INSTRUMENTATION ARCHITECTURE OF CONTINUOUS POSITIVE AIRWAY PRESSURE FOR NEWBORNS

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Abstract: *This paper presents a project that aims at the development of a ventilatory support prototype for Continuos Positive Airway Pressure - CPAP - to be applied in a Pediatric Intensive Care Unit (ICU). This system is microcontrolled by important variables such as temperature, humidity and air pressure provided to the newborn. Its components include a total of eight modules, which are: mechanical and pneumatic module, sensor, acquisition, control, temperature control, communication, power and user interface. In the making of the modules, the standards defined by norm NBR IEC 601 were used. The instrumentation architecture presented will be for a new device for future application, after further tests and validations, to be an alternative low-cost way to allow the continuation of the air current volume (inhaled and exhaled air), and the maintenance of the tissue oxygenation through the lungs. The results presented here are the steps towards the making of the instrumentation architecture of the device that is focused on the central part of the system electronics.*

Keywords*: CPAP, respiratory ventilation, instrumentation.*

1. INTRODUCTION

Lung disturbances are one of the main causes of mortality among newborn infants. Currently, with the development of new intensive treatment techniques that intervene in the respiratory system, newborn mortality has been decreasing, and there has been an improvement in the pulmonary capacity of individuals that have undergone this treatment. Among the several therapies for cases of respiratory insufficiency, the use of continuous positive airway pressure (CPAP) has been one of the most used. It is known that the utilization of CPAP as a treatment for respiratory insufficiency dates from the end of the 1930´s, through the application of facial masks for the treatment of pulmonary edema, pneumonias and obstructive respiratory diseases (Kamper, 1999). The use of continuous positive pressure in newborns was applied toward hyaline membrane in 1971, in which the utilization of this treatment was able to keep spontaneous and regular respiratory rhythm, with excellent results, including significantly reducing mortality (Sedin, 1994). Currently, its application takes place mainly among very low-weight newborns, since it provides an increase in functional residual capacity (FRC), the pulmonary complacency (PC) and most significantly the reduction of intrapulmonary shunt - in which shunt is an inequality in the ventilation-perfusion ratio (V/Q) – in addition to the decrease in the oxygen diffusion (Falcão, 1997). According to (Azeredo, 1994), it improves the inspiratory flux pressure due to the rise in the nasal-pharynx pressure, and the positive end-expiratory pressure (PEEP) increases the functional residual capacity by means of the re-expansion of collapsed and hypoventilated alveoli, improving the ventilation in areas with low V/Q. This leads to the decrease in hypoxemia through the reduction of the shunt and the shunt effect. The increase in the functional residual capacity raises the complacency and, therefore, decreases the respiratory work. The more precocious the use of CPAP is, the less necessary the oxygen therapy is. Babies that are treated with CPAP right after mechanical ventilation present slighter chances of reintubation (Morley and Davis, 2004). Thus, the

continuous positive airway pressure is defined as spontaneous ventilation with continuous positive pressure, whose utility is to expand the collapsed alveoli. Its main characteristic is to keep the airways, throughout all the inspiration and expiration, with a pressure superior to the environmental pressure, and all the ventilatory cycle is accomplished with a positive and constant pressure system. Because of this, one of the main objectives of its application is to avoid the complete elimination of the inspired gas generating greater alveolus stability and a better distribution of the gas in the alveolar units. The CPAP application system is basically made of three components or parameters: continuous flow of the inspired gas mixture, a connection device between the system and the airway of the patient, and positive pressure generation mechanism in the system (Troster and Toma, 1996). The inspired gas deriving from sources of compressed air and oxygen, heated and humidified adequately, must be attached to an oxygen analyzer, as well as to a fluxmeter for better control of flux and fraction of the provided oxygen (Kamper, 1999). The CPAP system is, therefore, a system that is able to stimulate the respiration by means of the use of the positive pressure inside the patient and to do so it is necessary to control the desired pressure for breathing, the humidity and temperature of the provided air, as well as the mixture of the oxygen with the atmospheric air so that some "richer" air can be sent to the patient. The main parts that compose the CPAP system are: the mechanical and pneumatic part, the electrical and the communication systems, presented in Fig. 1 as follows:

