Development of an Ambulatory Device for Monitoring Posture Change and Walking Speed for Use in Rehabilitation

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K. Motoi, K. Ikeda, Y. Kuwae, T. Yuji, Y. Higashi, M. Nogawa, S. Tanaka and K. Yamakoshi

Abstract—**Monitoring of posture change in sagittal plane and walking speed is important for evaluate the effectiveness of rehabilitation program or brace. We have developed a wearable device for monitoring human activity. However, in the previous system, there still remain several drawbacks for practical use such as accuracy in angle measurement, cumbersome cable arrangements, and so on. In order to improve these practical drawbacks, a new sensor system was designed, and its availability was evaluated. The results demonstrated that the accuracy of this system showed superior to that of the previous, and this system appears to be a significant means for quantitative assessment of the patient's motion.**

I. INTRODUCTION

IN order to evaluate the effectiveness of rehabilitation program or brace, physical therapist must assess the motion characteristics during standing up, walking, sitting up, and so on. However, they must usually assess these activities subjectively using direct observation. Therefore, quantitative assessment of activities is important.

Some ambulatory activity monitors have been developed [1~9], but these devices could not simultaneously measure the posture changes in sagittal plane and walking speed required especially in the fields of rehabilitation. Some methods also need complicated analysis such as wavelet transformation.

Given this background, we have developed a wearable system for monitoring angle changes of trunk, thigh and calf in sagittal plane together with walking speed [10], and reported its usefulness in the rehabilitation field [11~12]. However, in the previous system, there still remain several drawbacks for practical use as follows: (1) A subject had to carry all of four units, i.e., three sensor units (trunk, thigh and calf) and a data logger, and had to wear cumbersome cable arrangements. (2) As the gyro-sensor was installed only in the thigh unit, the accuracy in measuring dynamic posture and walking speed was not sufficient. In order to improve these practical drawbacks, a new sensor system was designed and its accuracy was evaluated. Using the new system, we also carried out the quantitative assessment of the patient's motion during rehabilitation programs.

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II. OUTLINE OF THE SYSTEM

Fig. 1 shows the outline of the sensor system for monitoring posture change in sagittal plane together with walking speed. The previous "four units" [10] are combined into two units, i.e., a trunk unit and lower limb sensors. Moreover, the gyro-sensor is installed in all of the three sensor units in order to improve the accuracy in measuring the angle during posture change and walking speed.

The trunk unit consisted of a 12ch data logger and a sensor unit for measuring trunk angle change. The lower limb sensors were specially designed as a knee supporter type, into which two sensor units were installed. These arrangements resulted in considerably simplifying the cumbersome cable assembly for practical monitoring.

Recording channel: 12 [ch]
Recording interval: 0.04 [s]
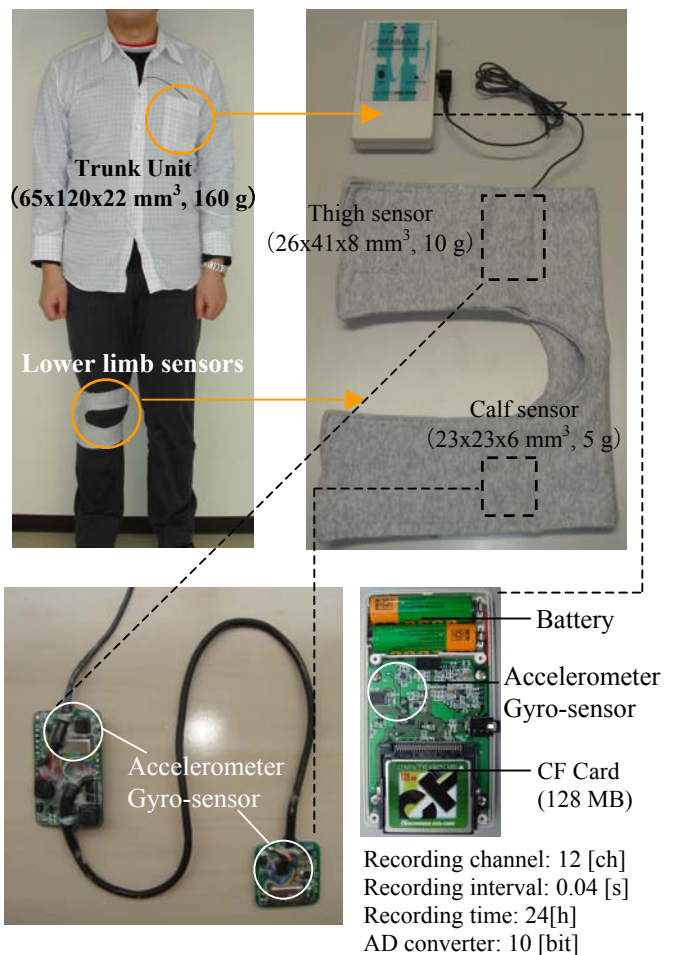Recording time: 24[h]
AD converter: 10 [bit]

