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# Development of a Neonatal Interactive Simulator by Using an RFID Module for Healthcare Professionals Training

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## 1. Introduction

This chapter of the book presents the experience and achievements attained in a project carried out by the National University of Colombia which is intended to design and implement tools for training students in medical and nursing techniques applied on neonatal patients. The main result to be shown in this chapter is a virtual and physical tool – based on RFID technologies – that simulates pathologies in neonates in order to teach students the correct use of medications by means of umbilical vein catheterization based on the medical interpretation of the patient's symptoms. In addition, professor's and student's testimonies are shown referencing their experience with the tool in the generation of different medical scenarios of diagnosis and in the application of dosification techniques.

This chapter is organized as follows: the project justification is presented in Section 2 along with other projects already carried out in this line of research; in Section 3, the design and the implementation is presented; next, in Section 4, the results are exposed and finally the conclusions and recommendations are stated by the authors.

## 2. Justification and background

### 2.1 Justification and problem definition

Around 100 million babies are born every year worldwide and approximately 10% of them need some assistance to start breathing; 1% of the total requires intensive resuscitation efforts such as endotracheal intubation and thoracic massages (Murphy & Halamek, 2005). In neonatology, undesirable events that emerge from medical practice can have a negative impact on the neonate's formation and growth. Hence, medical and nursery personnel training and learning processes with real patients carried out before become a decisive factor when saving lives and guaranteeing adequate prognosis.

The traditional learning method has two stages: the theoretical knowledge and clinic experience. The limitations of those stages are illustrated in Table 1: the class environment is characterized by being extremely theoretical and by the lack of realism and the clinical setting is where at some point apprentices refine his or her abilities with live patients but associated with a high risk for their health. In addition, clinics are compelled to ensure

optimal treatment for their patients from the very first moment they are admitted (Hayes, 1994; Lynöe et al, 1998).

Class Environment
It is characterized by being passive in its learning opportunities It is focused on teaching instead of learning Lack of realistic signals, distractions or pressure Incapable of preparing the apprentice adequately for a real environment
Clinical Environment
Exposes patients to some degree of risk Learning opportunities are random Learning is limited by the swiftness of the moment, pressure and high inherent cost

Table 1. Limitations of traditional methods (Halamek, 2008)

Tools that have led to a new way to teach and learn based on Medical Simulation (Murphy & Halamek, 2005 ); Ostergaard et al, 2004 ; Ziv et al, 2006) by using computational tools and mannequins are being used to avoid experimenting with real patients and overcome the limitations of conventional medical training

Simulation with training equipment allows saving lives and improving quality of life since medicine students can acquire skills and key competences such as the appropriation of new knowledge, making fast and safe decisions, and the acquisition of clinical experience in environments similar to those that take place in real emergencies.

Nevertheless, one of the greatest challenges of the simulation and the use of mannequins is that the condition of a real patient changes throughout time depending on the quality and swiftness of the diagnostic and the treatment; in contrast mannequins are stable and the pathology evolution is left to the imagination of the doctor or nurse because the symptoms are difficult to simulate in the dummy.

Even though the quality of simulators that can be acquired in the market is excellent, there are some disadvantages such as their high costs and that the controllers which allow practicing the development of pathologies cannot be used because they differ from the Colombian health sector conditions. The medicine faculty of the National University of Colombia has developed its own philosophies, methodologies and technical approaches to diagnose and to follow schemes under adverse conditions like those found in healthcare centers in any region in Colombia. Nevertheless there is an important barrier to teach and learn because commercial simulators do not allow the presentation of these philosophies, methods and techniques developed in this institution. (Currea, 2004)

On top of that, many of the commercial simulators have limited communication infrastructures among the different elements of such simulators; such is the case of wired connections to exchange data between the controllers and mannequins that can be replaced by radio frequency technologies and radio identification (RFID).

Due to the importance of the topic and the mentioned limitations, a variety of tools for medical simulation have been developed in the present project by members of the Master in Industrial Automation of the National University of Colombia using dynamic models that allow the generation of diverse biomedical signals of a neonate in order to work with a more real perception. In addition, a virtual and a physical tool for the simulation of neonatal pathologies has been created based on RFID technology in order to teach students the correct way to

administrate medications through the umbilical cord based on the medical interpretation of the patient’s symptoms which are recreated by virtual reality using animated graphics.

