sustained high intensity activities that can lead to overuse syndromes, onset of acute change in health status, falls), confirm compliance with home therapy, validate activity diaries (which are usually inaccurate) [4] as well as enhance preventative and wellness programs by providing more comprehensive and easily deployable evaluation methods [5],[6]. Longer term monitoring of upper extremity hand and finger function will reveal hand function and use during daily activities that are meaningful to the patient, and allow clinicians to evaluate objective improvements in function with treatment.

II. METHODOLOGY

A. System Description

The Shadow Monitor was designed to measure finger flexion in a low cost and portable manner, and to be easy to don regardless of finger position. Sensors that change resistance went bent are encased within flexible fabric sleeves, and then attached to the back of selected joints using double-sided medical grade adhesive (MACTac, Stow, OH). Each encased sensor is a separate entity, allowing both precise placement of each regardless of hand size, and application of between one and eight sensors on any combination of joints simultaneously. In addition, the design allows sensors to be placed on joints without opening the hand or extending the joint, which may be required in cases of severe disability. Design aspects of the sensors and the system are presented elsewhere [7].

Signal conditioning electronics, memory storage, and the wireless transmission system are located in a small box (Fig. 1) that can be strapped to the arm. The basis of the system is a Tmote™ Sky device (MoteIV Corporation, Berkeley, CA). Each "mote" contains 10k RAM, 48k FLASH, external 1MB FLASH (for data storage), 8 12-bit A/D channels, 250kbps 2.4GHz IEEE 802.15.4 Chipcon Wireless Transceiver, and an onboard antenna. Operations are controlled by a Texas Instruments MSP430 microcontroller. Flexion data are sampled at 25 Hz using an onboard 12-bit A/D converter, and the entire system runs on 2 AA batteries.

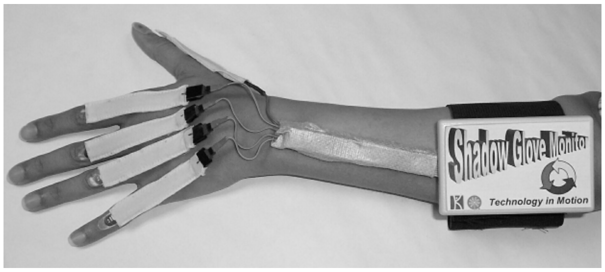

Fig. 1. Wireless Shadow Monitor with sensors placed over MCP joints.

Data can be stored in the "sampling" mote, or transmitted over the air to a similar mote device acting as a base station receiver ("receiving" mote) connected to a USB port on a nearby computer. The wireless protocol used is the IEEE Standard for Low-Rate Wireless Personal Area Networks (IEEE 802.15.4) [8]. This newer standard was specifically proposed for applications requiring extremely low power consumption and using lower data transmissions rates, such as sensor net monitoring, home health monitoring and telemedicine, and home automation [9]. It has also been proposed in the implementation of a wireless body area network (WBAN) for rehabilitation applications and ambulatory monitoring [10].

B. Test Description

In the feasibility testing performed here, one subject donned the Shadow Monitor on the right (dominant) hand, and five sensors were selected to record real time activity at the MCP joints of all the digits for a period of approximately 25 hours. The subject was a lab member familiar with the project, and all procedures were performed after KMRREC IRB consent was received. The sampling mote (within the Shadow Monitor) was configured to automatically search for a receiving mote and send data over the air to be stored on a nearby laptop computer. If the receiving mote could not be found (e.g., when the wearer went out of range of the laptop), the sampling mote stored data locally in the mote FLASH memory. When the receiving mote was detected at a later time, all stored data was extracted from local memory and sent over the air to the receiving mote, interspersed with the currently sampled data, until the memory was cleared.

After the system was initialized, calibrated, and verified to be operating correctly, the subject completed the work day, and took the laptop computer home and placed it in a central location in the home for the bulk of the trial. The subject was instructed to perform all activities normally, with the exception of those involving water, during which latex gloves were to be worn. Waterless hand cleaner was provided for hygiene purposes, and in order to shower, the subject was instructed to unplug the sensor cable and remove the signal conditioning box, and to wear a glove to keep the sensors and sleeves dry. The subject also was instructed to keep a diary of activities and to return the following day, with the device and laptop computer, to complete the 1-day trial before device removal.