Fig. 1. Outline of the sensor system.

Fig. 2 shows the algorithm for calculating angle of trunk, thigh and calf in sagittal plane. From the high frequency signal (0.5~25 Hz) of accelerometer, the motion acceleration A is calculated. Using this value, the system discriminates between static and dynamic posture.

In the static posture, the angle to the gravitational direction of each part θ_a is obtained from the low frequency signal (DC~0.5 Hz) of the accelerometer.

In the dynamic posture, the angle change is obtained by integrating the gyro-sensor signal. The reference output of gyro-sensor G_{ref} and the initial angle value θ_i are obtained from the sensor signals just before the dynamic posture.

III. SUBJECTS AND METHODS

Fig. 3 shows an experimental set up for evaluating accuracy of the system in measuring angle change and walking speed. Using CCD camera and capture board, movements of four markers attached on the subjects were simultaneously recorded with frame speed of 30 frames per second.

In front of the video camera, six healthy subjects (aged from 21 to 75 yrs old) were asked to take several posture changes, e.g. standing-up, sitting-up, walking, etc. Actual angle to the gravitational direction was calculated using four markers mentioned above. Estimated angle obtained from the system was compared with actual angle for evaluating accuracy of angle change measurement.

On the other hand, 11 healthy subjects (aged from 21 to 75 yrs old) were asked to walk with various walking speed. Actual walking speed was calculated from the moving distance of the marker attached on the subject's trochanter major. Estimated speed obtained from the system, was compared with actual speed for evaluating accuracy of walking speed measurement.

We also carried out the practical monitoring using 2 patients with hemiplegia (59 and 69 yrs) during rehabilitation program. Informed consent was obtained in each subject before the studies were carried out. The signals from each sensor were recorded continuously from throughout the rehabilitation program, and posture changes of subjects were also recorded using a digital video camera. The lower limb sensors were attached on the paralyzed side, and subjects used a cane during standing up and walking.

IV. RESULTS AND DISCUSSION

Fig. 4 shows typical recordings of the angle changes in sagittal plane during standing up, sitting up and bending forward in three healthy subjects. Definitions of each angle (θ_1, θ_2 and θ_3) are schematically shown at the top of the figure. In these recordings, each line denotes the angle obtained from the sensor output, while the plots denote those obtained from four markers (0.03 s intervals). As shown in these recordings, the angles measured by the sensor system coincide well with those obtained from four markers.
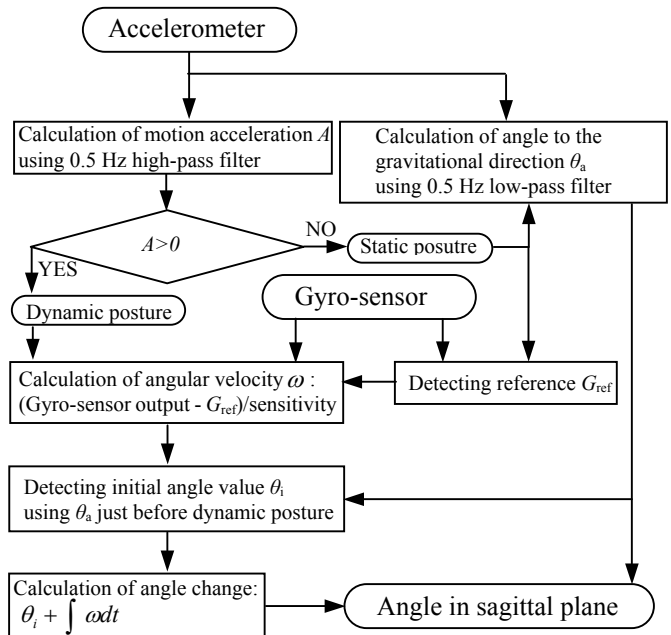