2.2 The medical simulation: context and background

A simulator is an artificial representation of the real world giving the enough fidelity to achieve a specific goal in the learning process (Halamek et al, 2000 ; Ostergaard et al, 2004; Rall & Dieckmann, 2005) .  
Medical Simulation is also defined as the imitation of a real thing, situation or medical process for the practicing of skills and resolution problems (Halamek, 2008). It is a recent method for learning among healthcare areas, and it reduces the gap between cognitive skills and clinical experience.  
In general, medical simulation has been structured into 5 categories; see Table 2, according to the method proposed by David Gaba (Small et al, 1999) : verbal, standardized patients, body parts trainers, computerized patients and electronic patients.

Category	Characteristics
Verbal Simulation	It is based on knowledge communication by using role plays.
Standardized Patients	Actors that perform and evaluation, for instance, on the way to obtain clinical data, the necessary skills to carry out physical checkups as well as communication and professionalism.
body parts trainers	Anatomical models of body parts showing a normal state or representing any illness or problem.
Computerized patients	Interactive patients that can be either software-based or part of an internet-based world.
Electronic Patients	These are software applications that operate over a virtual reality or a mannequin and the clinical environment mimicked is integral.

Table 2. Schemes of medical simulation

The main advantages of simulators are (Halamek, 2008 ; Murphy & Halamek, 2005 ; Ziv et al, 2006) :

- It does not generate any risk to the patients due to it reduces the error probability or undesirable events in human beings.
- It allows practice without interferences and interruptions.
- It facilitates feedback from both the professor and training environment to the student.
- Simulations can be organized in convenient moments for both trainees and trainers.
- It can be scalable in intensity in order to know the needs of apprentices in all levels of experience.
- It allows the practice of unusual routines and situations.
- It promotes the integration of cognitive, technical and behavioral skills.
- It facilitates the training of students into multidisciplinary teams.
- It promotes the use of multiple learning strategies.
- It facilitates an objective evaluation for each student.

Simulation has been formally used in medical training in the last decades. Nevertheless, representation of signs and symptoms referenced in the literature or in the theater can be actually considered as the predecessors of non-technical simulation. Application of this tool was delayed because of high costs and lack of rigorous testing which generated skepticism as well as resistance to change (Ziv et al, 2006). Some of the most relevant predecessors of simulators for medical training are presented in the following sections.

### 2.2.1 Computerized simulators

Computerized simulation in the medical area started in 1960 with a graphic communication system (Khalifa et al, 2006). Computers facilitated the mathematical description of the human physiology and pharmacology as well as the worldwide communication and the design of virtual worlds (Smith & Daniel, 2000). This resulted in the development of a virtual reality prototype for medical training in which the user was represented by an avatar which was capable of handling its virtual instruments and carrying out medical procedures. This platform allowed several users and multiple modules of simulation that allowed the creation of a shared virtual environment (Stanfield et al, 1998); in this latter aspect, N T and Smith and the colleges from California University used their experience in cardiovascular physiology and anesthetics to develop “Sleeper” which was the precursor of the current BodySim® designed for practicing resuscitation (Cooper & Taqueti, 2004). Years later, MicroSim® would be released to the market; a CD-ROM of Laerdal intended to provide structured training in medical emergencies (Perkins, 2007).

Currently, all the branches of surgery including general surgery (McCloy & Stone, 2001), urology (Hoznek et al, 2003), neurosurgery (Spicer & Apuzzo, 2003), gynecology (Letterie, 2003), and orthopedic surgery (Tsai et al, 2001) have made use of virtual reality in one way or another. In addition, anesthesiology and other medicine subspecialties oriented to procedures such as gastroenterology, lung science and cardiology that have been included in the area of virtual reality (Gillies & Williams, 1987).

### 2.2.2 Physical simulators

Mannequins to teach obstetric skills and reduce high mortality in infants were patented in 1960 (Buck, 1991). In particular, Resusci Annie®, Laerdal’s emblematic product; is one of the first landmarks in the history of medical simulation because even when it was initially designed for mouth to mouth respiration, it subsequently evolved by integrating a spring in its chest to allow cardiopulmonary resuscitation.

The first patient simulator at human scale was called Sim 1® and it was built by the University of California. Some features of this simulator include pupils that can dilate, jaw that can open, eyes that can blink, respiratory movements and heart beat synchronized with temporal and carotid pulse (Cooper & Taqueti, 2004).

