Toward the Design of a Wearable System for Fall-Risk Detection in Telerehabilitation

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Abstract

Telemedicine represents a valid aid in rehabilitation process. A remote therapist in a telerehabilitation program could monitor daily motion activity and assign motion-rehabilitation tools on the basis of the fall risk. However, one problem is detection of the fall risk itself. Web-based video-camera images alone do not help the remote assessment of the fall risk using the most commonly used qualitative tests based on visual observation. A novel wearable system to assess fall risk in telerehabilitation has been proposed based on an Inertial Measurement Unit and a medical protocol. It provides a score in four levels (1: no fall risk; 4: major fall risk). The telemedicine tool is integrated to the Global System for Mobile communication (GSM) net. Each component of the wearable system has been designed and integrated. Each component in the system has been tested individually and in a closed loop. One subject was monitored in a telemedicine link. The test showed a high degree of acceptance. The tool will be furnished to subjects along with a homecare device for daily routine monitoring of motion activity and could eventually be integrated with other systems designed to monitor other physiological parameters along with different aids and monitoring tools.

Key words: *telerehabilitation, stroke, fall-risk detection*

Introduction

Stroke events are one of the major causes of disability.[1] The design of a complete stroke rehabilitation process including the patient's home is a core requirement to ensure a successful outcome of the care program. Telerehabilitation could represent a valid aid for subjects involved in a rehabilitation process at home. A remote therapist, involved in a telerehabilitation program, could assign motion-rehabilitation tools on the basis of fall risk, which is not constant but changes with the patient's progress.[2] One of the major problems for the therapist is the assessment of fall risk. Telepresence by video camera connected to homecare does not allow correct assessment of fall risk using qualitative observation (or partially qualitative) tests such as the Tinetti test.[3] Without this correct information, it is not possible for the remote therapist to assign, for example, a particular cane or to assign a Codivilla Spring[4] or to allow the patient to abandon any aid/support. In a previous study,[5] a methodology was used in motion laboratories that allows the quantitative assessment of fall risk on the basis of posturography acquisitions with different constraints (eyes open; eyes open on foam; eyes closed on foam) performed by means of an Inertial Measurement Unit (IMU) with accelerometers, rate gyroscopes,[6,7] and a statistical clusterization process. Other studies using the same methodology used other clustering algorithms, based on a Neural Network classification.[8,9] The purpose of this paper is to integrate the wearable telemedicine tool in a telerehabilitation application that remotely furnishes to the therapist information on fall risk assessed by different algorithms in order to guide the therapist in assigning a therapy.

Design of the Telemedicine Tool for the Assessment of Fall Risk

PROBLEMS IN TESTING THE FALL RISK AND IMBALANCE IN TELEMEDICINE

The Test of Tinetti[3] is the gold standard for assessment of imbalance and fall risk for subjects with a motion disability.[6–9] It allows the categorization of the subjects in four classes; the first class identifies healthy subjects; the fourth class identifies the subjects with the highest level of imbalance and fall risk. The major problem of this test is that it is partially qualitative and it is based partially on visual observation. Telepresence in telemedicine allowed by Web video cameras (2-D representation) is not sufficient to aid the therapist to a correct observation (and thus the correct execution of the test), which should be 3-D.