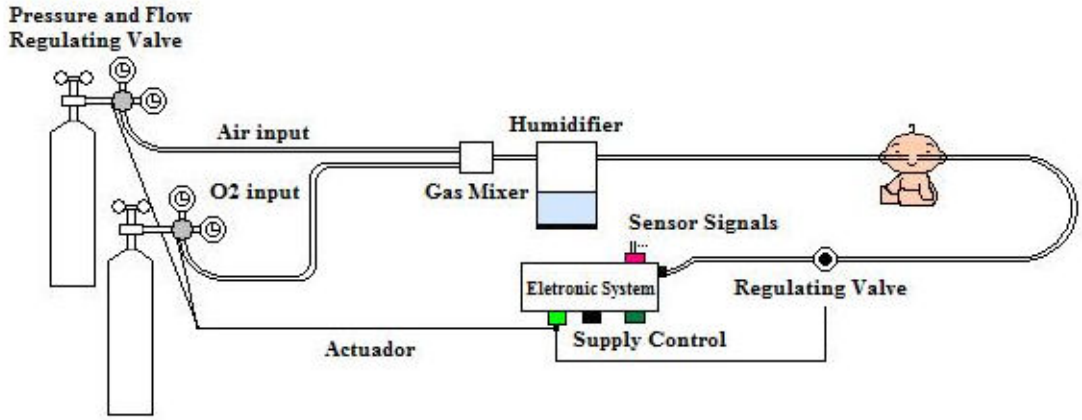

Figure 1: Representative diagram of the CPAP system.

The CPAP system had its efficacy proved in the 80's and that is why the devices that accomplish such function have been developed by a small number of manufacturers, which are mostly external. Currently, them market is predominantly companies from Germany and the United States. Thus, the cost of using such technology in the national market is high which is a limiting factor toward the purchasing and application toward the public health care system. It is known that it is necessary to propose, to the national market, some equipment that can accomplish the fundamental functions of these devices, and which have an easy user interface and an accessible price. This article presents a new point of view of the electronic part of a CPAP system, which will result in a new piece of equipment in the future. This new technology will be made by the research group of the Engineering and Innovation Laboratory (LEI) of the University of Brasília, in partnership with SEBRAE-DF. The electronic prototype of this system has a production price around R$ 4,500.00 (four thousand and five hundred *reais*) and supplies the requisites of norm NBR IEC 601.

2. PHYSICAL DESCRIPTION OF THE PROPOSED SYSTEM

The new CPAP system was conceived in a simplified way, this was done by only trying to attend to the indispensible and maximum exigency variables, according to doctors and manuals, for the maintenance of the respiratory system of the patient. Additionally, low-cost devices that are easy to acquired in the market and possible to replaced by similar ones is what makes it flexible for future alterations. Even so, the product to be developed will supply the necessary requisites for the correct operation, which will turn out to be functional and accessible. The developed system will be controlled with the PC through a Bluetooth protocol, which is an innovative characteristic compared to the commercial devices. The main system modules are: the mechanical, the pneumatic and the electronic modules. In the two first ones the configurations and dispositions are standardized by norm NBR IEC 601, having immutable characteristics, so they cannot undergo research innovations. It is on the electronic module that the researches and results proposed here are concentrated and it was subdivided in sub-modules, which are: sensor, acquisition, control, temperature control, communication, user interface and power, as presented in Fig. 2 below. In the

next sections, construction details and developed modules are presented – it is worth stating that the schematic drawings have been made with the software *Altium DXP2004*.

