Long Term Monitoring of Breathing Pattern Parameters by a Wearable System at COPD Patient's Home

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***Abstract*—Chronic Obstructive Pulmonary Disease (COPD) is a very prevalent disease which causes the deterioration of patient's quality of life and frequent hospitalizations. Telemedicine can be a valid tool to reduce this burden. CHRONIOUS is a FP7 EU project aimed to create a platform for home monitoring of chronic ill patients.. It is composed of a wearable system which is a sensorized T-shirt which collects and transmits data coming from various sensors, among which chestwall and abdomen respiratory volumes by means of two inductive bands sewn into the T-shirt, a technique called respiratory inductive plethysmography (RIP). The aim of this study was to assess the functionality and stability of the RIP included in the CHRONIOUS system for tidal volume (Vt) measurement on home long term setting. COPD patients were equipped with the CHRONIOUS system and were asked to wear the T-shirt for 1 hour per day, 3 days a week, for 2 months. We analyzed the data of one COPD patient (72 years old, BMI = 23 kg/m^2, COPD stage III, FEV1% = 49%, FEV1/FVC = 40%) who used the CHRONIOUS system for a total of 40 days, performing a total of 17 acquisitions of one hour each. We computed the average of Vt for each acquisition session. Normalized Vt showed good stability in terms of mean±sd during the whole period of acquisitions (1±0.3). Moreover it has been possible to discriminate the breathing activity in terms of compartmental contributions (abdominal or thoracic). The preliminary results presented in this study show the potential usefulness of this new telemedicine approach for the long term monitoring of breathing pattern parameters.**

Keywords-eHealth; telemedicine; home monitoring; chronic diseases; COPD; respiratory inductive plethysmography.

I. INTRODUCTION

Chronic diseases are the main cause of death in almost every developed country, and deaths from chronic respiratory diseases are second only to those from cardiovascular diseases (1). Chronic pathologies like Chronic Obstructive Pulmonary Disease (COPD), which the World Health Organization has predicted to become the third leading cause of death throughout the world by 2030 (2), determine a serious burden on patients and health care systems because of low quality of life and frequent and expensive hospitalizations.

The need to reduce this burden brought health care providers to promote national and international initiatives based on telemedicine services, which on one hand can perform a better follow-up of the patient at home and on the other aim to provide health domiciliary services and to prevent acute events that can lead to the hospitalization of the patient.

CHRONIOUS is a FP7 European project concluded in May 2012 that aimed to create a home platform for a generic health status monitoring schema, addressing people at risk or with chronic health conditions (3).

CHRONIOUS addresses a smart wearable platform, based on multi-parametric sensor data processing and fusion for monitoring people suffering from chronic diseases in long-stay setting. CHRONIOUS provides a continuous monitoring of the patient's parameters using audio observation methods and selected environmental and social context sensors while at the same time tracking their medical condition via vital signs sensors. In addition, the platform offers a touch screen interface for monitoring drug intake, dietary habits, weight and glycaemia values. All the acquired data are sent, through a mobile network connection to the Internet, to a central server, on which a Central Decision Support System (CDSS) addressed data analysis (5) (see Figure 1). Healthcare professionals are provided with full access to the patient's information and data continuously stored in the CHRONIOUS central server coming from the patient's wearable devices, in order to perform the offline remote monitoring of patient's conditions.

The CHRONIOUS wearable system (CWS) (see Figure 2) is composed of a T-shirt, made of washable stretch-material, into which are sewn several sensors that are connected to a microcontroller based concentrator. This device collects and transmits all data coming from the sensors via a Bluetooth wireless connection to a PDA or a personal computer. The CHRONIOUS wearable sensing framework provides a continuous acquisition of electrocardiographic signals, arterial blood oxygen saturation, heart rate, cough, posture, skin and ambient temperature. To evaluate the patient's breathing, the wearable platform acquires respiratory movements and volumes by means of two conductive bands sewn into the T-shirt which measure the movements of the chest and abdominal walls. This technique is called respiratory inductive plethysmography (RIP) and is well-known for its capacity of assessing the patient's pulmonary ventilation in a completely no-invasive way (4). RIP technique can provide information about respiratory volumes, timings, breathing frequency and asynchronies between chest-wall and abdomen.

