INSTRUMENTATION AND LABVIEW BASED CONTINUOUS PROCESSING FOR CHEST PHYSIOTHERAPY

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Abstract: Infant chest physiotherapy (CPT) has never been the purpose of any assessed scientific study although it is widely used for newborn babies suffering from bronchiolitis. It is thus compulsory to quantify the limits of the gesture to obtain the expected effect. In this paper, we present original instrumented gloves designed to perform measurements during the CPT act on babies to characterize the gesture. Associated electronics and software were specially developed with LabVIEW for data acquisition, continuous processing and analysis of the characteristic parameters. The measuring system and its readout electronics were calibrated. A drive to do measurement with babies in real situation validates the principle of the system. The analysis of the results highlights relevant parameters for typical phases of the CPT act.

1 INTRODUCTION

As the demand for clinical or medical instrumentation design increases rapidly, the techniques and methods used to convert medical and physiological information to electrical signals grow too. Quantitative responses must be relevant to allow a better understanding of the medical or clinical analysis through computer interfaces. In surgery or physiotherapy for example, the characterization of the gesture for a medical or a clinical act is more and more required (Davidson, 2002). The need of standard quantitative definition of chest physiotherapy gesture expressed by physiotherapists is at the beginning of our study. Hardly any study concerning the characterization of infant chest physiotherapy technique has been achieved. This paper presents the method and the system for the characterization of the physiotherapist gesture when performing chest physiotherapy act on newborn babies. First a chest physiotherapy technique is rapidly described in order to explain the need of practitioners regarding the definition and characterization of their gesture. We present the implementation of force and displacement sensors on innovative instrumented gloves that we designed to record the characteristic parameters of the gesture. In a second part, the study of the different components of a computer based measuring system is detailed. In particular, the acquisition system, the readout electronics, the acquisition program and important details of the coding are presented. Finally, measurement results are proposed, showing the reliable capability of the system to give a scientific definition of the gesture.

2 MEASURING SYSTEM

2.1 Medical Context

Bronchiolitis is an acute disease of the respiratory tract that affects young babies. In French-speaking European countries, the two consensus conferences, held in 1994 and 2000, concerning the management of bronchiolitis in infants have widely recommended the use of chest physiotherapy in order to provide care (ANAES, 2000). These techniques aim at generating forced respirations in order to improve bronchial pulmonary exchanges. More particularly in France, the forced expiration maneuver used is the Increase of Expiratory Flow technique (IEF). IEF technique is a thoracic-abdominal movement generated by the hands of the physiotherapist on the infant's chest. The infant being lain on a table, the physiotherapist places one hand on the thorax close to the neck and the other hand on the abdomen. The "thoracic hand" presses uniformly with its cubital part whereas the "abdominal hand" has a global support. The applied pressure sequences must be synchronized with the infant free respiratory cycle.

2.2 Assesment of Needs

These last years, due to management with the IEF technique, results have shown an improvement of the clinical evolution of babies' health preventing many of them from reaching the critical state of the hospitalisation (Postiaux et al., 2006). Consequently, the CPT act is more and more used and the efficiency of this physiotherapy technique is now currently admitted in France. Although the IEF technique requires a good know-how, the physiotherapist has an empiric approach and relies his practicing on his own perception. He adapts and controls the magnitude and the frequency of the gesture versus the sound of the infant respiratory system and his own sense of touch. A qualitative protocol for the IEF technique has been defined (Fausser et al., 2002) but no quantitative definition has been made. The demand is then twofold: on one hand, to prove the efficiency of the gesture for validating the technique; on the other hand, to characterize the gesture to enhance learning and create didactical situations.

2.3 Implementation of Force and Displacement Sensors

As it was decided to quantitatively define the basic gesture of the IEF technique, technical discussions between instrumentalists and expert physiotherapists, about the practical knowledge for doing the efficient gesture, allowed to choose its physical parameters to record. So, specific instrumented gloves were designed to measure during the CPT act (Maréchal et al., 2007): the space displacement of the physiotherapist hands, and the distribution of the force applied by the hands on the infant's chest. A third relevant parameter consisting of the sound of the infant respiratory system has to be taken into account too. Thus, the measurement system should neither modify the physiotherapist's gesture nor being cumbersome or disturbing for the infant.

