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Measuring Activities of Daily Living of Stroke Patients using Integrated Upper Limb Measurement System and ADL Measurement Table

ABSTRACT
To be able to automate some of the rehabilitation processes, it is necessary to be able to measure movement of stroke patients. This paper describes a complete system to measure the Activities of Daily Living (ADL) motions of healthy subjects and stroke patients. The system is composed of a customised table top, an Inertial Measurement Unit (IMU-based) to measure arm posture, and an Optical Linear Encoder (OLE)-based sensor to measure hand motion. The integrated system is designed to measure five ADL motions and save the data for further processing. The five ADLs measured are picking up a cup, zipping and unzipping a vest, picking up a phone, opening and closing a window, and wiping face with a towel. The system has been used to measure ADL motion data of fifteen healthy subjects and fifteen stroke patients.

1. INTRODUCTION
Activities of Daily Living (ADLs) refer to day to day self-care activities patients do. This can take place in their homes or in structured environment like the hospital. ADLs are used to measure functional ability and predict outcome of stroke patients, thus, improving their ability to do ADLs is a key element in their recovery from stroke. Although there are numerous scales used to measure ADLs [1], using actual motion data to analyse ADL performance is key in automating some ADL related activities. Being able to accurately measure performance in doing ADLs helps in predicting the success of upper arm recovery and patient management and outcome measurement.

Measuring and automating ADL movement, especially in the context of rehabilitation, may lend itself to automation since the activities tend to be repetitive and time-consuming to conduct. For example, reaching and grasping for an object across a table repeatedly for several minutes. Thus, some researchers have demonstrated of using a robotic suit to aid with ADL-based motion for rehabilitation [2]. A low-cost robotic system was developed by Sugar et al [3].

This paper discusses the integrated system to measure Activities Daily Living (ADL) activities of both healthy subjects and stroke patients, which is the first step in being able to design a robotic rehabilitation system. The main aim is to build the initial data pool of motion between stroke population and normal population in performing five specified table top ADL tasks. The rest of the paper presents the ADLs measured (Section 2), the system design (Section 3), and the experiments conducted (Section 4).

2. ACTIVITIES OF DAILY LIVING (ADL)
Activities of Daily Living (ADL) define the tasks each individual must be able to do to be able to function independently. One effect of stroke is the inability or difficulty of a person to carry out ADLs. Among the common ADLs that are normally used by therapists for rehabilitation [4], five have been selected for this project.

The ADLs chosen are limited to the upper limb and requires a variety of upper limb movement to carry out. For example, shoulder rotation and abduction/adduction and flexion/extension, elbow extension and flexion, wrist or upper arm pronation and supination, and finger extension and flexion.

To be able to have a standard measurement platform, some of the ADLs have to be modified. For example, the window has to be replaced with a metal key box.

Picking up a cup - The subject must pick up the cup at its handle and place it as near to the mouth as possible, as if the subject is going to drink from the cup. Afterwards, the
The colour markers on the table indicate the location of the items to be used for measurement depending on the height of the subject. The chair is fixed in position, but foot rest are changed according to the height of the subject.

Figure 2: The chair has been modified with a padded upper back support to ensure that the upper body is straight.

Zipping and unzipping a vest - The subject must grasp the zipper with one hand and pull it all the way down and then back up again. This must be done without the help of the other hand. To aid subjects in grasping the zipper, especially stroke patients, a metal ring have been added to the zipper. Subjects could then use the metal ring to move the zipper.

Picking up phone - The subject must pick up the phone and place it as near to the ear as possible, as if answering a call. Then the subject must put the phone back down on the table.

Opening and closing a window - The subject must open a window and close the window. The window must be opened as wide as possible while making sure that the subject is grasping the window handle at all times. As an actual window is difficult to mount on the experiment table, we replaced the window with a steel enclosure (similar to a large key cabinet) (see Fig. 1). Operating the handle of the steel enclosure to open it mimics the same motion when opening a window with a similar handle - grasping the handle, twisting the handle to unlock, and pulling the handle away to open the window.

