AccelGait – USING INERTIAL SENSORS TO EVALUATE QUALITY OF GAIT

A. Sant'Anna[2], and N. Wickström[1,2]

1. Centre for Research on Embedded Systems, Halmstad University, SE-301 18 Halmstad, Sweden
2. Intelligent Systems Laboratory, Halmstad University, SE-301 18 Halmstad, Sweden

Gait analysis (GA) is an important tool in the assessment of several physical and cognitive conditions. The lack of simple and economically viable quantitative GA systems has hindered the routine clinical use of GA in many areas. As a result, patients may be receiving sub-optimal treatment. This project concerns the development of new mobile, cheap and easy to use quantitative GA systems using inertial sensors, which may facilitate the wide-spread adoption of GA as routine clinical practice.

1. Gait Analysis

It is of general consensus that gait analysis can provide information that is essential to the assessment of orthopedic patients. It is an effective way to evaluate and quantify how surgical intervention or other treatments affect a patient's gait [1]. In addition, there is evidence that gait analysis can aid the assessment of cognitive conditions. Certain gait characteristics, for example, can be used in the diagnosis of dementia and may have important implications for discriminating among dementia subtypes [2]. Changes in gait are also associated with aging, and are important when judging the ability of an older person to live independently [3].

A general measure of quality of gait can be obtained from: report questionnaires such as the Gillette Functional Assessment Walking Scale [4]; observational video analysis schemes like the Edinburgh Gait Score [5]; or rating systems such as the Functional Mobility Scale [6]. Although these assessments are useful and practical, they lack precision and objectivity [7].

On the other hand, very precise and objective measurements may be obtained in specialized gait labs, equipped with 3D motion capture (mocap) systems, force plates and other sensors. In-lab assessments are considered state of the art and have been shown essential to the assessment of cerebral palsy [8] and other surgical patients [9]. Nonetheless, these measurements are expensive, difficult to interpret, require special training and are not available to all patients [10]. As a result, many research findings relating gait analysis to medical conditions are not used in routine clinical practice, depriving many patients of potential benefits.

2. Inertial Sensors

As an alternative to gait labs, body-worn inertial sensors, such as accelerometers and gyroscopes, can be used for gait analysis. Inertial sensors have the advantage of being small and cheap. They can be embedded into clothing items or simply placed on the body embedded in a watch-strap or a belt. Another advantage of using inertial sensors is that they are mobile and can gather monitor the patient while performing normal daily activities, for example, at home or outdoors.

Inertial sensors have successfully been used to monitor falls and daily activities [11]; detect the phases of gait and other gait parameters [12] ; describe gait kinematics [13]; among other applications. However, the creation of a comprehensive quality of gait index, using inertial sensors, had not been addressed until now.

3. The Symbolic Approach

We proposed a new approach to the processing and analysis of inertial sensor data, which can improve the use of such sensors for gait analysis. This approach is based on the symbolization of the sensor data into building blocks, which when combined in different ways, represent different gait patterns. Similar approaches have been investigated for activity recognition applications using other sensors such as video [14] and mocap [15]. In this project, the symbolization approach was used in the analysis of inertial sensor data.

4. Activities Undertaken

The goal of this project was to devise a mobile, cheap and easy to use gait analysis system using inertial sensors that provides an objective quality of gait index which reflects the ambulatory condition of the patient. The system should help the assessment of patients at the clinic and also in uncontrolled environments such as the patient's home.

The project was divided into two main phases: development and testing.

- **Development**: This part of the project involved the acquisition of data in a gait lab, equipped with 3D mocap system and two force plates. The data was collected at the Lundberg Clinical Gait at the Sahlgrenska University Hospital in Gothenburg, Sweden. Eighteen healthy subjects were measured while walking with the mocap system and with our inertial sensor system simultaneously. The inertial sensor data was used to calculate a gait symmetry index and a gait normality index. The mocap data was considered ground reference and used to guide the development of the symmetry and normality indices.
- **Testing**: A separate data collection took place at the orthopedic ward of the Sahlgrenska University

Hospital in Mölndal, Sweden. Eleven hip-replacement subjects were measured with the inertial sensor system while walking along a 10-meter walkway. The time to complete the walkway and the number of steps taken were recorded. This procedure was repeated on the day of discharge from the hospital, and 3 months later. The patients also filled out a (EQ-5D) questionnaire about mobility, self-care, daily activities, pain/discomfort, and anxiety/depression. The inertial sensor data was used to calculate symmetry and normality indices for the patients at discharge and 3-months later. Results were compared to the questionnaire answers, average speed, average step length, and length of stay at the hospital. The goal of this part of the study was to determine if the proposed symmetry and normality indices reflected the level of recovery of the patients. Results indicated that the normality index, in particular, can potentially help assess the wellbeing and level of recovery of patients.

5. Results

Based on the symbolized signals, new measures of gait symmetry and gait normality were created. The proposed symmetry index was superior to many others in detecting movement asymmetry in early-to-mid-stage Parkinson's disease patients. Furthermore, the normality index showed great potential in the assessment of patient recovery after hip-replacement surgery.

Several publications resulted from this project, one of which was awarded the Best Student Paper prize at the International Joint Conference on Biomedical Engineering systems and Technologies [VII].

6. Conclusion

This project successfully devised a simple-to-use inertial sensor system, which can provide valuable information about gait symmetry and gait normality. This system can be used to provide quantitative information about quality of gait, and help assess the condition and recovery of patients. The system was validated against a state-of-the-art gait analysis system, and also evaluated in a real clinical environment.

Further investigations are needed in order to turn this into a commercial system. However, this project has demonstrated that such a system is feasible and can provide value to clinical institutions.