Since the force measurement system must be thin, flexible and painless for the baby, and because the force applied by the practitioner is as well quasi-static as dynamic, Force Sensing Resistor sensors (FSR) from Interlink Electronics were chosen. FSR are polymer thick film (PTF) devices which exhibit a decrease in resistance with an increase in the force applied to the active surface (Interlink, 2004). After an exhaustive comparative study of different sensors, we have chosen the most appropriate one as far as their size and cost are the lowest, for equivalent technical properties. Such sensors have already been used for biomedical devices (Morris et al., 2006).

The FSR sensors are glued on a cotton glove by an adhesive band (supplied by 3M). What is innovative with such gloves is the location of the sensors. Investigation of the contact between the physiotherapist hands and the infant body has been led so that we can characterize it. The contact shapes have been determined after several tests according to the referent physiotherapist, so that the most interesting pressures applied during the IEF act can be seen and measured. Regarding hygiene and medical environment, a thin medical latex glove is worn over the instrumented glove so that the sensors are not directly in contact with the skin of the toddler.

Besides, the measurement of the position of the hands of the physiotherapist is performed thanks to a six-degree of freedom electromagnetic tracking device, the Flock of Birds (FoB, from Ascension Technology). It is composed of one transmitter and two receivers. Each receiver is placed on a cotton glove on the upper side of the back of each hand. Manufacturer claims that the system accuracy is 1.8 mm and 0.5° RMS for position and orientation respectively within a working range of $\pm$ 1.2 m in any direction. No conductive material must be present near the system because interferences produce significant error measurement (LaScalza et al., 2003). This system is suited to our application because the transmitter is placed 30 cm far from the head of the baby and the displacement of the hands doesn't exceed 5 cm in each direction.

2.4 Signal Conditionning

Preliminary trials were made with the referent physiotherapist in order to determine the range for our application. Then, we designed the FSR signal conditioning according to the manufacturer's advices among suggested electrical interfaces.

For a force-to-voltage conversion, the FSR device is the input of a current-to-voltage converter. In the shown configuration (Figure 1), the output voltage is inversely proportional to the FSR resistance. An output swing of 0 V to 10 V is desired to enhance the sensitivity of the measurement system. Vref is set to -

5 V. It is to be noticed that a variation of the reference voltage would lead to a variation of the output voltage. The supply voltage should be constant. Hence, a precision voltage reference, the AD584, was chosen for that purpose. The current through the FSR should be limited to less than 1 mA/cm^2 of applied force, to prevent from damaging the sensor. Rg value of 15 kΩ was chosen to limit the current and maximize the output voltage range. Moreover, the risk of electronic noise is avoided with these sensors because the value of resistance in the feedback loop is high enough. This circuit is simple, easy to implement, reliable and costless.

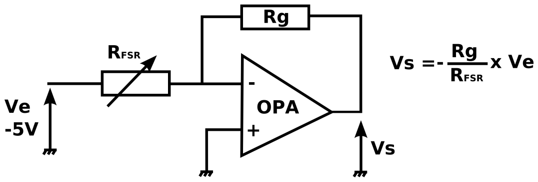

Figure 1: FSR associated electronics.

3 DATA ACQUISITION AND PROGRAMMING

FSR sensors voltage responses are acquired using a NI-9205 DAQ card and NI cDAQ-9172 compact chassis for USB interface communication. It features a 32 single-ended analog inputs with a sampling rate up to 250 ksamples per second. Figure 2 is a block diagram of the system. The program is written in Graphical programming using National Instrument LabVIEW version 7.1 since dataflow language is well adapted for application with parallel tasks. Sampling rate was chosen at 200 Hz for each sensor. This has been defined after tests and recordings of the CPT act: observation of the gesture pointed out important variations lasting about 100 ms. In order to have enough samples to acquire and plot the signals, we chose a resolution of 5 ms which is well adapted to have enough accuracy.

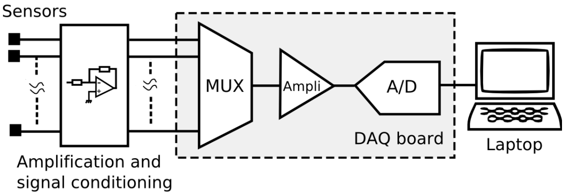

Figure 2: Acquisition block diagram.