Wiping face with a towel - The subject must pick up the tissue and place it as near to the face as possible. Then the subject must do a circular motion three times, as if wiping the face with the tissue, in counter clockwise (if using the right hand) or clockwise (if using the left hand) direction.

3. SYSTEM DESIGN
3.1 ADL Measurement Table
A table and chair set-up has been customised in order to measure ADLs uniformly. The table's height has been customised according to the national anthropometric data of the subjects so that the set-up can accommodate any subject regardless of height (see Fig. 1). For Singapore, anthropometric data (average heights of male and female citizens) has been obtained from the Ministry of Health.

The table top has also been labeled with markers to indicate the location of the items for used in the ADL (cup, phone, window (steel enclosure), and towel). The blue labels indicate...
cante item location for tall subjects, red for medium-height, and black for short ones. The seat has been fixed in position so the table markers ensures that the subject’s arm would be maximise elbow extension when doing the ADLs despite height variations of the subjects.

The chair has been customised by fixing its position through the addition of a platform. To help with subject comfort, foot rests have been added under the table. The foot rests can be changed according to the height of the subject. Additionally, the chair is also customised by adding a padded upper back support, which ensures that the subject sits straight during ADL execution by providing a 15 degree difference between the shoulder and the lower back. This makes the whole torso perpendicular to the floor during measurement (see illustration in Fig. 2). Since subjects would include stroke patients, a special vest has been designed to minimise shoulder movement due to compensatory movement.

3.2 Upper Limb Measurement System

3.2.1 Measuring the Arm Motion using IMU

We used inertial measurement units (IMU) sensors which contains nine sensors inside: 3 accelerometers, 3 angular rate gyro and 3 magnetometers. Data from the sensors are integrated to obtain the orientation (roll, pitch, and yaw) of each sensor unit. To measure whole arm motion, we used two IMUs, one for the upper and one for the lower arm. Details of the derivation of the arm parameters using the IMU data, including the calibration details, can be found in [5].

3.2.2 Measuring the Hand Motion using OLE-based Glove

To measure the hand motion, subjects wear a glove (SmartGlove) that is fitted with Optical Linear Encoder (OLE) sensors. The finger joint angles are measured by converting the linear motion of a strip over the joint to angular data. The principles of the OLE for joint angle motion is described and validated in [6]. The SmartGlove uses ten OLEs to capture the flexion-extension motion of the 10 finger joints based on the multi-point sensing method. The glove can measure 15 degrees of freedom in total, including the DIP.

The glove measures the metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints while the distal interphalangeal (DIP) joint is estimated based on anatomical constraints, assumed to be (2/3) of the measured PIP value. Fig. 4 shows the SmartGlove. The glove is calibrated for every subject prior to use.

3.2.3 Hardware

The IMUs we used are from K-Sensor by K-Vest (Manchester, NH, USA). Each IMU provides drift-free orientations and calibrated 3 DOF linear accelerations, 3 DOF angular velocities and 3 DOF magnetic data. Data from the nine sensors are integrated to obtain roll, pitch, and yaw angles of the IMU itself. Each sensor connects wirelessly through a receiver that is attached to a computer. Two IMUs are used measure arm motion.

The SmartGlove is manufactured in the lab, including all its components from the glove itself to the OLE sensors. The gloves were made in three different sizes (small, medium, large) based on international sizing standards to accommodate subjects of differing sizes. The glove connects to a computer via Bluetooth protocol.

The whole measurement set-up would include all the following items: IMU sensors (2), SmartGlove, Computer (controller), ADL Measurement Table, Chair with platform and footrests, Vests, Steel enclosure (window), Phone, Cup, and Towel.