 DOI: 10.1089/tmj.2008.0106

A NEW TOOL FOR THE ASSESSMENT OF FALL RISK IN TELEMEDIINE

The proposed telemedicine tool is based on an IMU, 60-second posturography acquisitions, and off-line algorithms for the clusterization and the assignment of fall risk on the basis of the IMU data; the tool also articulates with a Global System for Mobile communication (GSM) unit. The core element is thus the IMU used in the clinical application. It features three mono-axial accelerometers (3031-Euro Sensors, US) and three rate gyroscopes (Gyrostar ENC-03J-Murata, Japan), which were assembled together and oriented according to an orthogonal reference system. A full description of the design and construction of the IMU (*Fig. 1A*) has been published.[6,7] Three different clusterization algorithms can be used for the assessment of fall risk using the IMU acquisitions based respectively on: Statistical Clustering,[5] Neural Networks,[8] and Neural networks trained by the Mahalanobis-distance.[9] It should be considered that in Statistical Clustering[5] the motion analysis for the assessment of the fall risk was made off-line in a personal computer and was based only on one algorithm using statistic clustering. It should be performed directly within the wearable system to allow assessment of fall risk using three different contemporary algorithms. The choice of the GSM communication components took into great consideration the feasibility of integration to other possible wearable components for the position monitoring and potential for monitoring other physiological parameters. This study focused on communication systems open to easy integration of third-party components and allowing the exact detection of the global positioning system (GPS) position. Many GPS/GSM systems fulfilled this requirement. The memory card Kingston (Kingston Technology Company, Inc., Fountain Valley, CA) with a capacity of 2 GB has also been integrated with the GPS/GSM unit for metadata storing. A PIC micro-processor µP PIC 16F877 (Microchip, USA) with the language Assembly has been used for the detection of fall risk using the three different clustering algorithms. *Figure 1B* shows the system with the communication unit.

Data Exchange and Validation of the Telemedicine Tool

Validation of the IMU as a standalone system[6,7] and a full description of the power of the test have been published.[5,8,9]

WEIGHT AND SIZES OF THE TELEMEDICINE TOOL

The use of a large number of electronic components (passive and active) with the packages for surface montage technology (SMT) allowed minimization of volume and weight. The final weight of the complete telemedicine system developed using SMT was 1.49 N in weight and 40 cm^3 in volume for the sensor head and 4.84 N in weight and 492 cm^3 in volume for the other wearable components. Each component of the telemedicine system has been designed and integrated.

AGREEMENT WITH GOLD STANDARDS

The system as a whole has been validated in stand-alone applications in previous studies.[5,8,9] The output was similar to the Tinetti test in the case of all the three algorithms applied. A remote therapist may also use an approach that accounts for all three different clusterizations in the case of discordance.

STRUCTURE OF SMS (SHORT MESSAGE SERVICE TP GSM?)

Figure 1C shows the structure of the SMS. Three characters are used to anonymously map 0–999 subjects (or a higher number if a hexadecimal representation is used) in the section code of patient (COD-PAZ). Obviously for privacy reasons we preferred to navigate a code without name and surname. Two chars are used in the case of the fall risk assessed by means of the statistic clusterization. Two chars are used in the case of fall risk assessed by means of Neural-Networks (FR-NN). Two chars are used in the case of fall risk assessed by means of Neural Networks and Mahalanobis Training (FR-NN-MA). Two chars are used in the case of fall risk assessed by means of statistic clustering (FR-SC).

FAILURE RATE INVESTIGATION

At the end of the application, the system then sends one SMS. The application was repeated 20 times to investigate the success of the connection. The system did not show any failures.

ACCEPTANCE OF THE TELEMEDICINE TOOL

One volunteer was monitored for 20 days. *Figure 1D* specifically shows the evolution of the fall risk index using the statistic clusterization algorithms. *Table 1* shows the high acceptance of both this subject and the therapist.

Discussion and Conclusions

Telerehabilitation could represent a valid aid for subjects in motion rehabilitation processes at home. For subjects after stroke, for example, it is essential to have a prompt and constant program of care delivery both for the neural and motion rehabilitation. During rehabilitation at home, one of the major problems is to remotely assess fall risk. On the basis of the risk of fall, it is in fact possible to assign an aid along with tools for the assessment of the motion activity. Unfortunately, the telepresence function available in telemedicine applications does not help in the qualitative and/or partially qualitative evaluation. A novel tool has been proposed that allows assessment of the fall risk according to three different algorithms and an SMS-based communication to the remote therapist on the basis of an IMU and a GSP/GPS unit and a medical protocol. Each component of the wearable system has been designed and integrated. Each component in the system has been tested individually and in a closed loop. The test in a telemedicine link showed a high degree of acceptance. From a global point of view, the study furnished three added values to the scientific field of telerehabilitation. The first added value is an accurate tool for the distant assessment of fall risk. The second added value is the availability of three different indices of fall risk, suitable to construct an objective methodology, guiding the therapist to a correct and objective decision. The third added value is the starting point for the design of a decision grid based on a quantitative test useful to construct a legal and regulatory approach in telerehabilitation to protect the therapist.