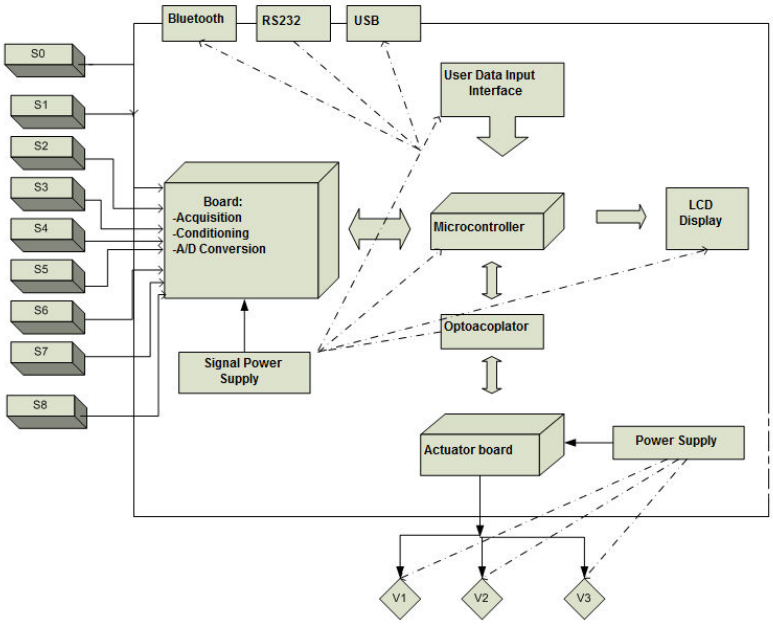

Figure 2 – Block diagram of the sub-modules that compose the electronic system.

2.1.Characterization of the CPAP system

The electric input ruled by norm NBR 13534 demands electrical power 110/220 VAC 50/60 Hz, and with the use of an internal battery, 24 VDC 2.2 A/h. For the Pneumatic Input the same norm imposes that both the Compressed Air and the Oxygen is within 300 and 400kPa (43,511 a 58,015 psi), and these exigencies have been contemplated in the system proposed here. As regards to the Mechanical and Pneumatic Modules, the actuation of the system for the regulation of the valves responsible for the administration of the gases to the system involves: air regulating valve, O2 regulating valve and CPAP regulating valve. To have an efficacious control and with little waste of energy a Pulse Width Modulation (PWM) is used. The PWM is used to control the voltage supply to a load (in this case, the valve), through the utilization of the system feeding common to an interrupting key, controlled by a desired frequency and for a determined percentage of time with the key turned on/off. Thus, it is possible to provide the desired amount of load to a valve with little waste of energy. This waste of energy refers to the way the actuator systems were treated before, when the load was fed according to a dimmer that caused waste of energy of the system. For the actuation in CPAP an integrated circuit Drive DRV 103. DRV 103 was used as a force key that uses the PWM as an output. This is applied to valves, solenoids, relays, actuators, engines, positioners, and others. Among its characteristics, it also has an energy control system, which not only delivers a DC load before the PWM through the adjustment of the delay, but also permits the adjustment of the Duty-Cycle and the signal frequency. Circuits of protection and isolation have been inserted to protect the microcontroller and isolate this part of the circuit. The used valves are proportional VP12, manufactured by NORGREN, which have external feeding 24 VDC and are commanded by a signal from 0 to 8 volts.

The module sensor has the function to acquire all the pieces of information of the CPAP system and transmit them to the microcontroller in a reliable and precise way. It was necessary to study all the requisites for the CPAP system in details, such as preciseness, operation zone, material, etc. As already presented in Fig. 1 and Fig. 2, in which it is shown the location of each item of the proposed system and each component that makes part of it, Tab. 1 below presents the signals that will be read with their respective characteristics and the chosen components, so that it can analyze the instrumentation of the developed system. Details of the construction must be considered, such as the distance between the pressure/flow regulating valves and the main module, which must not exceed 2.5 meters. The control of these valves will be made through current, therefore the cables that transmit the current pulses must be thick and with low impendence to avoid the tension fall. The power valve and the current pulses for control stream through these cables. The cables must be covered for the connection of sensors to the conditioning and acquisition module, and the source cables for the feeding of the integrated circuits must be twisted.

Table 1. Description of the electronic system divided into input actuation.

Input Signal (IS)	*IS Characteristic*	*Interface device*	*Conditioning the signal – what must be done?*
Inspiration pressure	From 0 to 35 cmH_2O	Digital potentiometer-AD8400	Go through device PG309, go to µC and from this one it is obtained the command to actuate in the valve through DRV103
Inspiration Flow	From 0 to 50 L/min	Digital potentiometer-AD8400	Go through device PG309, go to µC and from this one it is obtained the command to actuate in the valve through DRV103
O2 Concentration (FiO_2)	From 21 to 100%	----	----

Table 2. Description of the electronic system - sensoring.

