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Quantifying Functional Mobility Progress for Chronic Disease Management

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***Abstract*—A method for quantifying improvements in functional mobility is presented based on patient-worn accelerometer devices. For patients with cardiovascular, respiratory, or other chronic disease, increasing the amount of functional mobility is a large component of rehabilitation programs. We have conducted an observational trial on the use of accelerometers for quantifying mobility improvements in a small group of chronic disease patients (n=15, 48 – 86 yrs). Cognitive impairments precluded complex instrumentation of patients, and movement data was obtained from a single 2-axis accelerometer device worn at the hip.**

In our trial, movement data collected from accelerometer devices was classified into Lying vs Sitting/Standing vs Walking/Activity movements. This classification enabled the amount of walking to be quantified and graphically presented to clinicians and carers for feedback on exercise efficacy. Presenting long term trends in this data to patients also provides valuable feedback for self managed care and assisting with compliance.

I. Introduction

Chronic disease places a large burden on populations, and health systems in many countries have developed strategies to improve chronic disease management. The research activities described in this paper can support the aims of government strategy, by supporting and improving the capacity of rehabilitation care providers and individuals to prevent and better manage risk factors and established chronic disease.

Chronic disease patients include those with type 2 diabetes mellitus, cardiovascular disease (coronary heart disease, heart failure and stroke), chronic respiratory disease (chronic obstructive pulmonary disease and asthma), renal disease and depression (as a co-morbidity of these chronic diseases).

A large component of chronic disease rehabilitation programs is assessing mobility. Mobility needs of patients include assistance to get out of bed, walking with assistance, walking independently, and undertaking the daily living activities required from their home environment (eg. walking 50 meters plus ascending 3 stairs). Widely used indices of rehabilitation include the Functional Independence Measure Score (FIMS), the Berg Balance and the Timed Up and Go (TUG), and many of these and similar indices have been found to have high sensitivity for predicting falls risk in patients [1],[2],[3]. However, due to their nature, these tests are performed periodically. An assessment tool that provides more frequent or even continuous assessment of mobility enables rehabilitation progress to be more closely monitored, allowing a therapist to potentially adjust or modify exercise programs based on the additional information.

This paper describes an accelerometer-based tool that can enhance assessment of discharge readiness, by providing frequent mobility information and quantifying progress of rehabilitation. Movement data is used to construct a daily activity profile for a patient, which provides an overall assessment of the patient's rehabilitation progress, and determines the degree or time of day of their lack of mobility for better management.

The remainder of this paper provides an overview of the method used to capture movement data (Section II), the classification of data (Section III), and clinical use in a hospital-based observational trial (Section IV).

II. Patient Movement

Our trial involved the collection and analysis of patient movement via a single waist-mounted device measuring acceleration in the longitudinal and anterior-posterior axes. There is a tremendous body of related research activity in the area of measuring human movement. Examples include measuring movement for age group or disease determination [4],[5], chronic disease management [6],[7],[8], pain management [9], daily activity assessment [10], and falls assessment [11]. The strong interest in this area is evidenced by high number of related papers appearing in the 2005 proceedings of this conference (IEEE EMBS). In comparison with related research, we believe our approach has the following advantages:

- it only requires fitting a device in one position which is important when dealing with patients who have cognitive as well as physical impairments; Some projects involve multiple devices (eg. angle, knee, hip, shoulder) each requiring a strap or belt;

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- data can be obtained while the patient roams; other projects require gait analysis in a specific location (eg. gait lab);
- our system is relatively cheap; some competitive research use optical motion analysis systems by camera techniques (stick-on reflector dots) which are expensive and confined to measurements in one space;
- real patient data is better than simulated data obtained from a different demographic. For example, other groups are developing algorithms from young or healthy patient cohorts.

In our study, data from movement sensors was used to provide acceleration signals, the angle of the patient's upper torso with the vertical plane, and a daily activity profile for the patient. By review and analysis of these measures, a more in-depth understanding can be gained by patient carers of the potential risks for each patient, and how to best tailor a rehabilitation program for each individual patient.

We evaluated several accelerometer-based monitoring devices, the smallest measuring 35×53×7 mm and weighing 23g. Acceleration was measured in two axes: Longitudinal (vertical) and Anterior/Posterior (front-to-back) at 10Hz.