Gaba built the Comprehensive Anesthesia Simulation Environment (CASE) prototype in 1986 en Stanford. Similar to other innovations, its high cost limited the acquisition of the mannequins to a reduced quantity in medical centers. Several European centers developed their own computerized mannequins for simulation. ACCESS®, Sophus® and Leiden® are three examples of inexpensive simulators developed worldwide (Chopra et al, 1994). After, the KISMET® simulator (1993) introduced distant-surgery, which initially had low realism in quirurgic simulations but was quickly improved parallel to the progress in technical elements and computer power. The partial mannequin Simulator-K was developed to assess cardiac abilities (1990) (Takashina et al, 1990).



At the same time, UltraSim® reproduced the relevant abdominal pathology in obstetrics and gynecology; then, the ophthalmic training system evolved into virtual reality with EYESI® produced by VRMagic; this one was initially designed as a simulator of vitreoretinal surgery and then it became the learning tool of a deeper ophthalmic surgical procedure (Khalifa et al, 2006).

The first training program based on simulation of neonatal resuscitation was developed in Stanford University by the mid 90's (Halamek et al, 2000); then, Gaumard Scientific Company produced a mannequin of a neonate capable of simulate cyanosis.

### **2.2.3 Electronic simulator**

A computer application was developed by the end of the 90's which enabled remote observation and control of the most relevant signals for the neonates monitoring (cardiac frequency and skin color), and also, a virtual model of the patient was implemented in which the vital signals could be controlled by an external Java application (Korosec et al, 2000).

In the year 2000, Laerdal presented SimMan®; it was the first human-scaled portable mannequin designed to train the skills and performance on resuscitation scenarios. This model also generates heart beats, mimics respiration and blood pressure and allows the trainer to develop and to edit his or her own scenarios or reuse preset scenarios (Perkins, 2007).

Then, SIMA adopted a new approach and introduced a personal computer, software, a monitor and 8 training scenarios. Currently, SimBaby® is the simulator used for training neonatal resuscitation which includes the software and a technologically advanced and interactive mannequin.

These commercial simulators have excellent quality but present some disadvantages; among them are the high cost (Halamek, 2008) and the fact that there are special training centers needed that at the same time require instruments, monitors, mannequins and technical personnel to control and supervise training (Korosec et al, 2000).

## **3. Proposed design for the neonatal pathologies simulator**

Taking into account the characteristics of the models presented in Section 2, and in order to build a tool for both Medicine and Nursery students to acquire skills in diagnosing neonatal patients, an interactive simulator has been designed. This device consists of a screen that allows the instructor to program the health status of a patient by modifying its vital signs to create different pathologic and non-pathologic scenarios; then students are asked to define what they believe should be the appropriate treatment.

The vital signs are simulated because they are the main indicators that reflect the physiological status of vital organs (brain, heart and lungs) which immediately express the functional changes in the organism. The vital signs are the measure of different variables: cardiac frequency, pulse, respiratory frequency, blood pressure (systolic, diastolic and average) and temperature. Nevertheless, literature also recommends complementing these parameters with other useful measurements such as Pulse-Oximetry.

Acquiring the ability to interpret in an adequate and opportune way those physiological parameters (vital signs) is essential in medical training as it helps healthcare professionals and first aid personnel in selecting an appropriate treatment among the different choices. Determining and analyzing vital signs is very important during an emergency where many

patients arrive with a huge variety of clinical conditions, especially for neonatal patients whose symptomatology cannot be described thoroughly. Healthcare students must learn how to choose the correct medicine and dose according to the patient's particular symptoms. The minimum increase of a dose or the wrong medicament injection can be very prejudicial for an infant, it also can cause death in extreme cases. Hence, a mannequin has been adapted to identify some medicines that trainees apply via umbilical vein catheterization and to show the health status after the treatment.

Figure 1 shows the graphic scheme of the neonatal pathologies simulator its main elements are: a graphic interface that shows the vital signs and allows selecting the medication, an RFID medicines programmer, a syringe applicator, a mannequin that identifies medications and a tool to acquire data.