III. RESULTS

Continuous wireless data were collected for approximately 25 hours on 1 set of batteries. During this time, the monitor successfully operated in all data collection modes (local data storage, immediate over-the-air transmission of new data, and simultaneous transmission of new and stored data). When the laptop was placed in the car to go home, the system stopped collecting data and had to be restarted. This was later traced to a broken solder joint on the battery holder. In addition, in the middle of the night, one of the wires connecting the index MCP sensor to the signal conditioning box became disconnected, preventing data capture for the index MCP for approximately 3 hours until the subject woke up and reconnected the wire.

The raw data log files contained 68MB of ASCII data in text format, which included a timestamp and five raw A/D values representing flexion of each MCP joint. Because the data are not always stored sequentially when the sampling mote is out of range of the receiving mote, the raw data was first sorted by timestamp, and then the raw flexion values were converted to angles using calibration data collected at the start of the session.

Finally, angle data was post-processed in three different ways to explore short term flexion trends, longer term flexion trends, and cumulative flexion trends. Each of the plots below is based on the same dataset and covers the same timeframe. The 25 hour trial began at approximately 2 p.m. (marked on the plots as hour 0) and ended approximately 3 p.m. the next day. For the first few hours, the subject performed office work while seated at a computer (hours marked 0-3). After commuting home, the subject performed housework and prepared dinner (hours 4-7) and then relaxed and watched TV before retiring to bed to read and then sleep (hours 8-15). After waking up, the subject prepared for and commuted to work, arriving before hour 17. The morning was spent with more office work at the computer, followed by lunch, some organizing activities, and a meeting, before the device was removed at hour 25.

Short term flexion trends can be seen in Fig. 2. Mean flexion and standard deviation were computed over each five minute interval across the entire 25 hour period, for each MCP joint individually. Mean flexion values are lower for all MCP joints during office work (19° ± 10) (reading, typing and using the mouse) while household, hygiene and dressing activities are represented by higher mean flexion values (i.e., joints more closed than open) (28° ± 13). Higher flexion and lower values of standard deviation are evident during sleeping and during some aspects of office work (32° ± 2). Larger standard deviation values represent larger changes in hand position, or more regular hand activity over the averaged interval.

Longer term flexion trends are shown in Fig. 3. The entire data set has been reduced into 60 minute averages. Mean flexion values show a higher range for the pinkie and ring fingers, while the thumb and index tended toward lower values (i.e., on average a more open joint position). Over the 24 hour cycle, there is no clear trend in average finger posture, although the pinkie, ring, and middle fingers tended to be more flexed in the evening and during the night. It is anticipated that these longer averages may show change over a diurnal cycle in individuals with brain injury.

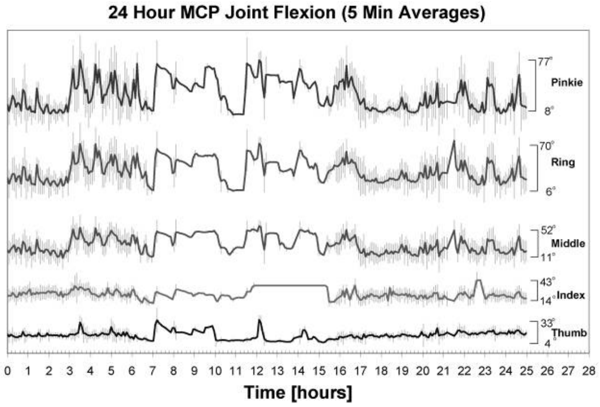

Fig. 2. MCP flexion averages (every 5 minutes) with standard deviation whiskers. The index sensor wire became disconnected during the sleep interval, as indicated by the flat line.

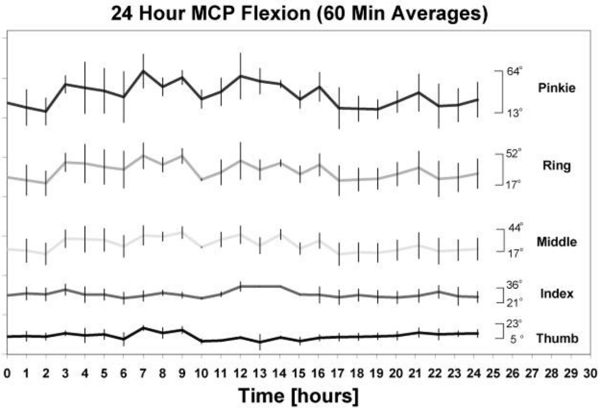

Fig. 3. MCP flexion mean, standard deviation (60 minute intervals).

