Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

FrA05.1

Applications of a Textile-Based Wearable System for Vital Signs Monitoring

Marco Di Rienzo, *Member IEEE*, Francesco Rizzo, Paolo Meriggi, Bruno Bordoni, Gabriella Brambilla, Maurizio Ferratini and Paolo Castiglioni

***Abstract*— A new textile-based wearable system, named MagIC (Maglietta Interattiva Computerizzata) has been recently developed for getting unobtrusive recordings of cardiorespiratory and motion signals during spontaneous behavior. The system is composed of a vest, including textile sensors for ECG and breathing frequency detection, and a portable electronic board for motion assessment, signal preprocessing and wireless data transmission to a remote computer. In this study the MagIC System has been used to monitor vital signs 1) in cardiac inpatients in bed and during physical exercise and 2) in healthy subjects during exercise and under gravitational stress. All recordings showed a correct identification of arrhythmic events and a correct estimation of RR Interval. The positive results obtained in this study support the routine use of the system in a clinical setting, experimental environments, daily life conditions and sport.**

I. Introduction

At the moment, there is a growing demand for smart devices capable to record biological signals without interfering with the subject's spontaneous behaviour.
A visionary solution to the problem was proposed in 1996 at the MIT, when researchers foresaw the possibility to develop wearable systems for the unobtrusive monitoring of vital signs based on textile sensors [1]. Since then several groups in the world [2, 3, 4], including our laboratory, have been working on the implementation of this innovative concept.

Our textile-based device, named MagIC (Maglietta Interattiva Computerizzata) is now available [5,6]. In the following a brief description of the system and the results concerning its applications in clinics and to healthy subjects during physical exercise and gravitational stress will be illustrated.

M. Di Rienzo (corresponding author), F. Rizzo, P. Meriggi and P. Castiglioni are with the Centro di Bioingegneria, Fondazione Don Carlo Gnocchi ONLUS, Via Capecelatro 66, 20148 Milano, Italy (Phone: +39-02-40308305; fax: +39-02-4048919; e-mail: mdirienzo@cbi.dongnocchi.it frizzo@cbi.dongnocchi.it, pmeriggi@cbi.dongnocchi.it pcastiglioni@cbi.dongnocchi.it).

M Ferratini, B. Bordoni and G Brambilla are with the Cardiac Rehabilitation Unit of Santa Maria Nascente Center IRCCS, Fondazione Don Carlo Gnocchi ONLUS, 20148 Milano (Italy) (e-mail: mferratini@dongnocchi.it bbordoni@dongnocchi.it gbrambilla@dongnocchi.it).

II. Methods

A. System Description

The MagIC System is composed of a vest including textile sensors and a portable electronic board (Fig.1). The vest is mainly made of cotton and lycra and is fully washable. Special textile conductive fibers are woven into the garment at the thorax level so to obtain two ECG electrodes. The contact between textile electrodes and the subject's body is guaranteed by the elastic properties of the vest. The vest also includes a textile-based piezoresistive transducer for the assessment of the respiratory frequency. Through textile paths still obtained by using the same conductive fibers, ECG and respiratory signals fed a portable electronic module -having size and weight of a small cell phone- which is placed on the vest through a velcro strip. The electronic board detects also the subject's movement through a 3-axis accelerometer and transmits all signals via a Bluetooth connection to a remote computer or a PDA for data visualization and storage on disk or memory card.

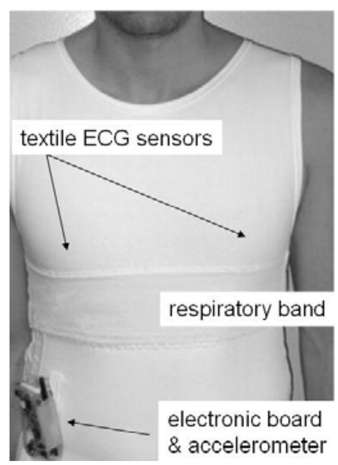

Fig. 1. The MagIC System.

