

A SYSTEM FOR MONITORING POSTURE AND PHYSICAL ACTIVITY USING ACCELEROMETERS

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Abstract- Accelerometers can be used to monitor physical activity in the home over prolonged periods. We describe a novel system for objectively and continuously monitoring movement, suitable for patients with chronic diseases including congestive heart failure and chronic obstructive pulmonary disease. The key design criteria were ease of use by, and comfort for, the patient together with the provision of clinically relevant information. The patient's posture, energy expenditure and movement are clinically important parameters that can be measured by accelerometry. A data processing schema in which these parameters are extracted is described.

Keywords - physical activity, accelerometers, congestive heart failure, chronic obstructive pulmonary disease

I. INTRODUCTION

Advances in technology have made possible new and innovative methods of health care delivery. Home telecare, in which the patient's health is monitored remotely at home, is one such method. This paper discusses the use of a triaxial accelerometer within a home telecare system for monitoring physiological and functional parameters for daily living.

Continuous home monitoring can allow changes in health status to be detected and treated early. It also provides more information on the patient's day-to-day health for the clinician. When monitoring the condition of patients with neurodegenerative or chronic diseases, a knowledge of their body movement and physical activity levels during the day is important.

Movement and functional status is traditionally assessed by interviewing the patient or their carer, or by utilising validated questionnaires. These methods of assessment are subjective and rely on the patient or carer to recall events, so that the discrepancy between the patient and clinician evaluation can often be considerable [1]. Direct assessment of the patient using a trained observer can provide a more objective means of assessment, however relying on inferences made about a patient's normal function from a short period of observation in a contrived setting is less than ideal.

Accelerometry is a technique that allows body movement to be directly and continuously measured and quantified in a natural setting for the patient. In this study we have focussed on utilising accelerometry for managing patients with congestive heart failure (CHF) or chronic obstructive pulmonary disease (COPD) although the system can also be applied to a range of other conditions. The design and implementation of a home telecare system specific to the needs of CHF and COPD patients has been outlined elsewhere [2, 3].

II. BACKGROUND

Accelerometers have been used for several decades to monitor body movement in subjects [4, 5], and, more recently, for determining posture [6, 7]. Technological advances have allowed the development of miniature, low powered, wireless accelerometer devices that are suitable for use by "free-living" subjects over prolonged periods [8]. We chose to use accelerometry for measurement of movement-related parameters in the system for CHF and COPD patients.

Piezo-resistive accelerometers operate by measuring the acceleration along the sensitive axis of the device. The measured acceleration has two components: 1) a gravitational (d.c.) component, and 2) a component due to other acceleration forces (a.c. component).

The d.c. output component is due to the gravitational acceleration vector, g , acting on the device. In a triaxial accelerometer (a device consisting of three orthogonally mounted accelerometers) the d.c. component of the output can be used to determine the orientation of the device.

The a.c. component is the result of accelerations other than g acting on the device. If the device is worn by a person, the a.c. component of the output signal is created by body movement. There may also be artefact caused by movement of the device relative to the subject through being knocked, or through clothing shift.

III. HOME SYSTEM SET UP AND WEARABLE DEVICE PLACEMENT

As the accelerometer device is to be worn for extended periods, ease of use and comfort are of primary importance. It must be simple to put on, and must cause minimum inconvenience to the patient. With this in mind, we chose to use a single, waist-mounted, triaxial accelerometer. The design of the device is described by Salleh *et al* [9]. It is contained within a small pager casing, measuring 71x50x18mm and can be easily attached to a belt. Accelerations are sampled at 40Hz and then transmitted via a

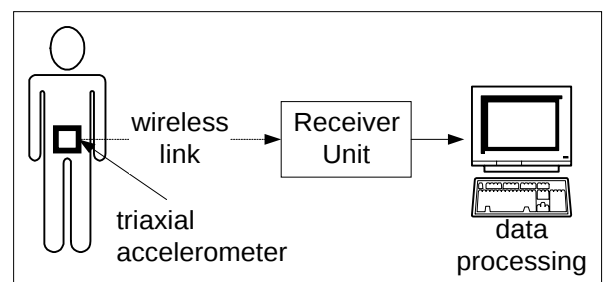


Fig. 1. The accelerometry monitoring system

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wireless link to a personal computer for analysis. Fig 1 shows a block diagram of the system.

Locating the device on a waist belt means that it is close to the centre of mass of the patient when standing, which is important for monitoring energy expenditure and overall body movement. A number of researchers have conducted studies in which an accelerometer was placed at the sacrum [8, 10]. However, during testing of our device, subjects found it more difficult to attach the device to the back of the belt than to the front, and complained of some discomfort when sitting with the device attached to the low back. Therefore we chose to position the device above the anterior superior iliac spine as subjects found this to be the most comfortable and easiest point of attachment.