Finally, the data has also been processed to reveal periodic cumulative activity. This "jointometer," analogous to a pedometer, provides total joint angle traversed (both flexion and extension) during a period of time. For each joint, j, the total angle excursion (TAE) every second is computed below, where MCPangle(n) is a single joint angle value measured at 25 Hz.

$$TAE\,j = \sum_{n=1}^{n=25} abs[MCPangle_j(n) - MCPangle_j(n-1)] \qquad (1)$$

Fig. 4 shows cumulative joint movement over 30 minute intervals for each of the five MCP joints, with the resultant values summed or "stacked" in the plot to represent total joint excursion of the hand over time. From this chart, periods of inactivity are very obvious, including the sleep interval from hour 7 to 15, and a meeting conference at hour 21 that lasted approximately 30 minutes.

Percentage contributions of each joint to the total can be evaluated. All appear to track one another, with the contributions from the middle and ring MCP joints slightly

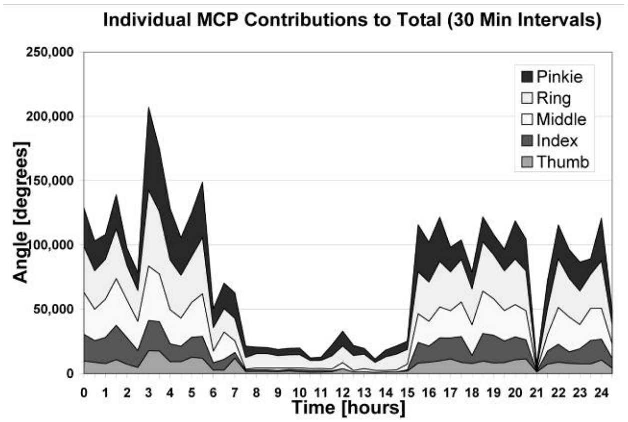

Fig. 4. Cumulative movement for each MCP joint every 30 minutes. All MCP values are stacked to show overall hand excursion in degrees.

larger in value. This was due to a mouse trackball which the subject "drove" primarily with the middle and ring fingers during office work.

IV. DISCUSSION

The different data processing methods revealed different aspects of the subject's hand activities. Five minute averages better show periods of higher activity (large standard deviations) and frequent changes in joint flexion angle, revealing the range of postures that a subject assumes during the night and day. For example, the sleep interval shows approximately 11 changes in hand position, from full flexion to full extension. Very small standard deviations indicate that the subject moved very little between changes in position, a characteristic of sleep.

Periods of inactivity were much more evident when considering the "jointometer" approach by calculating total angular excursion. Total joint excursion does not always track finger posture; for example, during the day (hours 15 to 25), total finger excursion is relatively independent of mean finger flexion, which fluctuates significantly during the same interval (Fig. 2). Measured posture is different from cumulative activity, making total joint excursion another useful outcome measure for hand function for identifying bursts of activity level that correspond to physical therapy or volitional motions. For example, a peak of intense activity is evident in hour 3, which was not as obvious in either of the other data representations.

Improvements to the device have been made as a result of this evaluation, including the adoption of a flexible one-sided medical grade tape to secure the sensor wires (MACTac, Stow, OH) against accidental disconnection during large wrist motions or sleep. In addition, data compression algorithms will reduce the total size of the raw data file, extend battery life (due to lower payload size), and extend the available "out of range" time during which an individual can leave the home and run errands.

The individual in this trial had no restrictions in hand range of motion, and was able to don a latex glove to wash dishes and take a shower. However, we will develop a simple plastic bag with a Velcro or adhesive closure that can be easily donned to avoid water contact. (Water will not damage the sensors or sensor sleeves, although it should be avoided. Contact with water may short the sensor leads together, although no safety issues or damage will occur; the monitor will simply record invalid data.)

V. CONCLUSION

Using the Shadow Monitor to monitor finger flexion for 25 hours showed clear periods of different activity levels and a range of different hand postures during passive and volitional activities. Real time joint motion can be used to evaluate compliance with therapy regimens and true function effects of an intervention, and to assess overall functional levels and objective hand use outside the clinic. Future work will focus on extended data collection sessions with healthy individuals and those with brain injury, data processing and feature extraction methods to classify activities, and on increasing the robustness of the system.

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