A user interface was developed for analysing data and screenshots from this application are shown in the three-panel Figure 1 (a, b, c). The top-left of each panel shows a subject in three different positions: standing, bending and fallen on the floor in panels (a), (b), and (c) respectively. Accelerometer data collected from a monitoring device corresponding to the video frame is shown in the top right of Figure 1 (the vertical axis is units of acceleration or g, scaled from -2.0 to +2.0). One of the ambulatory devices had the capability of 2-lead electrocardiograph (ECG) measurement, and this output synchronized to the video frame is shown in the bottom right of each panel. This paper concerns mobility analysis and discussion on cardiac monitoring is not progressed here.

From the output of the accelerometers, we can also derive the angle of the upper torso with the vertical plane. The derivation of the upper torso angle is based on the use of the effect of static gravitational acceleration on the accelerometers. Thus assuming the device is worn in the sagittal plane at the waist, as shown in Figure 2, then the longitudinal axis should reflect a steady state value of 0g when the torso is horizontal and 1g when vertical.

The bottom left of each panel in Figure 1 shows a dial representing the angle of torso which relates the position of the upper-body to various activity patterns. A simple clinical application of the torso angle measurement is detection of periods when the body is horizontal, especially for adverse events such as a fall.

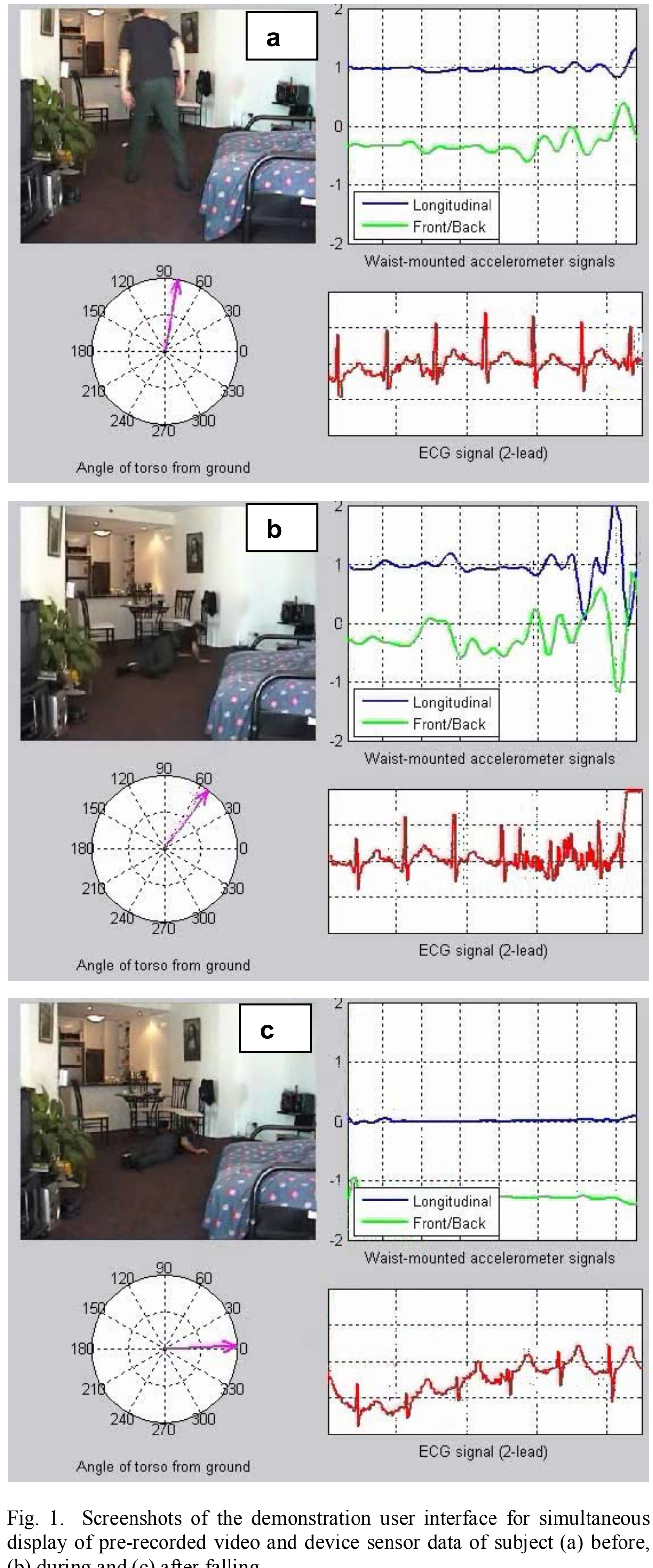

Fig. 1. Screenshots of the demonstration user interface for simultaneous display of pre-recorded video and device sensor data of subject (a) before, (b) during and (c) after falling.

$$\theta = \frac{180}{\pi}\arctan\left(\frac{\bar{a}_v}{\sqrt{1-\bar{a}_v^{2}}}\right) \qquad (1)$$

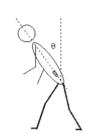

Fig. 2. Illustration of device position for measuring torso angle θ, where $\bar{a}_v$ is the mean longitudinal acceleration, clamped in the range [-1g, 1g].