3.1 Continous Processing (Figure 3)

In the aim to display the measurements when the gesture is being performed, we decided to process the signals on-the-fly during their acquisition. The length of the trial, up to several minutes, and the number of signals (fifteen) increase rapidly the amount of the collected data. Regarding these parameters, the recording of the data must be done throughout the measurement. The DAQ board performing the acquisition stocks the samples in its circular memory. The Ni DAQmx driver ensures the continuous transfer of the digitized data to the computer memory. The reading of the samples is done block by block with the LabVIEW program by the Analog Input (AI) Read routine returning data from the buffer. This high level priority routine is expensive in terms of performance. As a matter of fact, for slow frequency rate acquisition when AI Read is called, data might not be all present in the buffer. So, AI Read will wait for data to be available. This waiting time from a priority task involves heavy performance cost. To remedy this, Châlons recommends an optimisation of the computer resources when a continuous processing is desired (Châlons, 2001). In order to acquire and process a continuous amount of data, we used a new programming technique in our code which stands for a call of the AI Read routine only when needed. To do so, a variable is used to indicate the number of analog input data remaining in the buffer. The new version of the DAQ driver NI-DAQmx 8.3 makes easier the programming by using a simple Read property node that returns the state of the buffer. This frees enough resources to activate other asynchronous tasks that are less time critical such as display and file storage, and allows continuous display.

This solution is low cost to perform ”real time” acquisition and display, in comparison to Real Time hardware modules. The program runs on a conventional Laptop PC, Pentium M CPU at 1.6 GHz with 512 MB RAM under Windows 2000. Any reasonably current PC should be compatible with our measurement system. The program has been tested and shown to operate reliably.

3.2 Monitoring and Visualization

Before each trial, a user friendly interface enables the user to supply information about the management of the patient. Sex, age, size, weight and pathology are also asked. A text box is dedicated to comments and evolution of the clinical state. All information are saved in a result file detailed further. While gesture is performed by the physiotherapist, waveform plot dis-

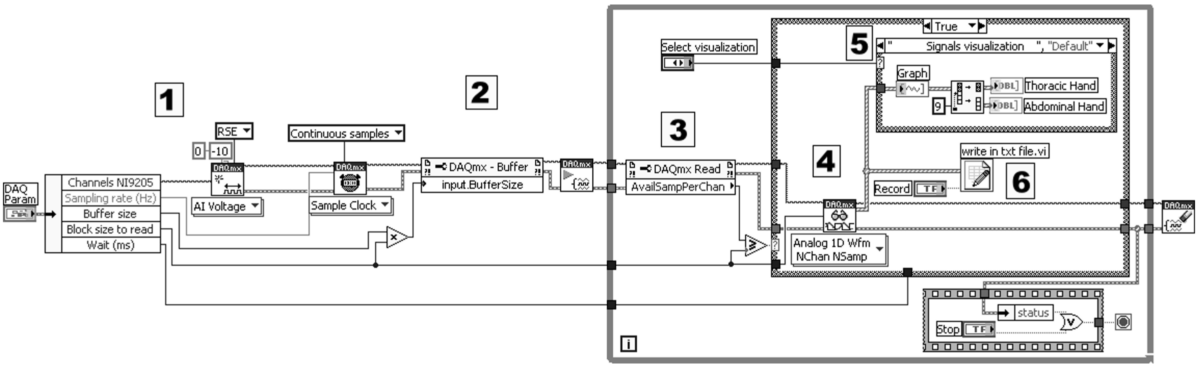

Figure 3: Structure of the LabVIEW acquisition program: (1) acquisition configuration; (2) definition of buffer size; While loop: (3) reading buffer state; (4) reading of samples by AI read routine if the buffer is fulfilled; (5) graphical display update and (6) file storage when AI read routine is not solicited.

plays signals issued from each sensor in ”real time”. The monitoring screen is presented Figure 4.