Read signal (RS)	*Characteristic*	*Sensor*	*Signal of output*	*Characteristic*	*What must be done?*
O2 Flow	0-50 l/min;	F900-N-5-0 2,0 m/s →166 l/min 5% accuracy	Analogical signal	RS232, it must be used AMP 5 pin connector	Channel A/D
Compressed air flow	0-50 l/min	F900-N-5-0	Analogical signal	RS232, it must be used AMP 5 pin connector	Channel A/D
Inspiration Flow	0-50 l/min	F900-N-5-0	Analogical signal	RS232, it must be used AMP 5 pin connector	Channel A/D
Temperature of the plate	$85^oC < Tp < 90^oC$	TMP05BRT-500RL7	Digital signal (CMOS/TTL)	Output SPWM	Direct connection with µC uses two pins
Temperature / humidity of the air	$32^oC < Tar < 38^oC$ 90%<UR<100% Without condensation	SHT75	Digital signal (CMOS/TTL) Compensate the non-linearity	2-wire complete sequence	Direct connection with µC uses two pins
O_2	From 21% to 100 %	R24MED	Analogical output needs amplification	Circuit with a 10k load and amplification	
Inspiration pressure	Minimum = 0 cm H_2O Maximum = 60 cm H_2O	MPX10D	Analogical Differential pressure	Analogical	Channel A/D
Expiration Pressure	Minimum = 0 cm H_2O Maximum = 60 cm H_2O	MPX10D	Analogical Differential Pressure	Analogical	Channel A/D

Table 3. Description of the electronic divided into actuation.

Actuation Signal	*Characteristic*	*Interface devices*	*Actuation forms*
O_2 Valve	Digital of the µC	DRV103	The device output is PWM; it actuates regulating the valve
Compressed air valve	Digital of the µC	DRV103	The device output is PWM; it actuates regulating the valve
Inspiration circuit valve	Digital of the µC	DRV10X	Regulating the pressure value of the air provided to the patient

The communication module contains the CPAP system communication with a microcomputer for the data acquisition, in real time, of sensor values and actuations in the system. The utility of this part is the execution of the more advanced monitoring, maintenance, upgrades and tests. Bluetooth wireless protocol is a narrowband communication technology (2.4 to 2.485 GHz) whose main objective is to substitute the cables that connect devices, while keeping high security levels. Among the principal characteristics of this technology it stands out for its low potency, low cost and small dimensions. The communication between the acquisition module and the computer will be implemented with Bluetooth protocol. The module used on the acquisition board is KC11 with a 100-meter reach, and for the reception of data by the PC a KC210 module is used to connect the USB gate of the PC. The KC11 module has 14 I/O inputs, but also contains serial communication through the utilization the UART microcontroller´s. This characteristic guarantees to the proposed system, the possibility of using it by establishing a connection between the two components, and then making some terminal software to collect the signals and send the commands, with the utilization of KC210 plugged to the computer. A firmware is already pre-installed in the modules so that there is this communication.

The user interface will be made through a panel which will contain a LCD, buttons for the input of variables and start button. In this interface the user can visualize the temperature of the plate, temperature and humidity of the air and FIO2 flow, along with determining the values of the input pressure for CPAP, O2 concentration (FIO2) and the inspiration Flow. Thus, the user can monitor and set up input parameters to fulfill the needs of the patient.

In the power module it is important to pay attention to all the system consumption characteristics so that a reliable source for the CPAP system can be adjusted. In the control module a microcontroller PIC-16F877 was used, manufactured by Microchip; in addition, it was necessary to increase the number of analogical channels, and because of this, it was also necessary to utilize an analogical multiplexer. For protection of the circuit components a circuit that limits the tension for each available analogical input was used. For the signals of the sensors, besides the input tension limit protections, first order low-pass filters were put to reduce the noise that may had been generated in the signal transmission and to serve as anti-aliasing filter, avoiding incorrect measurements.

3. RESULTS AND DISSCUSSION

Before any production of a printed circuit board, it was necessary to simulate the proposed circuits, accomplish calibration of the sensors and finally to determine the board layout. The board layout used was designed to optimize space by reducing the space needed for the components, this takes into account the little available space in hospital environments. The modules were tested individually and possible situations within the system were generated, observing the characteristics of the output signals and the performance of the system as a whole. Adjustments to the dimensioning of the components were made with the inclusion of instrumentation amplifiers INA 118 and INA 126, their off-set adjustment and gain regulation made separately. Isolation devices TILL111 were allocated in all the interfaces to accomplish the NBR norms and the alarms were applied and illuminated with colors and sounds established by NBR13163 and NBR13751 norms. In Fig. 3 below it is presented the board layout of the proposed systems in 3D, which are in the making and soldering process.