B. Experimental Procedures

CLINICAL SETTING - For evaluating the applicability of the MagIC System in a clinical environment, 31 cardiac in-patients of the Cardiac Rehabilitation Unit of Fondazione Don Gnocchi have been enrolled. In all subjects ECG signals were simultaneously obtained from the MagIC

System and a traditional ECG recorder (Fig 2. left panel). In 10 patients the recordings were performed while the subjects were at rest in bed, given their severe condition. In the remaining 21 subjects the assessment was obtained according to the following protocol:

- at rest (4 min lying, 1 min standing),
- during mild physical exercise (10min),
- while pedaling on a cycloergometer (15 min) and
- during the 6 min walking test

Through a comparison with the traditional ECG tracings the following aspects of the MagIC System were investigated: 1) signal quality, 2) artifact rate, and 3) capability to identify rhythm abnormalities, particularly atrial fibrillation, flutter, supraventricular and ventricular ectopic beats (isolated and runs), left and right bundle branch blocks, atrioventricular blocks.

Signal quality and artifact rate were quantified by measuring the percentage of the recorded signal in which QRS complexes could be correctly identified. The capability of the system to detect rhythm abnormalities was checked by experts who visually inspected the ECG tracings simultaneously obtained from the MagIC System and the traditional device.

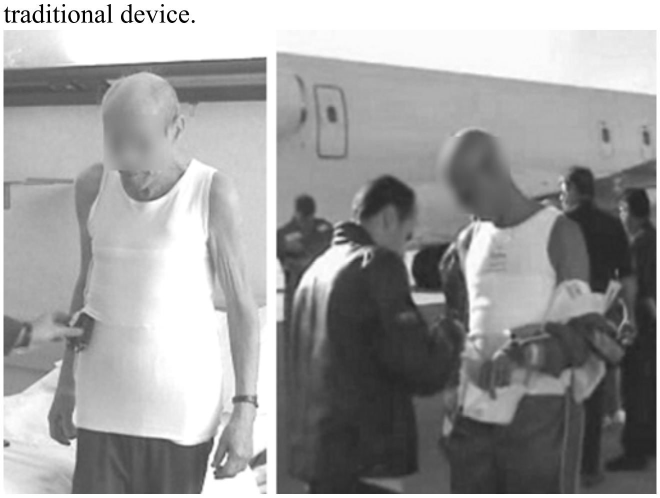

Fig. 2. *Left panel:* Cardiac inpatient wearing the system for the clinical monitoring. *Right panel:* Instrumentation of the test subject before the parabolic flight.

HEALTHY SUBJECTS – MagIC was also tested on healthy subjects to evaluate its performances in demanding applications.

In 9 healthy subjects the system was used to monitor the vital signs during a 6-minute walk and the incremental exercise test at the cycloergometer. The latter test consisted in pedaling at a workload that progressively increased until volitional exhaustion or until a certain fraction of the subject's maximal heart rate was reached.

Additionally, MagIC was used to collect data in experiments performed in extreme environmental conditions, i.e. during a parabolic flight and parachute jumps. In both instances the aim was to assess the capability of the system to describe cardiovascular alterations associated to gravitational stress. Concerning the first experiment, the subject wore the smart garment few minutes before boarding the plane and data were collected by the PDA (Fig.2 right panel). The recording started immediately after the subject's instrumentation and ended at the airplane landing. The parabolic flight lasted 75 min and included one parabola at 0.36g, four at 0.16g and ten at 0g. Reduced gravity was obtained for a period of about 20 seconds while the aircraft was at the apex of each parabola. During the microgravity periods the subject was either sitting or freely floating. Zero-g parabolas were preceded and followed by 1.8g accelerations, during which the subject was in supine position. In the second experiment MagIC was used to describe cardiovascular alterations associated to gravitational stress in parachutists before, during and immediately after the jump (Fig.3). After a 20 min flight, the parachutist jumped from 4800 meters, opened the parachute after 1 min of free fall, and landed at see level 2.5 min after the jump. The recording started few minutes before boarding and ended 2 min after landing. Also in this case data have been collected by the PDA.