The aim of this study was to assess the functionality and stability over time of the measurements provided by the RIP included in the CHRONIOUS system installed at patients' home, without any supervision of health care professional and in a long term setting.

In this work-in-progress paper the methods and some preliminary results of the first patient data analysis will be presented and plans for the whole data set analysis will be mentioned.

II. METHODS

A. The CHRONIOUS System at Patient's Home

Patients were equipped at home with a touchscreen computer (TC) which is connected through an USB cable to a device for air quality control. The TC has the possibility to connect to the Internet through a mobile phone network adapter.

Patients at home were also provided with the wearable platform (see Figure 2), which is the result of different test phases performed during the project in which a number of parameters have been considered both for best quality data acquisition and patient's comfort. The platform is equipped with two bands for the RIP, which is a system composed of two inductive bands, one positioned around patient's chest-wall and one around the belly, used to measure volume displacements of the two body compartments during breathing movements. Each band is composed of a conductive wire, the inductance value of which depends on its section area. As the patient breaths chest-wall and abdomen sections change and so its inductance values which are proportional to the volume of inhaled and exhaled air.

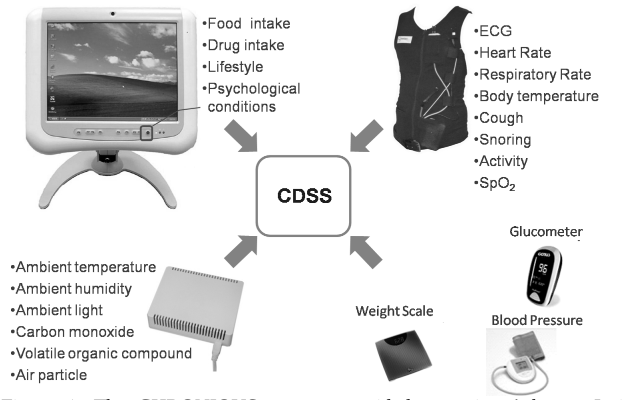

Figure 1. The CHRONIOUS system provided at patients' home. It is composed of a touchscreen computer, a wearable device, an air quality control device and some external devices, a weight scale, a glucometer and a blood pressure meter. All the data were acquired by the touchscreen computer and sent to a central decision support system for data analysis.

A microcontroller based device called Data Handler (DH) was designed and produced specially for the CHRONIOUS project. Once connected to the T-shirt it continuously samples incoming data from all the sensors and RIP signals in particular at a sampling frequency of 12.5 Hz, and communicate them through a Bluetooth wireless connection to a devoted software installed on the TC.

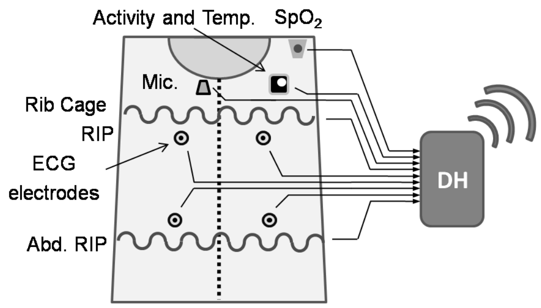

Figure 2. The CHRONIOUS wearable system (CWS) composed of the T-shirt equipped with the SpO_2 sensor, the activity and temperature sensors, the microphone, the four ECG electrodes and the two RIP bands for respiratory movements.

The software installed on the TC acts as a reminder and periodically asks the patient to wear the T-shirt and to switch the DH on. It automatically starts a Bluetooth communication with the DH and stores all the incoming traces of the sensors included in the T-shirt. After one hour the TC ends the data acquisition and automatically transmits the raw traces to the CHRONIOUS central server through an Internet connection enabled on purpose through a mobile phone modem. At the end of the acquisition session the patient can switch off the DH and undress the CWS.