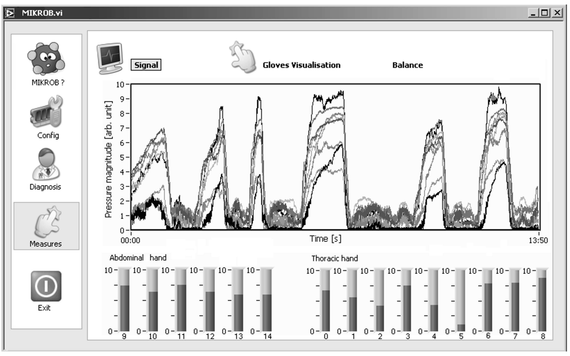

Figure 4: Monitoring screen.

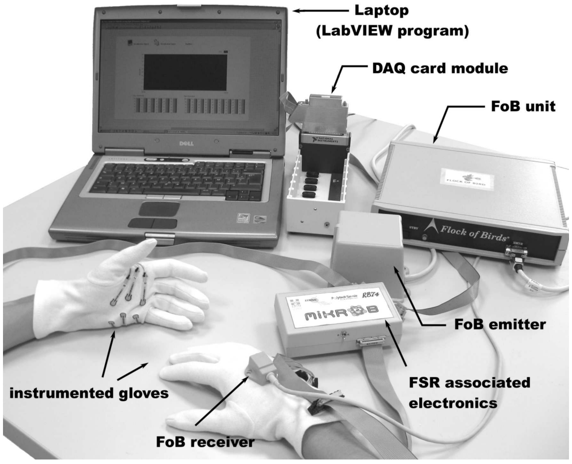

Figure 5: Whole measuring system.

Simultaneously to force measurements, the trajectories of the hands are recorded with the FoB sensors located on the gloves. The whole system is presented Figure 5.

3.3 File Output

For each trial the program saves the data in a *.txt file. Spreadsheet file format compliant for common software such as Microsoft Excel or OpenOffice Calc was not chosen because they have a limitation of 65536 rows. The file contains the values of the output data of the fifteen sensors versus the time, for each measurement. It also contains the acquisition parameters: measurement rate, trial start and end times. The average size of the result files is of 10 MB which is acceptable in comparison with actual disk space capabilities.

4 FIRST RESULTS

4.1 Calibration System Validation

Calibration of FSR devices before use is of inevitable occurrence. Calibration curves supplied by the manufacturer are carried out with the sensor placed between two rigid materials. However, it is worthwhile noting that the response of this kind of sensor depends on the nature and shape of the contact. Consequently, FSR sensors should be calibrated in the same situation as the use. Former studies focused on measuring forces developed by the human hand when gripping objects (Nikonovas et al., 2004). In this work, Nikonovas used FSR sensors between human hand tissues and stiff surface, nevertheless calibration was not made in the conditions of their use. Besides, Castro (Castro and CliquetJr, 1997) placed small rigid plates over and under the active area of the sensor to improve its behaviour during use, but for calibration the force was applied thanks to a small sphere. Regarding our application, the contact is between human hand tissues and human body tissues. Pertaining to the work of Castro, in order to enhance FSR response, we thought to insert plates on both sides of the sensors, but we can't mount them on rigid substrates since they could injure the infant during the CPT act. For use and calibration, we also tried to insert the sensors between different flexible substrates such as thin layers of polymer materials or silicones but it had no relevant effect on sensor response.

A specific workbench is implemented to calibrate the sensors in order to be in a situation closest as possible as between hand covered by cotton material and body (Figure 6). A plate of metal covered with a polymer layer realises the distribution of the applied force. We made comparative calibration to highlight the impact of the substrate. Dead loads in range of 0.1 kg to 1 kg were applied to the active surface of each sensor. With the same applied force but with different implementations, the sensor's response is strongly different. Figure 7 shows the calibration curves for the same sensor; alone (a) and implemented on the glove (b). In the end, keeping in mind that the stiffness of the hands of two physiotherapists may be very different, we decided to calibrate the sensor with identical impementation for all measurements. So, we use the static calibration curve obtained with the bench described before, the FSR being implemented on the cotton glove and covered with a medical glove.

However, the calibration gives the part-to-part repeatability but is not able to provide the absolute force magnitude during the measurement on newborn babies.