3.3 Software for ADL Measurement

A purpose-built software is used to measure ADL data of patients. The software integrates sensor data from the IMUs and SmartGlove and provides the interface for communicating with the sensors. Through the software, the computer can connect to the sensors, allow calibration of IMUs and SmartGlove, save and display captured data. In the figure, the left box displays the captured data while the right box is a video capture of the data in real-time. The menu of the software that shows how to connects to the sensors, calibrate sensors, and save data. The window also shows the actual data captured in real-time. The software can also display captured data for verification.

By running all sensors from the same computer, we manage to synchronise data from all sensors for every ADL measurement. Obtained data are time-stamped using the computer time. Synchronisation is critical during data analysis.

The data obtained are stored as extended mark-up language (XML) files. The unique XML format specifies the data from all DOFs of the arm and hands, as well as the time stamp. The format allows for detailed processing of the motion data.

4. MEASURING THE FIVE ADLS

Prior to the measurement experiments, approval from ethical review boards was sought first. The experiments began after receiving the ethical board approval.

SUBJECTS Fifteen healthy subjects (8 male, 7 female) from Nanyang Technological University, with ages from 21 to 75 years old, volunteered for the measurement experiments. Fifteen stroke patients were recruited from Tan Tock Seng Hospital with ages from 40 to 75 years old (8 male, 7 female). For the stroke patients, special inclusion and exclusion criteria were set including the duration of time after onset of stroke and with a particular shoulder, elbow and hand strength, absence of any upper limb deformity and visual, language and cognitive deficits. Pregnant subjects, prisoners, and those with legal restrictions or incapacity were excluded. All subjects must give their consent before they can participate in the experiments and stroke patients were accompanied and assisted by their therapists during the course of the experiments.

MEASUREMENT EXPERIMENTS After orientation the following data are gathered from the subjects: height, gender and hand dominance. Depending on the height of the subject, the following items are adjusted: Foot rest, Location of table top items, Vest, and SmartGlove. The subject is then fitted with the IMUs on the arm and the SmartGlove
on the hand. Then the subject is asked to sit on the chair and wear the vest. The vest has straps that secure the subject to the back of the chair. Then the IMUs on the arm and the SmartGlove are calibrated prior to every use. After doing the ADL for the dominant side (healthy subjects) or the unaffected side (stroke patients), the non-dominant side (healthy subject) or the affected side (stroke patients) doing ADLs are measured as well. The data obtained are stored for further processing.

4.1 Discussion

Each measurement experiment lasts for about one hour, from setting-up and orientation of the subjects until the end even though measurement of the actual ADL lasts less than one minute per ADL. The bulk of time is spent on wearing the IMUs and SmartGlove and calibrating them.

Several issues were encountered with the stroke patients. The first one is the insufficient muscle control of the affected side, such that there was always a chance losing grip of the cup or the phone. While we used ceramic cups for the healthy subjects, we had to use plastic cup for the stroke patients to prevent breakage in case they drop it accidentally. The second issue encountered was the presence of hand spasm for some patients, which could cause patients to lose their grip on the phone or cup. Some patients could not open their hands to grab the phone or cup and had to be assisted by the therapist. The last problem we encountered which caused the longest delays in the experiment is the insufficient strength of the stroke patients to finish one ADL task. When this happens, the therapists intervenes and lets the patients relax before continuing with the experiment.

Preliminary data obtained from two subjects are shown in Fig. 5. We used Dynamic Time Warping ([7]) to compare the wrist movement in the x-axis of two healthy subjects when picking up the cup ADL. Fig. 5 shows the final result of the DTW, which indicates high similarity in motion of the two subjects.

5. CONCLUSION

In this paper, we have discussed an integrated system that measures ADL motion using customised chair and table designed around the five ADL and two measurement systems. We have successfully obtained data from 30 subjects, half of which are healthy and half are stroke patients. This study is just an initial step towards the completion of a robotic rehabilitation system. What has been accomplished in this paper is the quantification and accurate capture of complete upper limb motion (from proximal to distal) while doing rehab related activity (i.e., the ADLs). Future work involves the processing and analysis of the data collected.

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6. REFERENCES