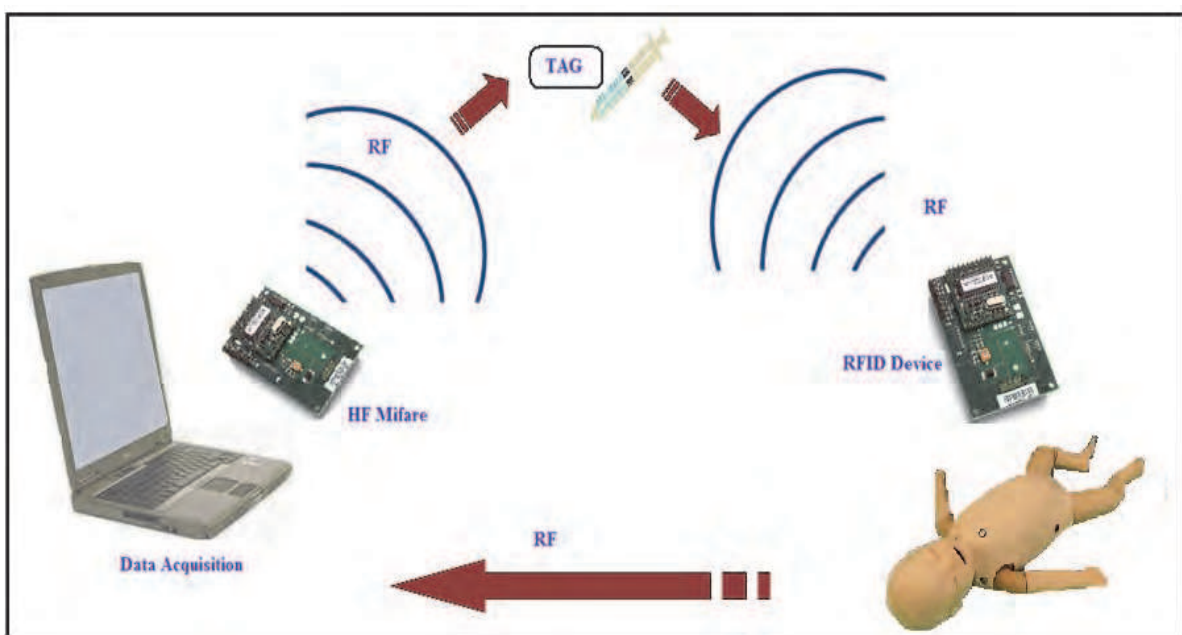


Fig. 1. Graphic of a virtual and physical simulator of a neonatal patient

In a training scenario, students and instructors must do the following: the instructor changes the vital signs of the patient (frequency and maximum and minimum values) through the graphic interface that shows the vital signs such as: ECG, pulse, pulmonary pressure and CO<sub>2</sub> and O<sub>2</sub> levels. In this way, the instructor can modify the health status in order to generate diverse medical scenarios. Subsequently, the student has to choose the applying medication and its dose once the diagnostic has been carried out through the same graphic interface.

The data of the medication and its dose chosen by the student for treating the patient are sent by an RFID programmer connected to the computer to the fields of an RFID Tag that is attached to the syringe (see Figure 1). In addition, the mannequin has an RFID reader embedded in its abdomen to receive the data stored in the Tag when the syringe is approached to the identifier by the student.

Once the described process is carried out, the vital signs of the patient are automatically modified by the software in the mannequin according to the chosen treatment. In this way, a new health condition is presented to the student as a feedback indicating whether the choice of medication and dose has been the correct one or not. The neonate's condition is reported continuously to the computer by using an acquisition tool implemented with wireless

communication between the emitting module in the mannequin and the receptor in the computer. In this way the patient’s health is constantly monitored not only by watching the mannequin but also it can be seen in the graphic interface. The mannequin produces cardiac sounds. It also recreates the skin flushing and, by an LCD screen, it is possible to see its rectal temperature and cardiac frequency.

4. Theoretical foundations

In this chapter is presented the previous investigation made about the vital signs which are relevant to accurately make a diagnostic over a newborn’s health as it would happen in real life. Numeral 4.1 summarizes the main medical signals that were simulated: ECG, cardiac frequency, pulse, respiratory frequency, arterial pressure and levels of CO2 and O2, among others. The selected medicines to be used in the system are shown in numeral 4.2 as well as some parameters such as the supply method and affected variables. These medicines can change the health status of the newborn which will be immediately reported to the computer where the instructor can evidence the decision made by the trainee considering the changes in vital signs and appearance.

4.1 Variable monitoring

Intensive care units were created due to the need of exhaustive and strict monitoring of patients with high risk pathologies. The current status of a patient is assessed by watching and continuously recording the physiological and pathophysiological parameters and then their evolution as result of the therapeutic applied by watching the hemodynamics. Nowadays, monitoring patients is an important part of all medical care due to it allows watching the progress of a patient and guarantees an early detection of adverse events or late recovering. In Figure 2 the variables that were simulated in this project are presented.