III. MOVEMENT CLASSIFICATION

Output from the 2-axis accelerometers can also be used to generate a daily activity profile for the patient. By roughly classifying the activity of a patient over the whole day, a more in-depth understanding can be gained as to the potential risks for each patient, or how to best tailor a rehabilitation program for each individual patient.

Our algorithm classifies activity into three categories:

1. Lying, 2. Sitting/Standing, 3. Walking/Activity

These three classes describe the vast majority of activity in our work with rehabilitation patients. In order to perform this classification, two types of features were derived from the two-axis accelerometer data:

1. Angle of upper torso from horizontal
2. Kinetic energy expended over an interval

Angle of torso is described briefly above. Our derivation of kinetic energy expended uses outputs from both accelerometer axes (anterior-posterior and longitudinal), and assumes a mass of the patient of 70kg.

The process used for classification is shown in Figure 3. The torso angle is first used to determine whether the upper body is lying or upright. It should be noted that the absolute value of the torso angle is used, to allow for times when the device is inadvertently placed upside down on the patient by clinical staff. Finally the kinetic energy of the window is used to discriminate between sitting/standing or walking/activity.

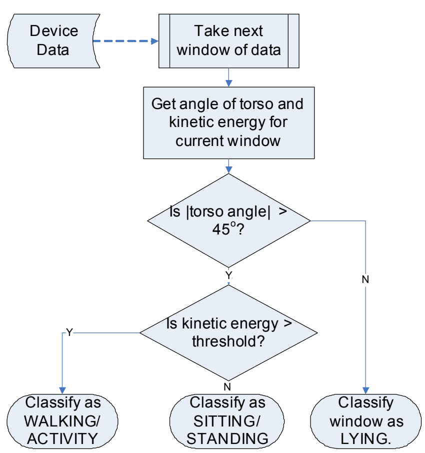

Fig. 3. Flowchart used for activity classification

IV. CLINICAL USE

In order to validate the usefulness of accelerometer-based tools and movement classification, we undertook an observational trial on 15 chronic disease inpatients aged 48 – 86 yrs (mean 67 yrs) undergoing functional mobility rehabilitation at a local public hospital. Patients consented to wearing one or two monitoring devices on a custom belt continuously over a 95-day period. Example medical histories for four of the patients enrolled in the trial are presented in Table 1.

Data collected from the devices was classified into “Lying” vs “Sitting/Standing” and “Walking”, which enabled therapists to quantify for the first time, periods of high patient activity and increased activity levels. Over the duration of the trial, we were able to construct long term trends in activity levels. Examples of long term trends for the four patients from Table 1 are shown in Figure 4. The box-whisker plots on the left of Figure 4 show the percentage of the day spent in each classified state. The boxes have lines at the lower quartile, median, and upper quartile values. The whiskers are lines extending from each end of the boxes to show the extent of the rest of the data. These plots are constructed from all available activity profiles for a particular patient over the trial duration, and allow comparison of activity levels between patients. The plots on the right of Figure 4 illustrate the percentage of the day spent in each classified state varying over time. Such plots can be used to illustrate changes in the amount of time spent in each activity state.

The goal of many chronic disease rehabilitation programs is often to increasing functional mobility, which can be detected and quantified with these activity profiles. The clinical benefit of such measures is a progress indicator to provide feedback to a rehabilitation specialist or physiotherapist on the rehabilitation program prescribed for a patient. Clinicians involved with this study have been able to quantify improvements in activity levels as a result of the rehabilitation program and contribute this to care planning. Also this kind of analysis can demonstrate the time of day in which patients are most vulnerable to injury from walking and other activities. Exercise programs may be targeted towards these times for an effective rehabilitation program.

TABLE I
PATIENT DETAILS

Patient Ref	Age	No. of Prescription Medications	Medical History
4	68	7	AAA repair, splenectomy, multiple fractures, IHD, hysterectomy, temporal arteritis, cerebellar CVA
6	50	8	MV endocarditis, septic embolic CVA, OSA, asthma/CVA, OA, HTN, obesity, umbilical hernia replacement
7	85	9	total hip replacement, valvular heart disease, OA, DVT, breast Ca, cervical Ca, hypothyroidism, glaucoma
10	77	14	Multiple CVAs, rheumatoid arthritis, LV thrombus, gastrointestinal bleeding, pelvic fractures, HTN, osteoporosis

Example medical histories for chronic disease patients assessed in our study.
Patient Ref column refers to plots shown in Fig. 4. CVA = cerebral vascular accident/stroke, IHD = ischemic heart disease, AAA = abdominal aortic aneurysm, OSA = obstructive sleep apnea, HTN = hypertension, OA = osteoarthritis, MV = mitral valve, LV = left ventricular, Ca = cancer.