Fig. 2. Algorithm for calculating angle in sagittal plane.
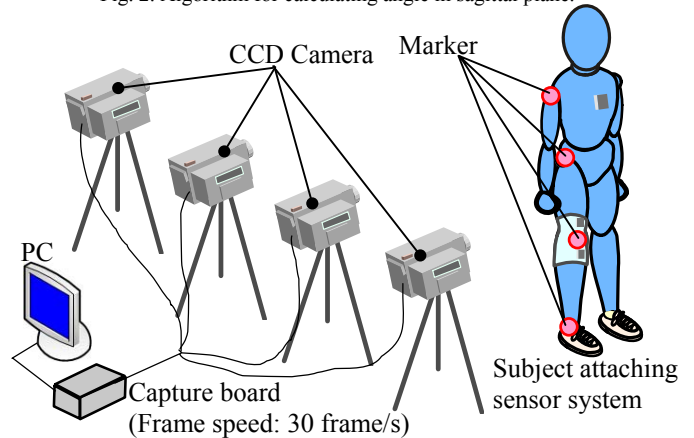

Fig. 3. Experimental setup for evaluating accuracy of angle changes and walking speed measurement.
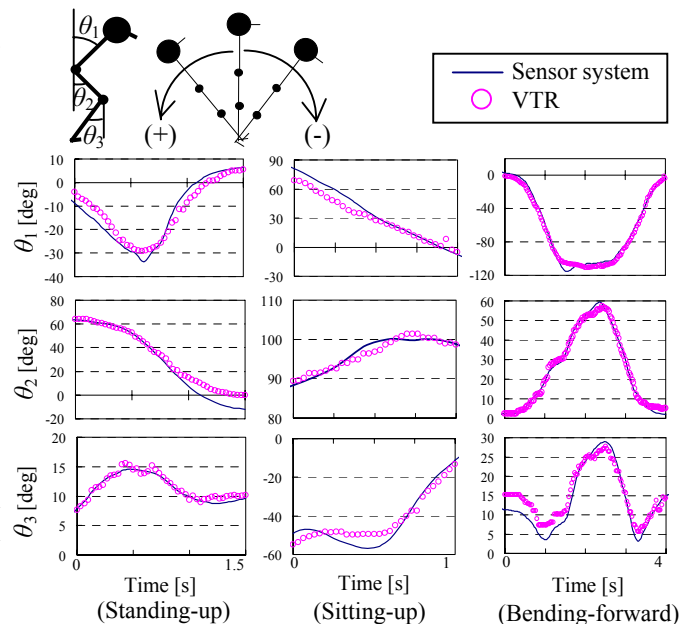

Fig. 4. Typical recordings of the angle changes in sagittal plane.

Fig. 5 shows the scatter diagrams between the angles obtained from the sensor system and those from the four markers during posture changes in six subjects. From these results, fairly good liner relationships are observed in each three part within wide range of the angle. The results also demonstrated that the accuracy of this system (r=0.997) showed superior to that of the previous system (r=0.986)[10], and the new system could measure not only static, but also dynamic posture with high accuracy.