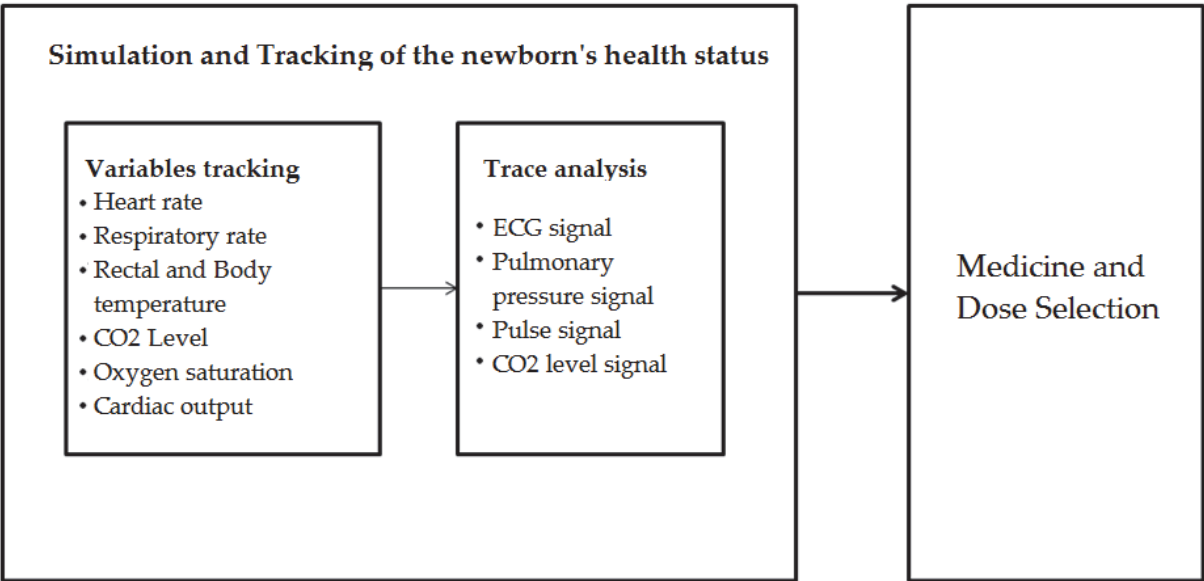


Fig. 2. Diagram of the virtual simulator of a neonate patient (Software)



#### 4.1.1 ECG Signal y cardiac frequency

##### *Signal morphology*

The heart is the central structure of the cardiovascular system. Contraction of any muscle is associated with electrical changes called “depolarization”; those changes can be detected by electrodes located on the body surface. Although the heart has four chambers, from the electric point of view it has only two as the two auricles contract together with the two ventricles (Hampton, 2008).

The muscular mass of the auricle is smaller than the one of the ventricles and in thus, the electrical change produced by the contraction of the auricles is also small. The contraction of the auricle is associated with the “P” wave of the ECG signal. The ventricular mass is large which generates a high deflection of the ECG signal when the ventricles are depolarized; that wave is called the QRS complex. The “T” wave of the ECG signal is associated to the returning of the ventricular mass to its electrical state – repolarization (See Figure 3.a).

The diagnostic of the diverse pathologies is done based on the analysis of the following characteristics of the ECG signal (see Figure 3.b) (Resiner & Clifford, 2006):

- Cardiac frequency (Heart Rate): the number of heart bits or pulsations is commonly the ventricular frequency. The normal range for an adult is between 60-120 bpm; for a newborn it fluctuates between 100 to 160 bpm.
- Regularity: R-R and P-P intervals are analyzed in search for anomalies.
- P Waves: Size, shape and position are analyzed.
- QRS waves (complex): Size, shape and position are analyzed.
- T Waves: Size, shape and position are analyzed.
- PR, QRS and QT intervals: These are analyzed and compared to standard ranges.
- U Waves: These waves are normally invisible, that is, their presence is symptom of anomaly.

##### *The implemented mathematical model*

In order to generate the synthetic signal, the dynamic model adapted from MsSharry (MsSharry et al, 2003) was used; this model generates a trajectory in a tridimensional space (3D) with (x, y, z) coordinates. The quasi-periodicity of the ECG signal is shown by the movement of the trajectory along a limit cycle of unitary radius in the (x, y) plane. Each revolution of this cycle corresponds to a heartbeat.