This location has two drawbacks when compared to attachment at the lower back. Firstly, the low back has less soft tissue and is therefore less likely to be affected by artefact. Secondly, the device is not left-right symmetrically aligned on the patient and this leads to some distortion of the output signal, particularly during walking, thus making it more difficult to analyse. However, we believe that the essential characteristics of the body acceleration signal can still be determined using a placement above the anterior superior iliac spine, and that the advantages of patient comfort and usability outweigh the disadvantages.

IV. PARAMETERS TO BE MEASURED

Accelerometers have been used to measure posture [6, 7], mobility and gait [4, 10] and metabolic energy expenditure [8]. These measurements indicate the amount of time that a patient spends engaged in various physical activities such as standing, sitting and walking as well as the amount of energy used during the day. Changes in these measures can be used to make inferences about changes in functional ability and health status. This has clinical importance for patients with COPD or CHF and we have included each of these parameters in our system design.

In addition to these parameters, we included monitoring of falls and stumbles. Fig 2 summarises the parameters measured by the system.

V. EXTRACTION OF PARAMETERS AND PRESENTATION OF INFORMATION

Having selected the parameters to be measured, it was then necessary to decide how often to compute each of them and to decide how they were to be determined and presented. It is clearly not sufficient to present the clinician with raw output signals from the accelerometer; relevant information needs to be extracted and presented in a meaningful form.

A moving window is used to measure and update the parameters every 30 seconds. Most of the required parameters are slow-changing and only hourly or daily updates are required. In contrast, a fall event should be responded to as close to the event as possible. It was decided to calculate all parameters twice a minute but then to present summarised information on an hourly and a daily basis.

Fig 3 illustrates a schema for analysis of the data. The approach is a hierarchical one in which coarse classifications

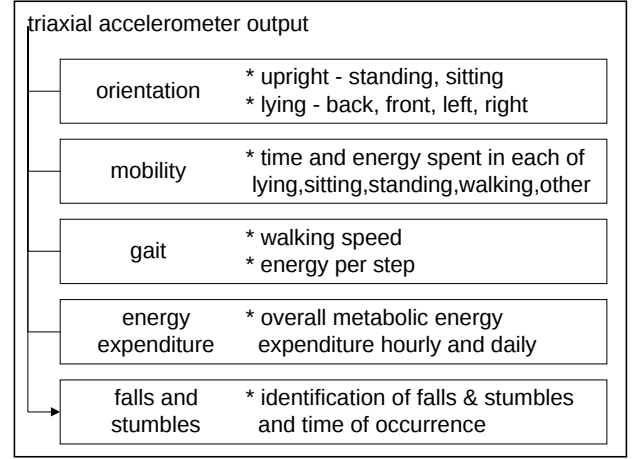


Fig. 2. Parameters measured by the system

are made and then refined when more detailed information is required.

Prior to computing parameters, the output signal from the accelerometer is pre-filtered to remove noise spikes and then low-pass filtered (3dB point at 0.25Hz) to separate the d.c. and a.c. signal components. The two component signals are used to determine each of the parameters.

A) Posture

Posture is a basic measure of function. The posture of a patient during the day provides insight into the routine of daily activities. There are several basic postural orientations that should be identified by the system: 1) upright states - standing and sitting; 2) lying states - lying, plus the body rotations: lying left side, right side, front and back.

The posture of the patient is determined by looking at the d.c. component of the signal and determining the device's orientation. The patient's postural orientation is determined from this since the orientation of the device relative to the patient is known.

B) Metabolic Energy Expenditure

Energy expenditure due to physical activity (EE_{act}) is a parameter closely related to mobility. It provides a quantitative measure of the energy expended in physical activity. There is a considerable body of research investigating the suitability of accelerometers to estimate EE_{act} , and determining the nature of the relationship between the measured accelerations and the actual metabolic energy expenditure [8].

Metabolic energy expenditure is calculated from the a.c. signal component using a relationship reported by Bouten *et al* [11],

$$IMA_{tot} = \int_{t=t_0}^{t_0+T} |a_1| dt + \int_{t=t_0}^{t_0+T} |a_2| dt + \int_{t=t_0}^{t_0+T} |a_3| dt$$

$$EE_{act} = 0.104 + 0.023 IMA_{tot}$$

where IMA_{tot} is the sum of the area under each of the three a.c. component accelerometer output signals.

Energy expenditure measurements are presented by the system on an hourly and a daily basis.