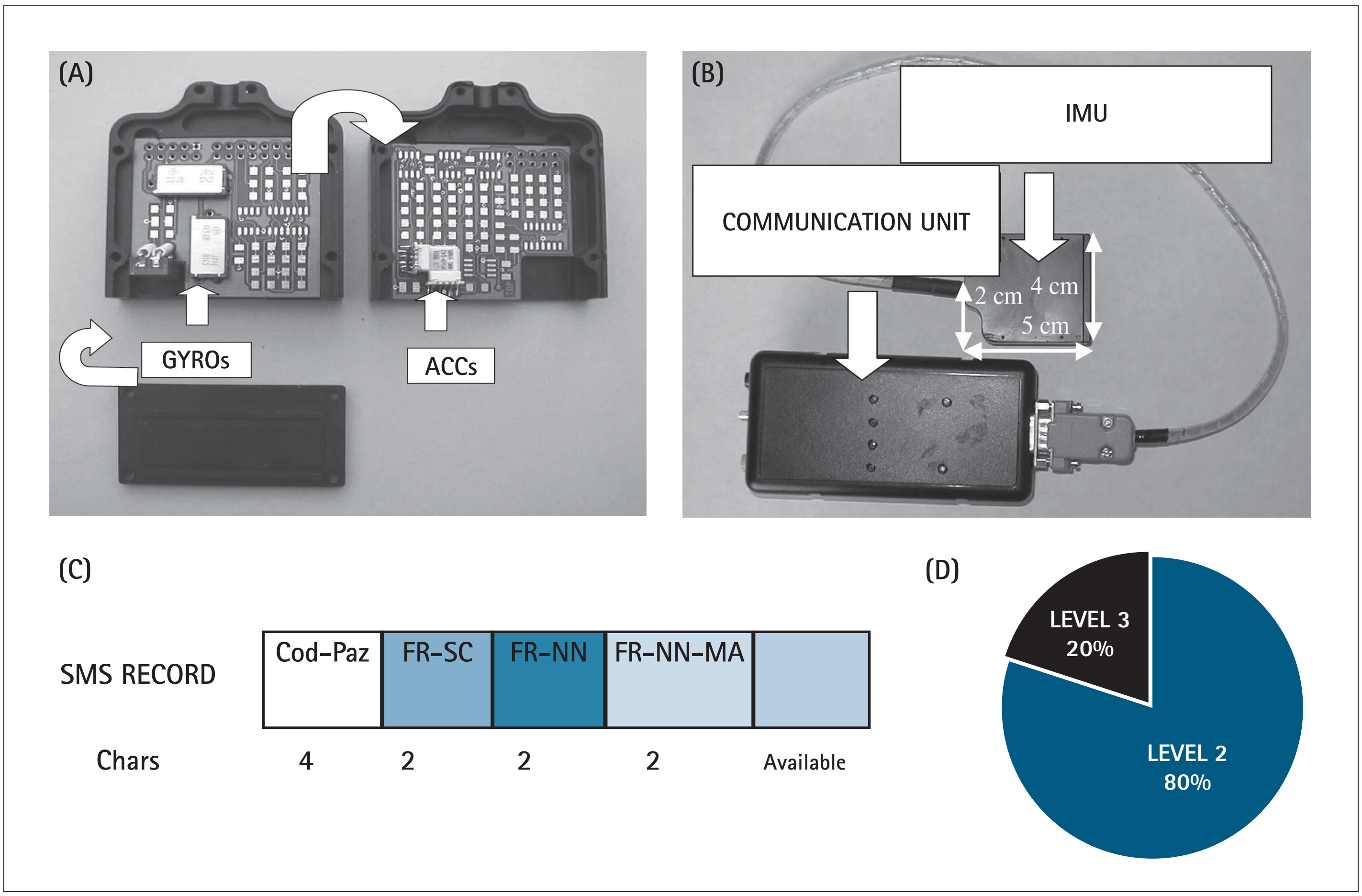

Fig. 1. (A) Details of the Inertial Measurement Unit: 3D affixation of the rate-gyroscopes (GYROs) and accelerometers (ACCs). **(B)** Details on the complete system: The inertial measurement unit (IMU) of the communication unit after boxing. **(C)** Structure of the short message service (SMS). (Fall risk assessed by means of Neural-Networks [FR-NN]; fall risk assessed by means of Neural-Networks with the Mahalanobis Training [FR-NN-MA]; fall risk assessed by means of statistic clusterization [FR-SC]; code of patient [COD-Paz]). **(D)** Evolution of the fall risk index using the statistic clusterization algorithms in a volunteer.

Table 1. Acceptance of the Telemedicine Application in the Case Study

ITEM	ASPECT	SUBJECT SCORE	THERAPIST SCORE
1	User-friendliness of the application	4	4
2	Telephonic help	3	3
3	Encumbrance (4: high encumbrance)	3	2
4	Clearness of instructions	3	4

1: minimum; 4: maximum.

FUTURE INVESTIGATION

The system will be furnished to subjects along with a homecare device for the daily monitoring of motion activity[10] (and eventually with other physiological parameters useful to investigate in stroke telerehabilitation) along with different aids such as canes and Codivilla Springs.[4] With that deployment, it will be possible to monitor several parameters related to the success and failure of the telemedicine application along with clinical acceptance of the telerehabilitation application as a whole embedding the tool for the fall risk assessment.

Acknowledgment

This work was funded by the Istituto Superiore di Sanità (the Italian NIH) in the 3-year long (2006–2008) program entitled "Design and Construction of Innovative Wearable Systems for the Monitoring of Kinematic Parameters."

Disclosure Statement