B. The Acquisition Protocol

The CHRONIOUS system was provided to COPD patients for a period of four months and they were asked to perform three acquisition sessions per week wearing the CWS, specifically on Monday, Wednesday and Friday of one hour each during which all parameters were sampled continuously and RIP signals in particular.

During each acquisition session patients were asked to sit, relax and breath normally during the whole hour, preferably while watching television or reading a book.

C. RIP Calibration

The data traces acquired through the RIP device represent the volume displacement of rib cage (VRC) and abdomen (VABD) during spontaneous breathing. The acquired data are not calibrated in terms of liters of breathed air as there were no devices at patient's home used as volume reference for calibration.

It is possible to perform a calibration of the volume traces in order to counterbalance the different contribution of the electronic gains on the sampled traces of VRC and VABD. This is done through the Qualitative Diagnostic Calibration (QDC) method (5), which states that variations of VRC and VABD during breathing occur from breath to breath even with breaths of equivalent volume (VT). These variations are reflected in the breath-to-breath standard deviation (SD) which can be used to compute a calibration coefficient.

Calibrated Tidal Volume (VTcal) can be computed as follow:

$$VTcal = M[K(VRC)+VABD]$$

where M is a coefficient that we cannot obtain as we did not provide any reference device for volume measurements to the patient. The coefficient K is a gain coefficient that compensates for sampling circuit asymmetries and can be computed as follow:

$$K = SD(VAB) / SD(VRC)$$

where SD(VAB) and SD(VRC) are respectively the standard deviation of the acquired not calibrated abdominal volume and rib cage volume.

We computed Tidal Volume (VT) using the following equation:

$$VT = K \cdot VRC + VAB$$

D. Data Analysis

For each acquisition the normal breaths were selected in order to exclude artifacts due to the T-shirt movements not related to breaths, and to exclude deep breaths, cough and other extemporary breathing events that might affect analysis.

For each breath we selected end-inspiration and end-expiration points on the VT trace in order to compute the not calibrated tidal volume (ΔVT) breath by breath. We computed mean (ΔVTm') and standard deviation (ΔVTsd') of the VT breaths for each acquisition session. We filtered further the selected breaths excluding the outliers according to the following equation:

$$\Delta VT > \Delta VTm' + 1.5 \cdot \Delta VTsd' \quad \text{or} \quad \Delta VT < \Delta VTm' - 1.5 \cdot \Delta VTsd'$$

After the filtering we computed the new mean and standard deviation values of the VT: ΔVTm± ΔVTsd. Finally we computed the average value (ΔVTav) of the ΔVTm of all acquisitions and used it to obtain the normalized tidal volume ΔVTn of each acquisition.

As the sampling frequency is known, 12.5Hz, it was possible to compute for each breath some breathing pattern parameters, such as inspiratory time (IT), expiratory time (ET) and respiratory rate (RR), which together with tidal volume can provide minute ventilation (VENT), which is the volume of air breathed during one minute:

$$VENT = RR \cdot \Delta VTn$$

III. RESULTS

For this preliminary study we considered a COPD patient (72 years old, BMI = 23 kg/m^2, COPD stage = III, FEV1% = 49%, FEV1/FVC = 40%) who used the CWS for a total of 40 consecutive days, performing a total of 17 acquisitions, about 1 acquisition every 2 days. We considered a total of 6640 breaths, an average of about 300 breaths per acquisition.

We computed the ΔVTn for each acquisition (i.e. the normalized tidal volume computed as an average of all the breaths in each acquisition session) and plotted the results as shown in Figure 3. The mean value of the plotted values was 1 and the standard deviation was 0.3.

As we were able to discriminate the two volume compartments, we computed the contribution of both to the normalized tidal volume during each acquisition session (see Figure 4).

IV. CONCLUSION AND FUTURE WORK

The CHRONIOUS system is a complex and complete telemedicine system that as a whole should provide very useful information about chronic patient's health conditions and breathing activity at home, and would allow clinicians to monitor the chronic disease progression in normal conditions and during normal patient's activities.

The CHRONIOUS system aims at monitoring chronic ill patients, in particular COPD patients. It gathers different patient's information and physiological parameters in order to combine them and be able to automatically monitor patient's conditions and disease evolution.