Fig. 6 shows the typical recordings of θ_2 and θ_3 during walking in healthy male subject (75 yrs). The dashed lines denote the second of heel contact and heel off obtained from VTR. From these results, maximum value of calf (θ_{31}) and minimum value of thigh (θ_{22}) coincide with heel contact and heel off, respectively. Therefore, using the thigh and calf angles in heel contact (θ_{21}, θ_{31}) and heel off (θ_{22}, θ_{32}), and leg length (thigh: L_1, calf: L_2), walking speed V_e is calculated using the gait model shown at this figure.
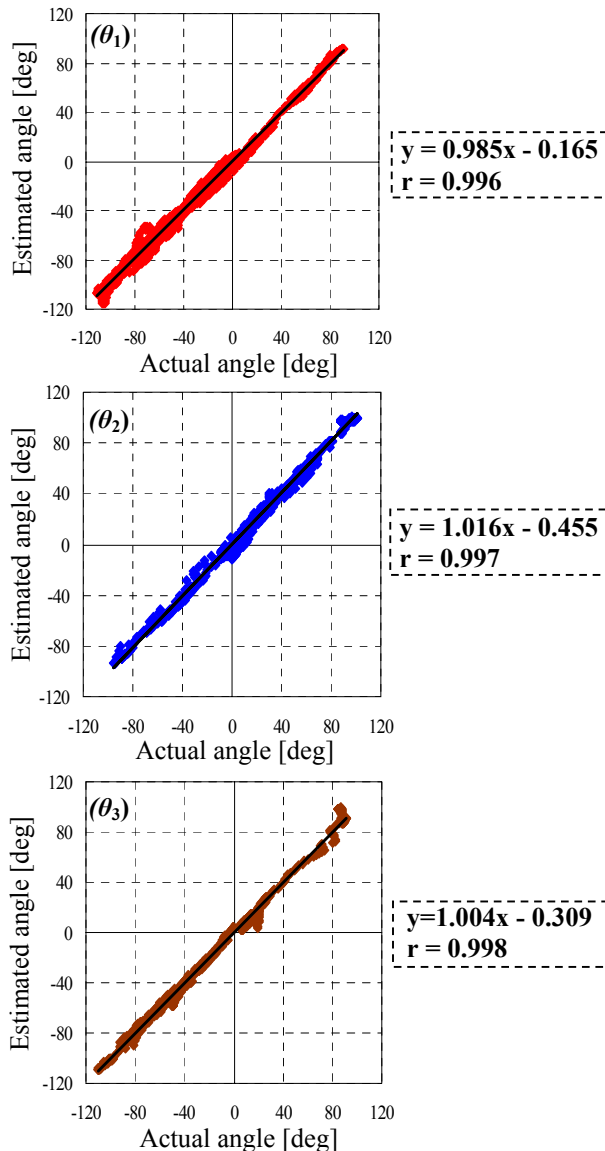
Fig. 7 shows the correlation between the walking speed obtained from VTR and those from the sensor system in 11 healthy subjects. As shown in this figure, estimated values from the sensor system coincide well with the actual values and quite good linear relationship is obtained within wide range of the walking speed. Marked differences between the subjects were not observed. The results demonstrated that the accuracy of this system (r=0.999) showed superior to that of the previous system (r=0.970) [10]
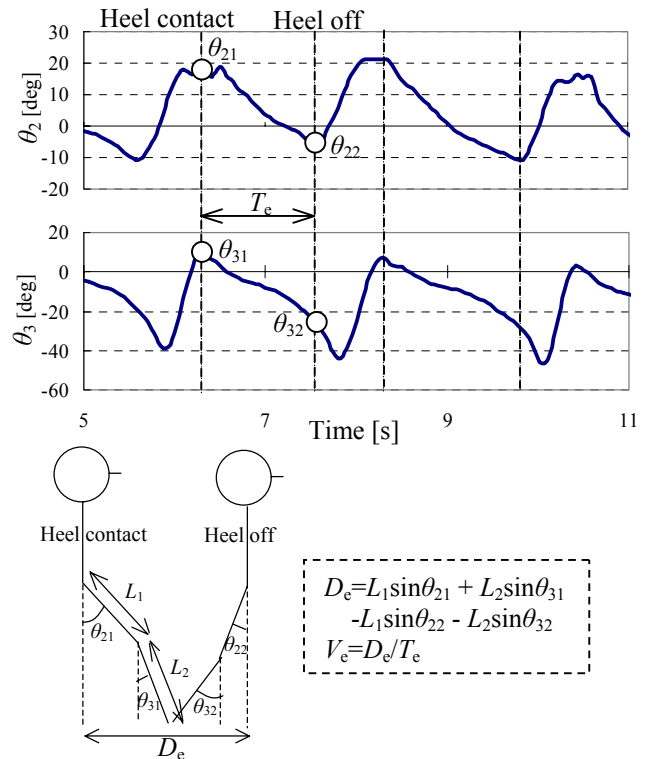

$$D_e = L_1\sin\theta_{21} + L_2\sin\theta_{31} - L_1\sin\theta_{22} - L_2\sin\theta_{32}$$
$$V_e = D_e/T_e$$