Fig. 3. *Left panel:* Parachutist wearing the MagIC shirt before the flight. *Right panel:* The same subject while performing aerial acrobatics during the monitoring.

III. RESULTS

A. Clinical setting

Concerning the signal quality, our data showed that MagIC provided readable signals (namely, adequate to detect the QRS complex) for more than 99% and 97% of the time in cardiac inpatients while lying supine and pedaling on the cycloergometer respectively. Signals from MagIC also allowed a correct identification of the targeted rhythm aberrances (see example in Figure 4).

Concerning the accuracy in the estimation of RRI, the Bland and Altman plots [7] derived from data collected during the incremental exercise test showed very small differences in the RRI estimates obtained by MagIC and the traditional ECG device (95% limits of agreement within 1 ms).

B. Healthy subjects

The signals collected in the 9 healthy subjects during the 6-minute walk and the incremental exercise tests were readable for more than 99% of the time and tachograms could be derived in all instances.

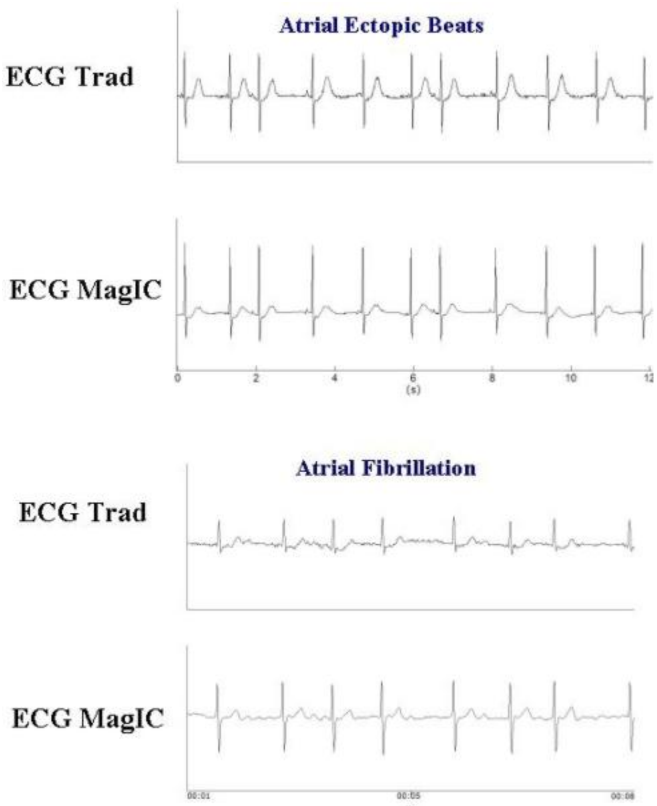

Fig. 4. Examples of rhythm aberrances as simultaneously recorded by a traditional ECG recorder and by the MagIC system.

Concerning the application of MagIC during the parabolic flight, the wearing of the smart garment did not interfere at all with the spontaneous activity of the subject nor reduced his level of comfort. Results of the experiments are shown in fig. 5. Throughout the whole flight the signal quality was adequate to derive the tachogram for all the heart beats and to quantify accelerations associated with each parabola. It can be observed that RR interval is significantly lower at 0g than at 1.8g, in agreement with the results obtained in a recent study based on tachograms derived from a traditional ECG recorder [8].

Also during experiments on parachutists, MagIC did not limited the subjects' movements in any way neither while performing aerial acrobatics during free fall. Results obtained during a parachute jump are illustrated in fig 6. It is evident the massive reduction in RR interval following the jump, with relative minima at the beginning of the free fall, at the opening of the parachute and while approaching the landing.

