ADVANCED MONITORING SYSTEM FOR CONVENTIONAL AND HIGH FREQUENCY VENTILATION

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Summary

The article deals with advanced monitoring techniques of artificial lung ventilation and modelling of the respiratory system. For these purposes, the unique system has been created which is able to measure basic ventilatory parameters as other monitoring devices but it is also capable to measure oeasophangeal and intraabdominal pressures and to evaluate isolated parameters of the chest wall and lungs. Furthermore, the system is able to model mechanical characteristics of the respiratory system, especially the alveolar pressure, in real-time. The most important features of system are patient‘s safety, user friendly design and possibility of storing the measured data in a database system for next statistical and clinical evaluation. The accuracy has been confirmed by a commercial ventilator Amadeus (Hamilton Medical, Rhäzüns, Switzerland). The system has been tested during animal experiments and during a human clinical trial in a faculty hospital.

Keywords

artificial lung ventilation, monitoring, high frequency ventilation, lung mechanics

Introduction

There are many techniques of conventional artificial lung ventilation (CV) that are widely used in clinical practice. However, these techniques can cause severe lung damages and also circulatory problems. Searching for new methods of artificial lung ventilation (ALV) that can provide the necessary gas exchange in lungs leads to implementation of new unconventional ventilatory techniques, especially high frequency ventilation (HFV). On the other hand, these unconventional techniques are different from CV. There is a strong need for a sophisticated monitoring system for rational application of HFV.

Methods

The unique measuring system called CHIMERA has been created for a detailed analysis and monitoring of ALV. The main requirements for this system were the capability to measure basic ventilatory parameters during both CV and HFV, independently on the type of ventilator. Moreover, the system had to be capable to measure the esophageal and intraabdominal pressures and to evaluate isolated mechanical parameters of the lungs, chest wall and the whole respiratory system. All these requirements should be performed in real-time. The matter of course was the user friendly design and maximum patient's safety. The CHIMERA system consists of two separate parts: the acquisition hardware interface (HW) and the evaluation software (SW). The complete system connected to a high frequency ventilator is presented in Fig. 1.

Acquisition hardware interface

The acquisition hardware consists of four blocks: transducers; signal conditioning and filtering circuits; data acquisition and system communication block and a power sources.

The flow and proximal pressure are measured by a special orifice, which is connected between the ventilator and the endotracheal tube. The pressure leads from the orifice are connected to pressure ports at the front panel of HW. The oesophageal balloon catheter can be connected through Luer-lock fitting which is also located at the front panel. These pressure ports are joined with a pressure transducers BSDX0100 and BSDX0025 (SensorTechnics, Munich, Germany). Intraabdominal pressure is measured with a standard pressure chamber BT-100 (Biosensors International, Newport Beach, California, USA) and has a special connector at the front panel as well.

Precise operational amplifiers OP27 (Analog Devices, Norwood, USA) are used for signal conditioning and fil-

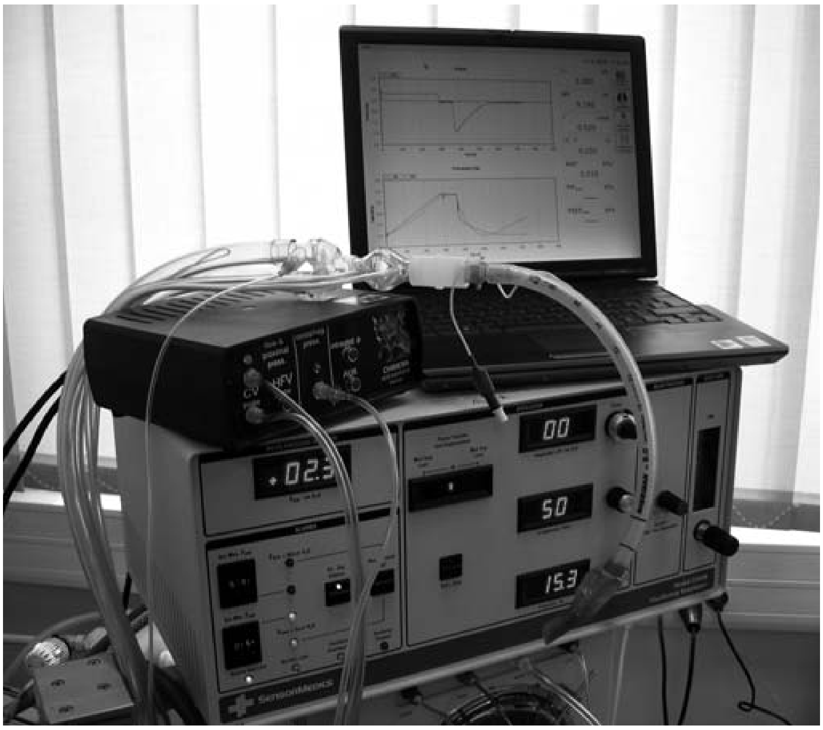

Fig. 1: The CHIMERA system – the acquisition HW with a flow orifice connected to a high-frequency oscillatory ventilator Sensormedics 3100B (Sensormedics, Yorba Linda, CA, USA) and a laptop computer with the evaluation SW.