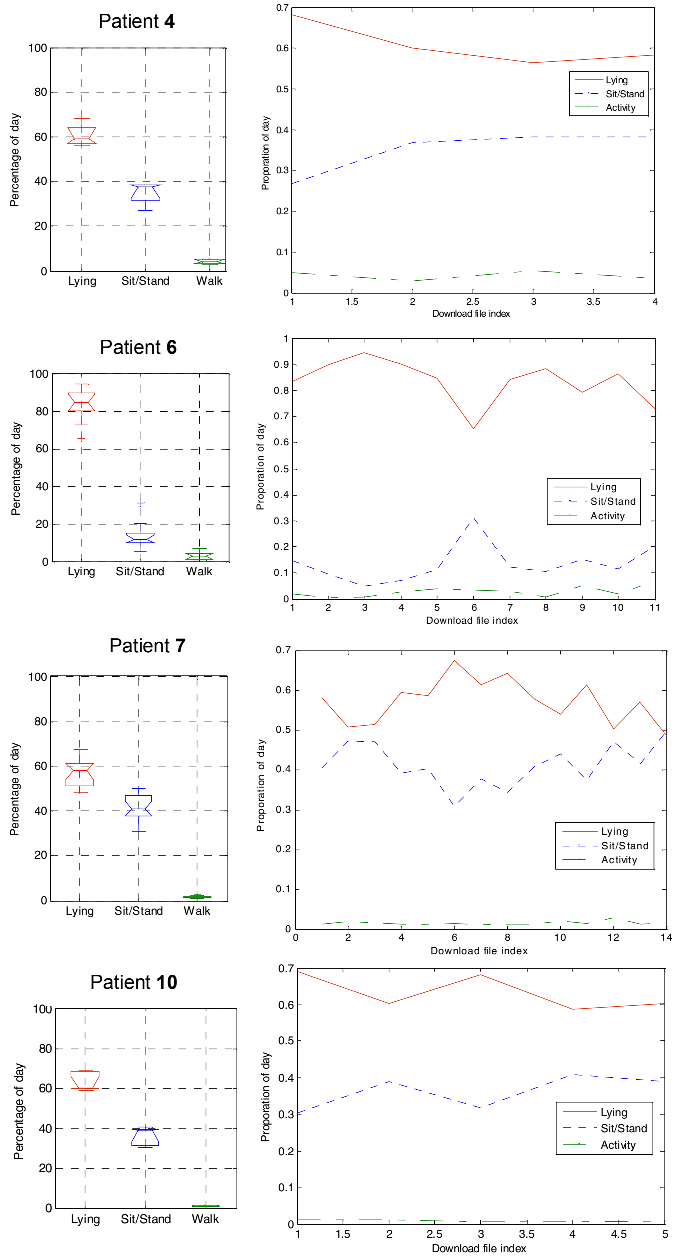

Fig. 4. Long term activity trends of the patients shown in Table 1.
Left: Box-whisker plots showing percentage of day spent in each classified state over period enrolled in trial (box lines at lower/med/upper quartiles); Right: Variation of activity levels over time, where patient progress can be linked to decreases in the amount of time spent in a "Lying" state.

V. Discussion

Results of this work demonstrate that it is possible to discriminate when a patient is standing, bending or lying/fallen from a single device worn at the hip, from which a daily activity profile can be determined. Related work undertaken by the authors [12] has also analyzed the frequency or harmonic characteristics of the gait cycle, which can be used to indicate improvements in the smoothness of gait and hence rehabilitation progress.

The evaluation of the devices performed in this project is a relevant and significant component of any medical device-based trial. Functionality, adaptability and patient and clinician acceptance of the devices requires assessment in order to decide on further trials or wider implementation of the technology. Patient suitability and acceptance of the devices in a subject group of older patients, especially those with neurological disorders, was an important issue in this trial. A post trial questionnaire issued to clinical staff found high satisfaction with most respondents indicating the trial was too short. From an end-user perspective, a monitor that is small, lightweight and unobtrusive is critical. From a clinician viewpoint, the provision of useful measures from the device and minimal impact on routine duties is important.

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