7. Bibliography

[1] R. B. Davis, S. Ounpuu, D. Tyburski, and J. R. Gage, *A gait analysis data collection and reduction technique*, Human Movement Science, vol. 10, pp. 575-587, 1991.

[2] D. Morgan, M. Funk, M. Crossly, J. Basran, A. Kirk, and V. Dal Bello-Haas, *The potential of gait analysis to contribute to differential diagnosis of early stage dementia: Current research and future directions*, Canadian Journal on Aging, vol. 26, no. 1, pp. 19-32, 2007.

[3] W. Zijlstra and K. Aminian, *Mobility assessment in older people: new possibilities and challenges*, European Journal of Ageing, vol. 4, pp. 3-12, 2007.

[4] T. F. Novacheck, J. L. Stout, and R. Tervo, *Reliability and validity of the Gillette functional assessment questionnaire as an outcome measure in children with walking disabilities*, Journal of pediatric orthopedics, vol 20, pp. 75-81, 2000.

[5] S. J. Hillman, M. E. Hazlewood, M. H. Schwartz, M. L. van der Linden, and J. E. Robb, *Correlation of the Edinburgh gait score with the Gillette gait index, the Gillette functional assessment questionnaire, and dimensionless speed*, Journal of Pediatric Orthopaedics, vol. 27, no. 1, pp. 7-11, 2007.

[6] H. K. Graham, A. Harvey, J. Rodda, G. R. Nattrass, and M. Pirpiris, *The functional mobility scale (FMS)*, Journal of pediatric orthopedics, vol. 24, pp. 514-520, 2004.

[7] M. H. Schwartz and A. Rozumalski, *The gait deviation index: A new comprehensive index of gait pathology*, Gait & Posture, vol. 28, no. 3, pp. 351-357, 2008.

[8] F. M. Chang, J. T. Rhodes, K. M. Flynn, and J. J. Carollo, *The role of gait analysis in treating gait abnormalities in cerebral palsy*, Orthopedic Clinics of North America, vol. 41, no. 4, pp. 489-506, 2010.

[9] R. M. Kay, S. Dennis, S. Rethlefsen, D. L. Skaggs, and V. T. Tolo, *Impact of postoperative gait analysis on orthopaedic care*, Clinical Orthopaedics and Related Research, vol. 374, pp. 259-264, 2000.

[10] S. R. Simon, *Quantification of human motion: gait analysis - benefits and limitations to its application to clinical problems*, Journal of Biomechanics, vol. 37, pp. 1869-1880, 2004.

[11] C. Bouten, K. Koekkoek, M. Verduin, R. Kodde, and J. Janssen, *A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity*, IEEE Transactions on Biomedical Engineering, vol. 44, no. 3, pp. 136-147, 1997.

[12] R. Williamson and B. J. Andrews, *Gait event detection for FES using accelerometers and supervised machine learning*, IEEE Transactions on Rehabilitation Engineering, vol. 8, no. 3, pp. 312-319, 2000.

[13] H. Dejnabadi, B. M. Jolles, E. Casanova, P. Fua, and K. Aminian, *Estimation and visualization of sagittal kinematics of lower limbs orientation using body-worned sensors*, IEEE Transactions on Biomedical Engineering, vol. 53, pp. 1385-1393, 2006.

[14] P. Fihl, M. B. Holte, T. B. Moeslund, and L. Reng, *Action recognition using motion primitives and probabilistic edit distance*, in 4th international Conference on Articulated Motion and Deformable Objects, pp. 375-384, 2006.

[28] G. Guerra-Filho and Y. Aloimonos, *A language for human action*, Computer, vol. 40, no. 5, pp. 42-51, 2007.

PARTNERS AND STATUS

· Project funding: The Promobilia Foundation.

· Clinical experiments are performed with Sahlgrenska University Hospital in Gothenburg and Mölndal.

PUBLICATIONS

[I] A. Sant'Anna, W. O. de Morais, and N. Wickström, *Gait Unsteadiness Analysis from Motion Primitives*, 6th International Conference on Gerontechnology - Pisa, June 4-7 2008.

[II] A. Sant'Anna and N. Wickström, *Developing a Motion Language: Gait Analysis from Accelerometer Sensor Systems*, IEEE 3rd International Conference on Pervasive Computing Technologies for Healthcare 2009 - London, April 2009

[III] Sant'Anna, A. and N. Wickström, *A linguistic approach to the analysis of accelerometer data for gait analysis*, Proceedings of The Seventh IASTED International Conference on Biomedical Engineering, BioMed 2010, February 17 – 19, 2010.

[IV] Sant'Anna, A. and N. Wickström, *A Symbol-Based Approach to Gait Analysis From Acceleration Signals: Identification and Detection of Gait Events and a New Measure of Gait Symmetry*, Information Technology in Biomedicine, IEEE Transactions on , vol.14, no.5, pp.1180-1187, Sept. 2010.

[V] Sant'Anna, A., A. Salarian and N. Wickström, *A new Measure of Movement Symmetry in Early Parkinson's Disease Patients Using Symbolic Processing of Inertial Sensor Data*, IEEE Transactions on Biomedical Engineering, vol.58, no.7, pp.2127-35, 2011.

[VI] Sant'Anna, A., N. Wickström, R. Zügner, and R. Tranberg, *A wearable gait analysis system using inertial sensors Part I: evaluation of measures of gait symmetry and normality against 3D kinematic data*, Proceedings of the International Join Conference on Biomedical Engineering Systems and Technologies, 2012.

[VII] Sant'Anna, A., N. Wickström, H. Eklund, and R. Tranberg, *A wearable gait analysis system using inertial sensors Part II: evaluation in a clinical setting*, Proceedings of the International Join Conference on Biomedical Engineering Systems and Technologies, 2012. Best Student Paper Award.