Since the energy expended in movement is much greater than in stationary activities such as sitting and lying, the value of IMA_{tot} is compared to a threshold value. If the energy expenditure is greater than the threshold value, then the subject is classified as moving about. The type of movement is then classified as either 1) walking; 2) a transition between lying and sitting or between sitting and standing; or 3) a fall or stumble.

C) Mobility

Significant changes in a patient's mobility may be indicators of changes in health status. For example, a state of worsening heart failure leads to increased breathlessness and a reduced level of activity, which is seen in the patient spending more time sitting and lying, and less time moving about.

In order to present a measure of the patient's mobility, the amount of time spent on each activity – sitting, standing, lying, and walking – together with the energy spent on that activity are calculated and presented on an hourly and a daily basis.

D) Gait

Changes in gait can be caused by a change in health status in COPD and CHF patients. A worsening condition may be reflected in a slower, less energetic gait.

Additionally, parameters of gait and sway have been found to be predictors of falls. Guimaraes and Isaacs [12] found that the gait of elderly fallers had the distinctive

characteristics of slow speed, short step length, narrow stride width, wide range of stepping frequency, large variability of step length and increasing variability with increasing frequency.

The peaks due to heel strike can be identified from the signal trace of a waist mounted triaxial accelerometer [10]. Once the peaks are reliably identified, the step rate, the energy expended in each step, and the variability in each of these two measurements can be calculated to provide a measure of gait.

E) Falls and Stumbles

Falls are one of the primary causes of morbidity in the elderly [13]. CHF and COPD can cause many risk factors that make patients particularly susceptible to stumbles and falls. These include hypotension, cardiac arrhythmias, infections and changes in medication. The data measured by accelerometers is suited to capturing fall and stumble events and may also prove to be useful for determining early predictors of fall events.

During normal daily activities, the body movement accelerations generally have a magnitude of less than $1g$. In running, however, the vertical peak accelerations may reach up to $5g$ [14]. Patients ill with CHF and COPD are unlikely to be able to run and so higher peak accelerations caused by running were not considered in this system.

Accelerations greater than 2.5 times normal accelerations are likely to be caused by a fall, a stumble or a collision. A threshold value of $2.5g$ was set, and any peak acceleration exceeding this threshold is flagged as an abnormal event. The time of the event, the peak magnitude and the posture and action immediately before and after the event are recorded. This provides a very simple measure of fall and stumble events.

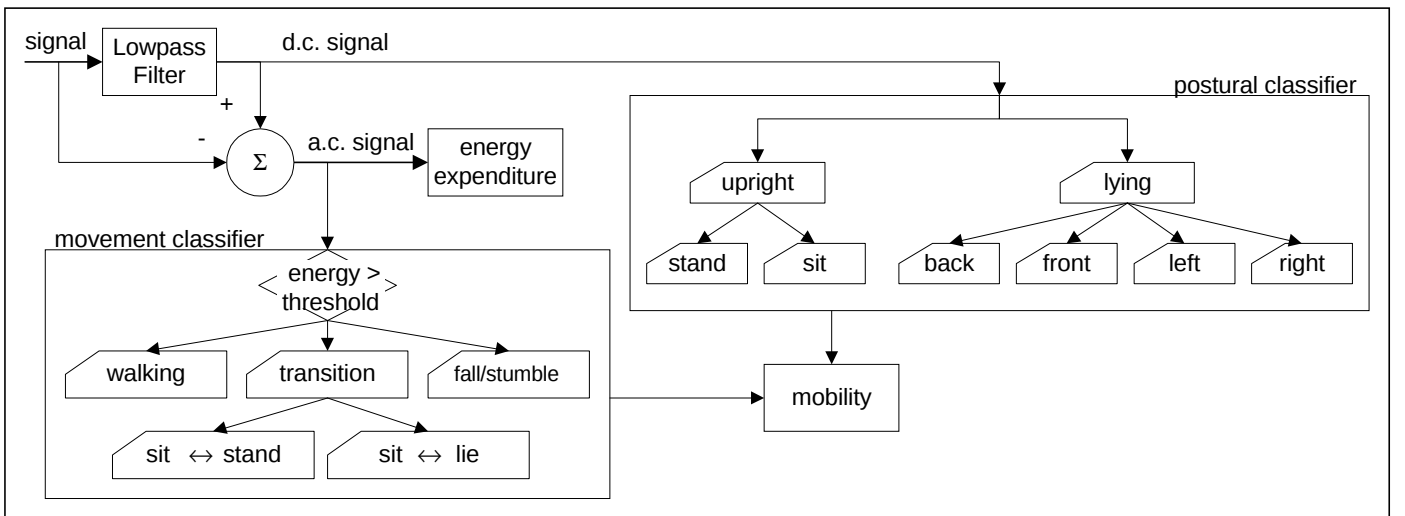


Fig. 3. Data processing schema for triaxial accelerometer

VI. INTEGRATION INTO A COMPREHENSIVE HOME TELECARE SYSTEM

The accelerometry system described in the preceding sections is being used in a field trial for community dwelling patients with CHF or COPD. The accelerometer forms part of a comprehensive home telecare system that also measures patient-reported health status and physiological parameters such as blood pressure, heart rate and weight.