The different points in the ECG (P, Q, R, S and T) are described as attractors or repulsors, positive or negative in the z direction; these are placed with fixed angles along the unitary circle given by: P, Q, R, S and T (MsSharry et al, 2003). The Dynamic equations of movement are given by a set of ordinary differential equations (Equations 1, 2, 3).

$$\dot{x} = \alpha x - \omega y \quad (1)$$

$$\dot{y} = \alpha y - \omega x \quad (2)$$

$$\dot{z} = - \sum_{i \in \{P, Q, R, S, T\}} a_i \Delta \theta_i e^{\left( -\frac{\Delta \theta_i^2}{2b_i^2} \right)} - (z - z_0) \quad (3)$$

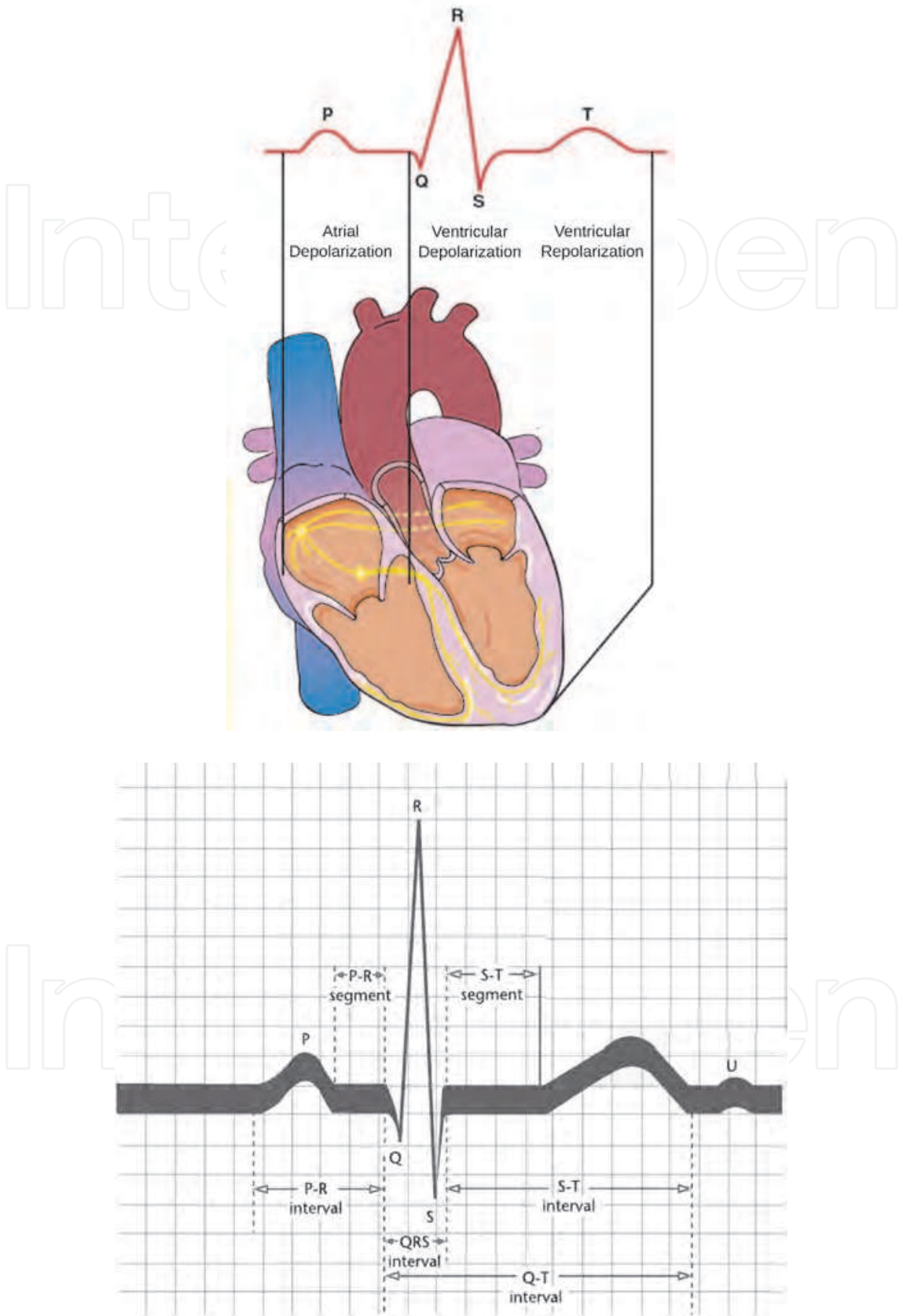


Fig. 3. a) Heart depolarization and repolarization (Jones, 2005), b) Characteristics of the ECG signal (Resiner & Clifford, 2006)