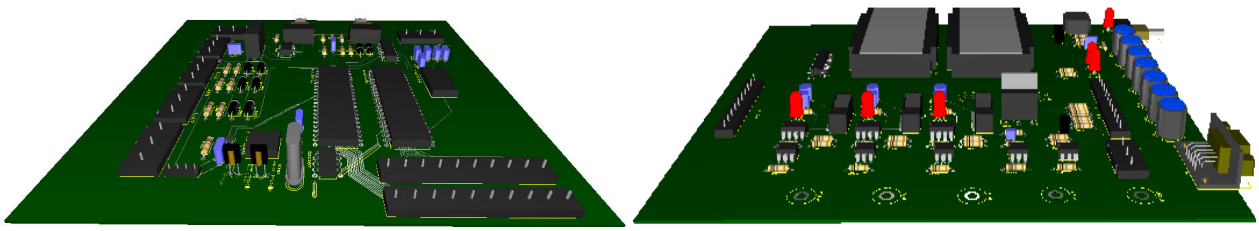

Figure 3 – Image the board layout of the proposed systems in 3D.

4. CONCLUSIONS

With the obtained results, it could be verified that the developed system is efficient and that choosing the sensors is the most careful part of the project. The analysis of the conditions of power, sensibility, among others, was fundamentally important to the good functioning of the electronic part of the CPAP system. Because low cost was considered of the time is spent was on the selection of components used. It is important to emphasize the contribution of this project at the national level, as well as its relevance. This is because along with there being so few manufacturers and only one of national origin, the product is acquired at a very high price. However, with the choice of low-cost components and being the equipment projected to be functional and low-consuming, it was possible to validate the electronics –the most important and fundamental part of this product.

The conditioning, actuation and alarm sound parts were simulated as much as possible and turned out to be satisfactory. Knowledge of instrumentation was fundamentally important to this project, as well as the search for

previously implemented solutions. For future improvements, a study of other control variables to add more reliability to the proposed system was suggested. Besides the accomplishment of tests of the *in vivo* system through a protocol of application to animals and human newborns – initially it will be tested in puppies and after the analysis of such data, it will be tested in human beings with the agreement and supervision of the Committee on Ethics and Animal and Human Medical Research of the University of Brasília – UnB.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Aly, H. Z., 2001.Nasal prongs continuous positive airway pressure: A simple yet powerful tool. Pediatrics, v. 108, p. 759-76.

Azeredo, C. A. C., 1994.Ventilação mecânica - invasiva e não invasiva. Rio de Janeiro: Revinter.

Falcão, M. C., 1997.Uso da pressão positiva contínua das vias aéreas (cpap) no período neonatal. Pediatria, v. 19:209-12.

Kamper, J., 1999. Early nasal continuous positive airway pressure and minimal handling in the treatment of very-low-birth-weight infants. Biology of the Neonate, v. 76, suppl. 1, p. 22-28.

Lima, M. R. O. et al., 2004. Comparação dos níveis de pressão positiva contínua nas vias aéreas através de dois sistemas. Jornal de Pediatria, Rio de Janeiro, v. 80, n. 5, p. 401-406.

Morley, C. J. and Davis, P., 2004. Continuous positive airway pressure: current controversies. Current Opinion in Pediatrics, Iv. 16, p. 141-145

Sedin, G., 1994. Ventilatory techniques in the treatment of newborn infants. J Perinat Med., v.22(6): 557- 63.

Scarpinella-Bueno, M. A. et al., 1997. Uso do suporte ventilatório com pressão positiva contínua em vias aéreas (cpap) por meio de máscara nasofacial no tratamento da insuficiência respiratória aguda. Rev. Ass. Med. Brasil, v. 43(3): 180-4.

Troster, E. J. and Toma, E., 1996. Insuficiência respiratória. In: LEONE, C.R.; TRONCHIN, D.M.R. eds. Assistência Integrada ao Recém-nascido. 1a ed., São Paulo, Atheneu. p.151-70.