Data is captured for 14 hours each day, from 7am until 9pm at a sampling rate of 40Hz. During this time data is transmitted continuously from the wearable device. However, data is lost when the patient goes out of range of the receiver unit, for example, when the patient leaves the house.

One of the aims of the field trial is to test the analysis system and validate the algorithms used to determine the parameters. In the field trial, data from the accelerometers is not processed in real time. Rather, data collected from the accelerometers is stored on a home personal computer. Each night the home computer uploads the data to a central server. The data is processed and the parameters calculated on the central server from where the actual signals and the calculated parameters can both be reviewed.

The system used in the field trial is focussed on patients with CHF and COPD. The technology could also be used for patients with other conditions in which home assessment of physical activity and body movement are important. Future work may include customizing a system for other conditions and possibly developing algorithms to measure other parameters that are important for those conditions.

VII. CONCLUSION

We have described a novel system for objectively and continuously monitoring patient movement in a home environment that classifies the patient's posture, energy expenditure and movement. The two primary design criteria were patient useability and the provision of clinically relevant information. This integrated system is being used in a home telecare field trial for patients with CHF and COPD.

REFERENCES

- [1] J. R. Lieberman, F. Dorey, P. Shekelle, L. Schumacher, B. J. Thomas, D. J. Kilgus, and G. A. Finerman, "Differences between patients' and physicians' evaluations of outcome after total hip arthroplasty," *The Journal of Bone and Joint Surgery*, vol. 78, pp. 835-838, 1996.
- [2] B. G. Celler, Conference Presentation EMBC, Istanbul, Turkey, 2001.
- [3] M. Mathie, B. G. Celler, J. Basilakis, N. H. Lovell, F. Magrabi, and K. Huynh, "A specification for a home telecare system for patients with congestive heart failure," presented at 10th International Conference on Biomedical Engineering, Singapore, 2000.
- [4] G. L. Smidt, J. S. Arora, and R. C. Johnston, "Accelerographic analysis of several types of walking," *American Journal of Physical Medicine*, vol. 50, pp. 285-300, 1971.
- [5] J. R. W. Morris, "Accelerometry - a technique for the measurement of human body movements," *Journal of Biomechanics*, vol. 6, pp. 729-36, 1973.
- [6] F. Foerster and J. Fahrenberg, "Motion pattern and posture: correctly assessed by calibrated accelerometers," *Behavior Research Methods, Instruments, & Computers*, vol. 32, pp. 450-7, 2000.
- [7] J. Fahrenberg, F. Foerster, M. Smeja, and W. Muller, "Assessment of posture and motion by multichannel piezoresistive accelerometer recordings," *Psychophysiology*, vol. 34, pp. 607-12, 1997.
- [8] C. V. C. Bouten, K. T. M. Koekkoek, M. Verduin, R. Kodde, and J. D. Janssen, "A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity," *IEEE Transactions on Biomedical Engineering*, vol. 44, pp. 136-147, 1997.
- [9] R. Salleh, D. MacKenzie, M. Mathie, and B. G. Celler, "Low power tri-axial ambulatory falls monitor," presented at 10th International Conference on Biomedical Engineering, Singapore, 2000.
- [10] A. L. Evans, G. Duncan, and W. Gilchrist, "Recording accelerations in body movements," *Medical and Biological Engineering and Computing*, vol. 29, pp. 102-104, 1991.
- [11] C. V. Bouten, K. R. Westerterp, M. Verduin, and J. D. Janssen, "Assessment of energy expenditure for physical activity using a triaxial accelerometer," *Medicine and Science in Sports and Exercise*, vol. 26, pp. 1516-1523, 1994.
- [12] R. M. Guimaraes and B. Isaacs, "Characteristics of the gait in old people who fall," *International Rehabilitation Medicine*, vol. 2, pp. 177-180, 1980.
- [13] M. Lange, "The Challenge of Fall Prevention in Home Care: A Review of the Literature," *Home Healthcare Nurse*, vol. 14, pp. 198 - 206, 1996.
- [14] A. Bhattacharya, E. P. McCutcheon, E. Shvartz, and J. E. Greenleaf, "Body acceleration distribution and O2 uptake in humans during running and jumping," *Journal of Applied Physiology: Respiratory, Environmental & Exercise Physiology*, vol. 49, pp. 881-887, 1980.