Where:

$$\alpha = 1 - \sqrt{x^2 + y^2} \quad (4)$$

$$\Delta\theta_i = (\theta - \theta_i) \bmod(2\pi) \quad (5)$$

$$\theta = \arctan(y, x) \quad (6)$$

$\omega$  is the angular frequency of the trajectory; time, angles,  $a$  and  $b$  values for a normal child can be found in (MsSharry et al, 2003).

Angular speed is obtained from the power spectrum of the signal given by the sum of Gaussian distributions described in the Equation 7.

$$S(f) = \frac{\sigma_1^2}{\sqrt{2\pi}c_1^2} e^{-\left(\frac{(f-f_1)^2}{2c_1^2}\right)} + \frac{\sigma_2^2}{\sqrt{2\pi}c_2^2} e^{-\left(\frac{(f-f_2)^2}{2c_2^2}\right)} \quad (7)$$

With  $f_1 = 0,1$ ,  $f_2 = 0,25$  and standard deviations  $c_1 = 0,01$  y  $c_2 = 0,01$  (MsSharry et al, 2003).

The synthetic signal was obtained in LabView ®, as can be observed in the Figure 4.

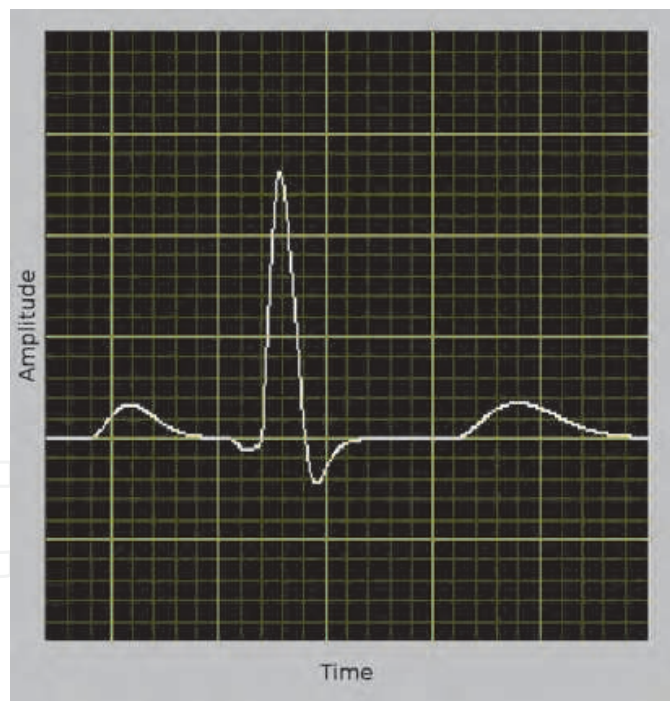


Fig. 4. Synthetic ECG signal

#### 4.1.2 Pulse signal

##### *Signal morphology*

When the heart beats, it generates a pulse wave caused by expansion of the arteries by the circulating blood. This signal has a rounded initial peak that smoothly decreases to a sharp

depression called "dicrotic notch" that occurs as a result of abrupt closure the aortic valve, finally descending to the diastole (see Figure 5.a). This particular waveform is due to the overlapping between a pressure wave, which starts from the heart to the periphery and the other, reflected at the bifurcation of the descending aorta (see Figure 5.b).