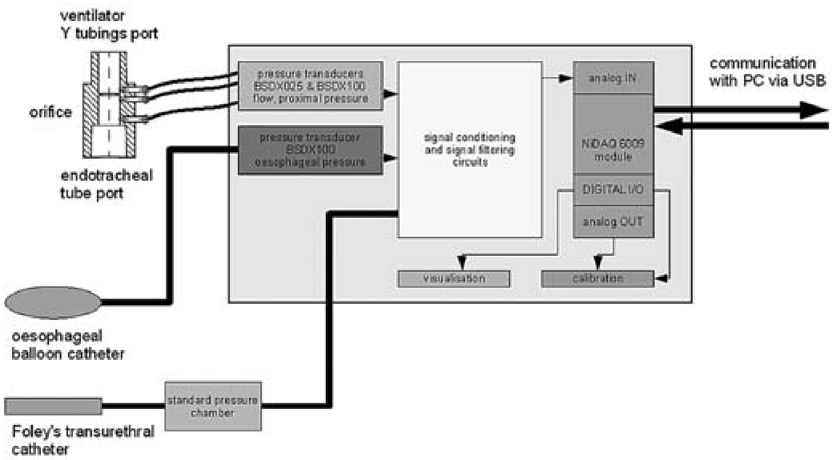

Fig. 2: Block diagram of the acquisition HW.

tering. The used filters are three stage Besel filters in MFB design. The cut-off frequency of filters is set to 2 kHz.

Data acquisition is realized by NiDAQ 6009 module (National Instruments, Austin, Texas, USA). This module has eight input 14bit A/D converter, two output 10bit D/A converter and twelve general I/O pins. With PC is connected via USB. The output of transducers is router through filters to analog inputs of NiDAQ 6009. The general pins and analog outputs are used for system calibration and LED indicators.

The HW is powered with special 12V medical power supply MPS-12 (MeanWell, Taipei Hsien, Taiwan). This switching supply is isolated and suited for medical devices. The complete scheme of the system is presented in Fig. 2.

Evaluation software

The evaluation software consists of the main program thread with a graphical user interface (GUI) and five other modular libraries which are serving the partial processes of whole evaluation system. All parts of SW have been developed in IDE Microsoft Visual Studio 2005, especially Visual C# 2005 and Visual C++ 2005 for platform .NET 2.0 (still compatible with .NET 1.1) running on Microsoft Windows XP. Robust programming techniques were used for maximum stability and performance. The block diagram of SW is presented in Fig. 3.

The GUI behaves like other ALV monitors; it displays the ventilatory and respiratory parameters as tidal volume, frequency, MAP, PIP, PEEP etc., it also shows breath, oesophageal and intraabdominal pressure curves, basic alarms and warnings. The arrangement of the GUI is optimized for user friendly control and also the color scheme was optimized for the environment of Department of Anaesthesia and Critical Care Medicine (DACCM) and Intensive Care Unit. The GUI is full screen rendered (optimized for both the standard and wide-screen resolutions) with suppression of other system messages so the computer acts only as a monitoring console. The main program thread hosts other libraries.

The first modular library, labeled as DataAcq, establishes the data stream and other system communication between the HW and SW. Also preprocesses data for further processing.

Next library, labeled as DSPFilt, serves for correction and filtering the signals. This library contains several DSP algorithms [2], [3] and is called number of time by other libraries in the whole evaluation process.

The next library, labeled as LnVParam, contains several dozens of algorithms for detecting breath curve and from that curves they evaluate the basic ventilation parameters. This library also preprocesses data for the next higher-level evaluation and modelling of the lung mechanical parameters.

The evaluation of the mechanical parameters assures the next library labeled as LungMechanix. This library contains algorithms taken from [3] for modeling mechanical parameters of the lungs and respiratory system. Because many mathematical operations are needed, this library is developed as a multi thread process, so the performance of the system is well optimized.

The last library, labeled as DataStorage, is used for data storage and exchange suitable for next clinical and statistical evaluations. Primary output file format is in XML language with corresponding specifications for Microsoft Excel spreadsheet and OpenDocument format as well. This type of output also contains headers with information about patient, notes, etc. The next output can be basic comma-separated values (CSV) format with a variable separator. Also the system is able to store data in an SQL database system. The screenshot of the evaluation SW is presented in Fig. 4.