This study was aimed at the evaluation of the wearable system and in particular of the breathing activity of COPD patients. Indeed, the CHRONIOUS wearable system allows the sampling of a number of parameters through the use of a sensorized T-shirt which, once worn, continuously samples volume displacement data during spontaneous breathing thanks to the integrated RIP system.

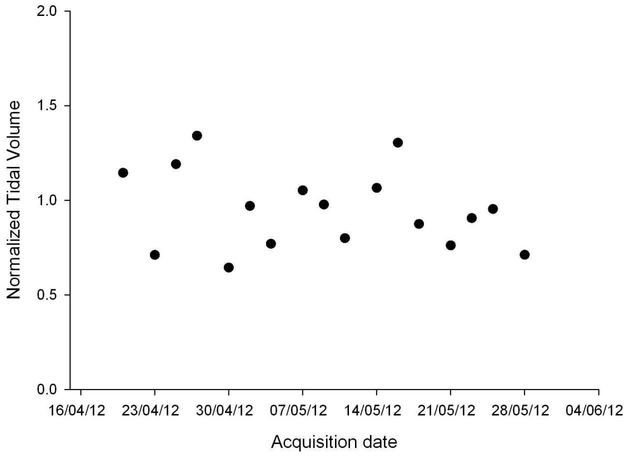

Figure 3. Normalized Tidal Volume (ΔVTn) computed for every acquisition session.

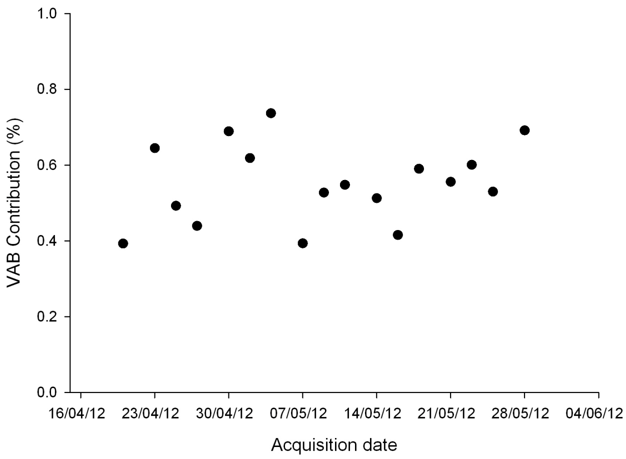

Figure 4. Contribution of the abdominal volume (VAB) to the Normalized Tidal Volume (ΔVTn) computed for every acquisition session. The contribution of the rib cage volume (VRC) can be obtained by subtraction (VRC = 1 – VAB).

The CHRONIOUS wearable system is the result of various tests with patients which highlighted different issues, both technical and of wearability and usability of the system. Each test allowed us to realize the final version of the T-shirt which has been used in the study described in this paper without any complain of the patients, and with their satisfaction in terms of wearability, which was evaluated through special questionnaires at the end of the project. As there were not usability problems, measurements have not been affected by this aspect.

This first analysis allowed us to determine whether the RIP system was able to measure breathing volumes during a long period without any supervision. The CHRONIOUS wearable system was left at patient's home for a period of 40 days, during which he could perform himself the measurement while no technical interventions were done.

Tidal volume measurements showed good stability in long period of time, as shown in Figure 3, taking into account that the system has been used only instructing the patient at the beginning of the study, without any further supervision at home. Patients were asked to wear the T-shirt day by day by themselves, and they were only instructed to perform some peaceful activity, like watching television or reading a book.

Moreover the RIP system allows the analysis of breathing of the two different compartments, rib cage and abdomen (Figure 4), and this is very important in COPD patients. Future work and further analysis will allow us to investigate about the implications of the contribution of one compartment over the other, also related to the position of the breathing patient. Asynchronies will be deepened, as these events are very frequent in COPD patients and indicative on patient's conditions.

Furthermore a wider and more comprehensive analysis need to be made including more patients enrolled in the study and cross-checking patients' conditions based on others sensors data.

AKNOLEDGMENT

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