Fig. 6. Typical recordings of θ_2 and θ_3 during walking and the method for calculating walking speed.

y = 0.985x - 0.165
r = 0.996

y = 1.016x - 0.455
r = 0.997

y=1.004x - 0.309
r = 0.998

Fig. 5. Scatter diagrams between the angle obtained from VTR and those obtained from sensor system during posture change including 6 subjects.
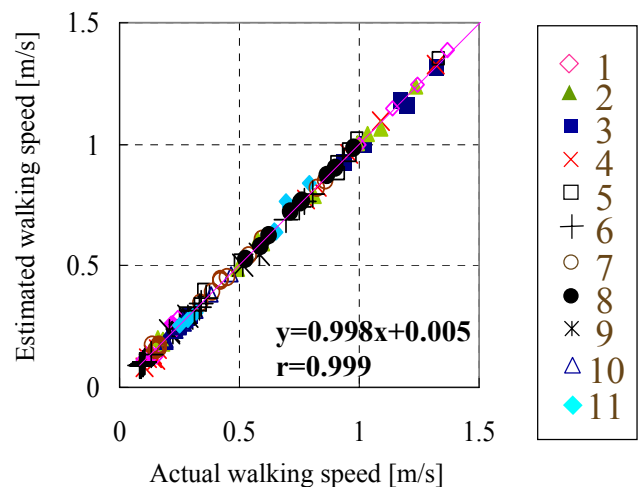

y=0.998x+0.005
r=0.999

Fig. 7. Correlation between the walking speed obtained from VTR and those from the sensor system including 11 subjects.

Fig. 8 shows the recordings of trunk, thigh and calf angle changes during walking, in the male patient (69 yrs, rehabilitation: 880 days) with or without brace (MAFO). From these recordings, in non-brace (left), the thigh was seen to move backwards with excessive degree (dashed line), in addition two peak points (plots) were detected. But, in attaching brace (right), the thigh was seen to move front evenly (dashed line) and the angle change was also smooth, and thus, the cadence also improved.

Fig. 9 shows the comparison of the angle changes between before and after rehabilitation program during walking, in female patient (59 yrs, rehabilitaion: 790 days) attaching the brace. As shown in this figure, the fluctuations were seen in maximum values of each part before rehabilitation, but high repeatability was seen after rehabilitation (Lines).
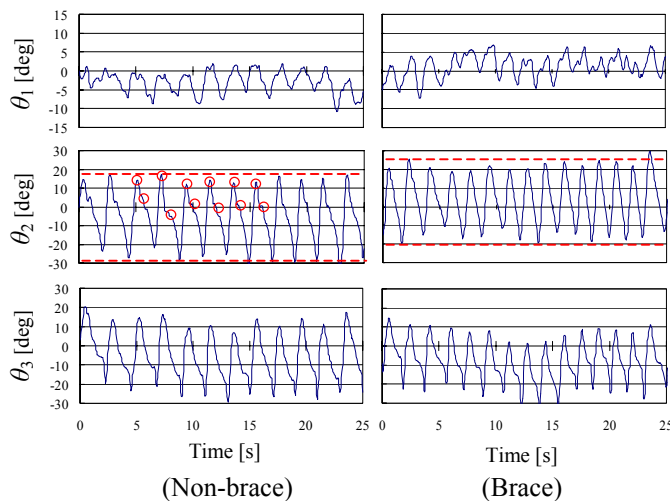

Fig. 8. The result of quantitative assessment of trunk, thigh and calf angle changes with or without brace during walking.
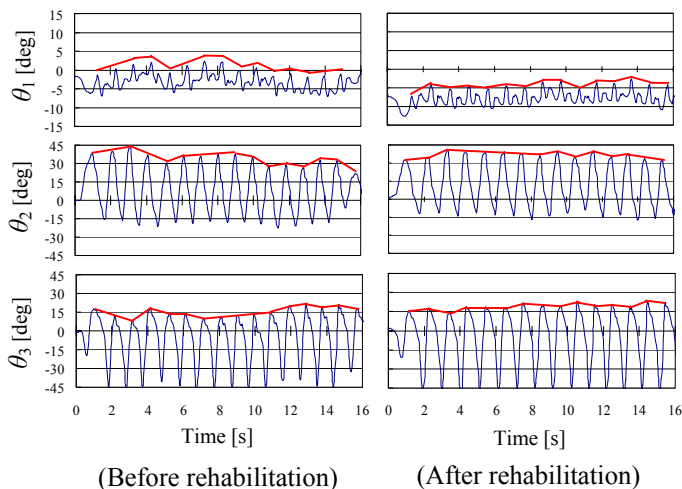

Fig. 9. Comparison of the angle changes between before and after rehabilitation program during walking.