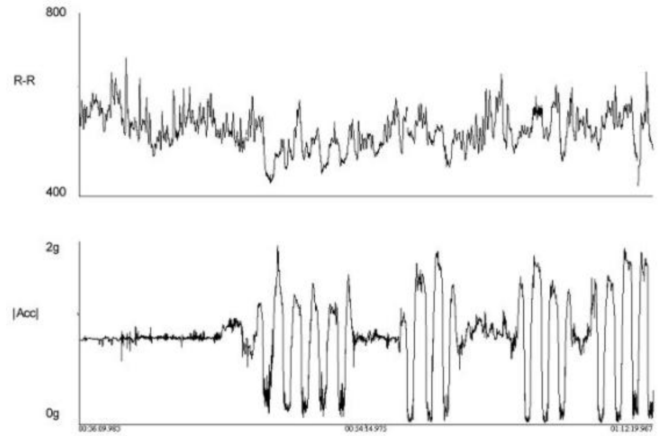

Fig. 5. Data collected by the MagIC system during the parabolic flight. *Upper panel:* Beat-by-beat RR Interval values. *Lower panel:* Modulus of accelerations.

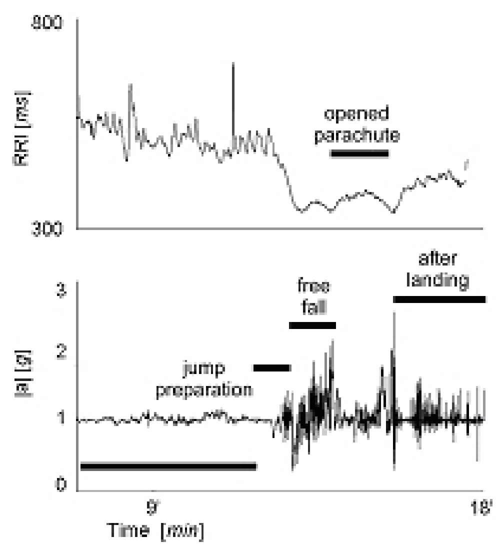

Fig. 6. Data collected by the MagIC system before, during and after a parachute jump. *Upper panel:* Beat-by-beat RR Interval values. *Lower panel:* Modulus of accelerations.

IV. CONCLUSION

A smart garment for the unobtrusive assessment of vital parameters based on textile sensors has been developed in our laboratory. The first applications of the system in a clinical setting and to healthy subjects provided positive results in terms of comfort, easiness of use, signal quality and performances. The positive results so far obtained support the routine use of MagIC in clinical setting, experimental environments, daily life conditions and sport.

ACKNOWLEDGMENT

The authors are grateful to Dr. Carlo Viberti and SPACELAND Italy (www.spaceland.biz) for the organization of the parabolic flight and to Dr. Giampiero Merati for the fundamental support in the organization and execution of the experiments with parachutists.

REFERENCES

[1] E. R. Post., M. Orth, 'Smart Fabric, or "Wearable Clothing"', Proc. of International Symposium on Wearable Computers. October 13 - 14, 1997. Cambridge, Massachusetts, p. 167-168G.

[2] SmartShirt™, Sensatex, USA: www.sensatex.com.

[3] LifeShirt, VivoMetrics, USA: www.vivometrics.com/site/index.html.

[4] Paradiso R, Loriga G, Taccini N. A Wearable Health Care System Based on Knotted Integrated Sensors. IEEE Trans Inf Technol Biomed, 2005; 9(3):337-344.

[5] Di Rienzo M, Rizzo F, Parati G, Brambilla G, Ferratini M, Castiglioni P. MagIC System: a New Textile-Based Wearable Device for Biological Signal Monitoring. Applicability in Daily Life and Clinical Setting. In Proc. IEEE EMB Conference 2005, Shanghai. IEEE Press.

[6] Di Rienzo M, Rizzo F, Parati G, Brambilla G, Ferratini M, Castiglioni P. A Textile-Based Wearable System for Vital Sign Monitoring: Applicability in Cardiac Patients. In Proc. Computers in Cardiology, 2005, Lyon. IEEE Press

[7] Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res 1999; 8(2):135-160

[8] Verheyden B. et al. Spectral characteristics of heart rate fluctuations during parabolic flight. Eur J Appl Physiol, vol 95:557-568, 2005.