No competing financial interests exist.

REFERENCES

1. Available at: http://www.stroke.org/site/PageNavigator/HOME (Last accessed March 2009).
2. Giansanti D, Tiberi Y, Maccioni G. Integration of motion sensor monitoring units in stroke gait telerehabilitation programs of continuity of care. *Telemed e-Health* **2009**;15:105–111.
3. Kandel ER, Schwart RJ, Jessell TM. *Principi di neuroscienze*. Ed. Cea, **2000**.
4. Available at: http://www.oposrl.it/pdf/molle_codivilla.pdf (Last accessed March 2009).
5. Giansanti D. Investigation of fall-risk using a wearable device with accelerometers and rate gyroscopes. *Physiol Meas* **2006**;27:1081–1090.
6. Giansanti D, Maccioni G. Comparison of three different kinematic sensor assemblies for locomotion study. *Physiol Meas* **2005**;26:689–705.
7. Giansanti D, Maccioni G, Macellari V. The development and test of a device for the reconstruction of 3-D position and orientation by means of a kinematic sensor assembly with rate gyroscopes and accelerometers. *IEEE Trans Biomed Eng* **2005**;52:1271–1277.
8. Giansanti D, Maccioni G, Cesinaro S, Benvenuti F, Macellari V. Assessment of fall-risk by means of a neural network based on parameters assessed by a wearable device during posturography. *Med Eng Phys* **2008**;30:367–372.
9. Giansanti D, Macellari V, Maccioni G. New neural network classifier of fall-risk based on the Mahalanobis distance and kinematic parameters assessed by a wearable device. *Physiol Meas* **2008**;29:N11–N19.
10. Giansanti D, Macellari V, Maccioni G. Telemonitoring and telerehabilitation of patients with Parkinson's disease: Health technology assessment of a novel wearable step counter. *Telemed J E Health* **2008**;14:76–83.

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Received: August 4, 2008
Accepted: September 18, 2008