V. Conclusion

The results obtained in this study demonstrated that the new wearable system could measure static and dynamic posture changes together with walking speed with high accuracy. Moreover, the attachment and cable assembly of the present system was convenient, and the algorithm for calculating angle changes was also simple. Therefore, the system could be suitable for practical use in rehabilitation.

On the other hand, it is clearly shown through the practical monitoring that this system could measure the detailed motion characteristics as dynamic posture, i.e., trunk, thigh and calf angle change in sagittal plane. Moreover, it is easy for the therapist to understand the posture changes in sagittal plane obtained from the system, and thus we suggest that the system can be a useful and significant means for quantitative assessment of the motion during rehabilitation programs, daily living and so on.

For convenience of subjects, development of telemetering system between the trunk unit and the lower limb sensors is preferable. This improvement is now in progress, and structural details and results of long-term measurement using this system will be reported soon.

References

[1] JO. Brooks, L. Friedman, DL. Bliwise and JA. Yesavage, "Use of the wrist actigraph to study insomnia in older adults," Sleep, vol. 16(2), pp. 151-155, 1993

[2] BD. Evans and AE. Rogers, "24-hour sleep/wake patterns in healthy elderly persons," Applied Nursing Research, vol. 7(2), pp. 75-83, 1994

[3] T. Tamura, M. Sekine, M. Ogawa, T. Togawa and Y. Fukui, "Classification of acceleration waveforms during walking by wavelet transform," Meth. Inform. Med., vol. 36, pp. 356-359, 1997

[4] FC. Schasfoort, JBJ. Bussmann and HJ. Stam, "Ambulatory measurement of upper limb usage and mobility-related activities during normal daily life with an upper limb-activity monitor; a feasibility study," Med. Biol. Comput., vol. 40, pp. 173-182, 2000

[5] M. Sekine, T. Tamura, M. Akay, T. Fujimoto, T. Togawa and Y. Fukui, "Discrimination of walking patterns using wavelet-based fractal analysis," IEEE Trans. Rehab. Eng., vol. 10(3), pp. 188-196, 2002

[6] RE. Mayagoitia, JC Lotters, PH. Veltink, H. Hermens, "Standing balance evaluation using a triaxial accelerometer," Gait and Posture, vol. 16, pp. 55-59, 2002

[7] R. Williamson and BJ. Andrews, "Detecting absolute human knee angle and angular velocity using accelerometers and rate gyroscopes," Med. Biol. Eng. Comput., vol. 39, pp. 1-9, 2001

[8] S. Miyazaki, "Long-term unrestrained measurement of stride length and walking velocity utilizing a piezoelectric gyroscope," IEEE Trans. Biomed. Eng., vol. 44(8), pp. 753-759, 1997

[9] K. Aminian, B. Najafi, C. Bula, PF. Leyvraz, and Ph. Robert, "Spatio-temporal parameters of gait measured by an ambulatory system using miniature gyroscopes," Journal of Biomechanics, vol. 35, pp. 689-699, 2002

[10] K. Motoi, S. Tanaka, M. Nogawa and K. Yamakoshi, "Evaluation of a new sensor system for ambulatory monitoring of human posture and walking speed using accelerometers and gyroscope," SICE Annual Conference 2003 Proceedings, pp. 563-566, August 2003.

[11] K. Motoi, Y. Kuwae, T. Yuji, Y. Higashi, S. Tanaka and K. Yamakoshi, "Preliminary study for human posture monitoring in the field of rehabilitation," Proccedings of the International Federation for medical and Biological Engineering, CD-ROM, vol. 8, 2005

[12] K. Motoi, Y. Higashi, Y. Kuwae, T. Yuji, S. Tanaka and Y. Yamakoshi, "Development of a wearable device capable of monitoring human activity for use in rehabilitation and certification of eligibility for long-term care," Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference Shanghai, CD-ROM, 2005