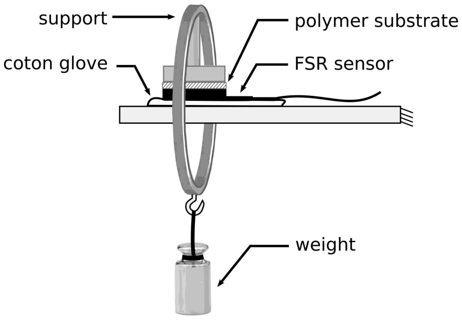

Figure 6: Calibration System.

4.2 Measurement Results

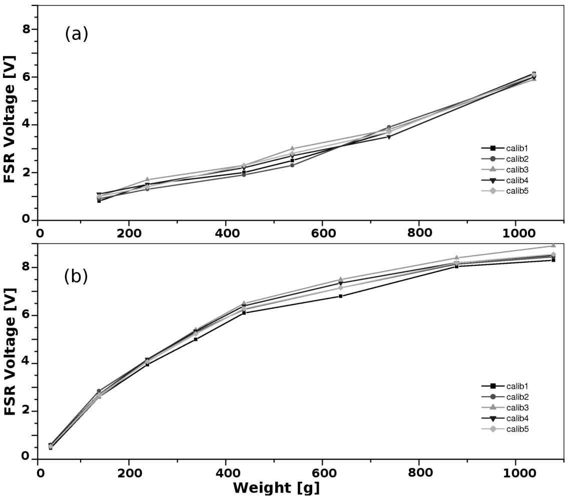

Figure 7: FSR calibration curves: (a) alone; (b) implemented on the glove.

The measurement with the whole system was performed in a physiotherapist consulting room from January to March 2007. The study was managed taking into account a population of 25 infants aged from 5 to 7 months suffering from bronchiolitis. This random trial was performed by the same expert physiotherapist, J.C. Jeulin.

Figure 8(a) shows the sensors responses acquired on the thoracic hand glove during two compressions on the chest of a 5-month-old infant, for a sequence of the gesture called "fast IEF". The FSR responses evolve synchronously. They are repeatable since the rising time of the applied pressure and the magnitude of the forces remain constant for each sensor in each compression. The displacement of the thoracic hand in the direction perpendicular to the table plane during one compression of a "fast IEF" is reported on Figure 8(b). These first results are consistent with the gesture qualitatively described as the referent one by the expert.

5 CONCLUSIONS

The measuring system, designed and created to record hands applied pressures and displacement during the act, has been validated. The choice of the sensors and their implementation respect the medical environment. Specific calibration according to the use has been achieved. Low cost portable hardware is used to acquire sensors signals. Custom optimized software has been developed with LabVIEW to process and display the data as in real time. The first results obtained are reproducible and consistent with the expert sensations. Our ongoing work in the framework

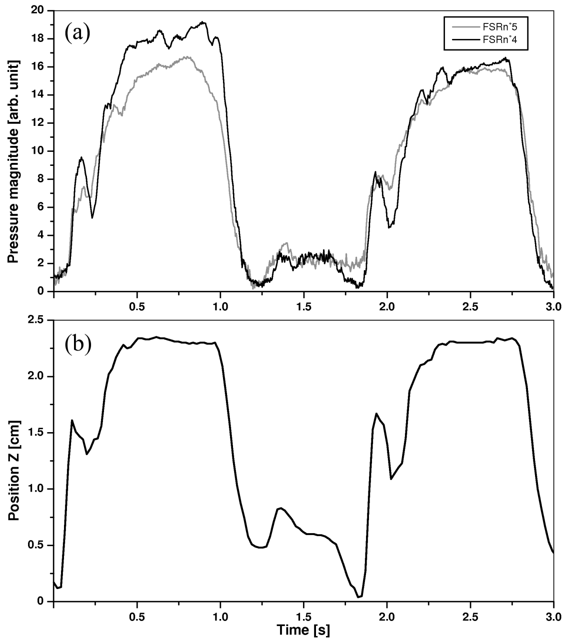

Figure 8: (a) Pressure (two FSR) and (b) displacement (FoB) responses of sensors on the thoracic glove.

of CPT enables quantitative investigations of the gesture.

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