Conclusion

The accuracy of system CHIMERA has been confirmed by a commercial ventilator Amadeus and a monitoring system Florian (Hamilton Medical, Rhäzüns, Switzerland). The system has been tested during animal experiments (labora-

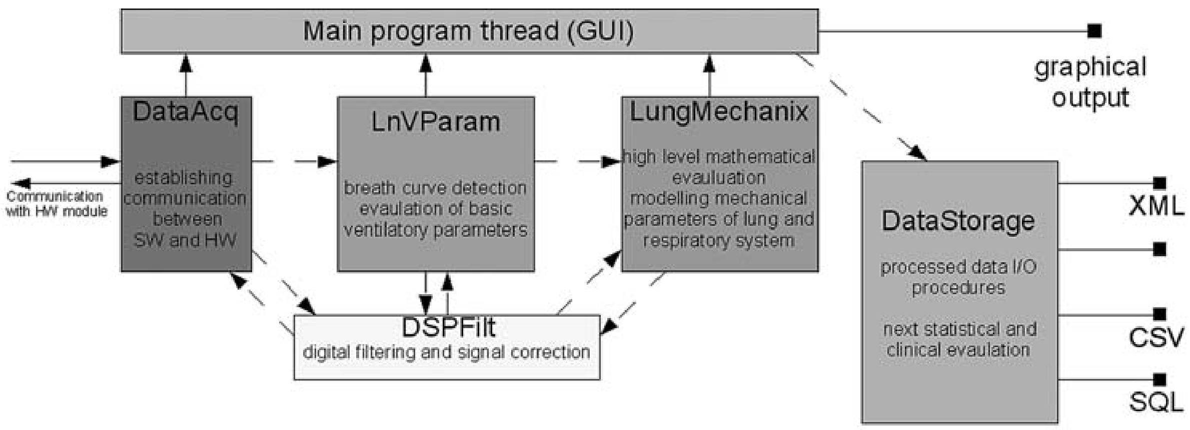

Fig. 3: Block diagram of evaluation SW.

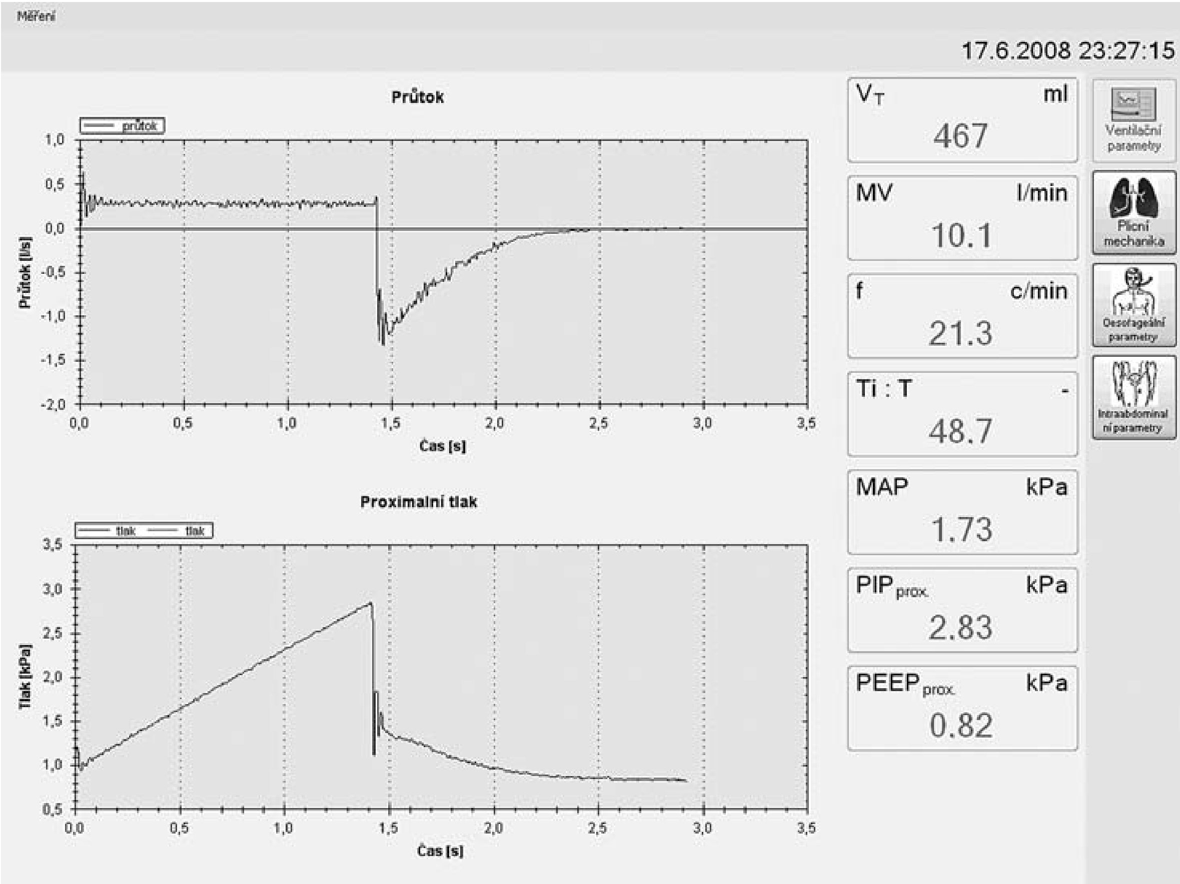

Fig. 4: Screenshot of the monitoring software.

tory rabbits) and during a human clinical trial in a faculty hospital. The main goal is to integrate this system into a set of devices used at an intensive care unit for further studies of ALV. It will conduct a feedback necessary for upgrades and other changes in whole system as well.

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