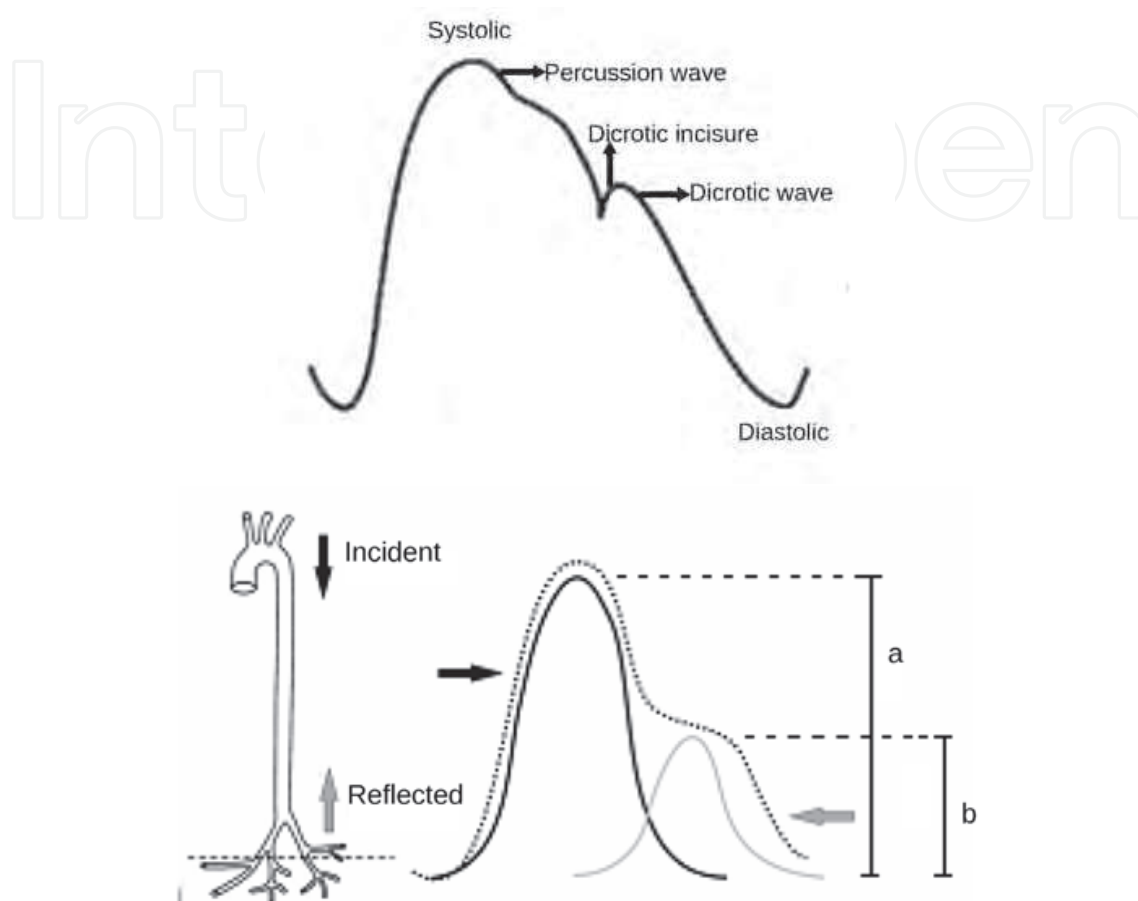


Fig. 5. a) Morphology of the pulse signal (Jones, 2005), b) Composition of the pulse signal (Vanetta & Gomez)

The Elasticity and status of arterial walls determine the size and shape of those waves. The pulse wave measures the speed at which blood travels throughout the vascular system. A slow or obstructed movement of the blood flow means slow transference of nutrients to the cell. This condition might result, among other things, in high blood pressure, lack of energy, low metabolism, loss of memory and can affect negatively the immune system.

In general, the following can be identified by analyzing the characteristics of the pulse signal:

- Premature levels of ageing and stress of the vascular system
- Efficiency of heart pumping
- Arterial elasticity and obstruction levels of large and small arteries
- Early signs of cardiac stress

#### *The implemented mathematical model*

In order to generate the synthetic signal a mathematical model was used, this model generates a trajectory in a tridimensional space (3D) with (x, y, z) coordinates. Each revolution of this cycle corresponds to a heartbeat. The waves that compose the signal are

described as attractors or repulsors, positive or negative in the z direction; these are placed with fixed angles along the unitary circle The Dynamic equations of movement are given by a set of ordinary differential equations (Equations 8, 9, 10).

$$\dot{x} = \alpha x - \omega y \tag{8}$$

$$\dot{y} = \alpha y - \omega x \tag{9}$$

$$\dot{z} = - \sum_{i \in \{R,I\}} a_i \Delta \theta_i e^{\left( \frac{\Delta \theta_i^2}{2b_i^2} \right)} - (z - z_0) \tag{10}$$

Where:

$$\alpha = 1 - \sqrt{x^2 + y^2} \tag{11}$$

$$\Delta \theta_i = (\theta - \theta_i) \bmod (2\pi) \tag{12}$$

$$\theta = \arctan(y,x) \tag{13}$$

The synthetic signal obtained can be observed in Figure 6

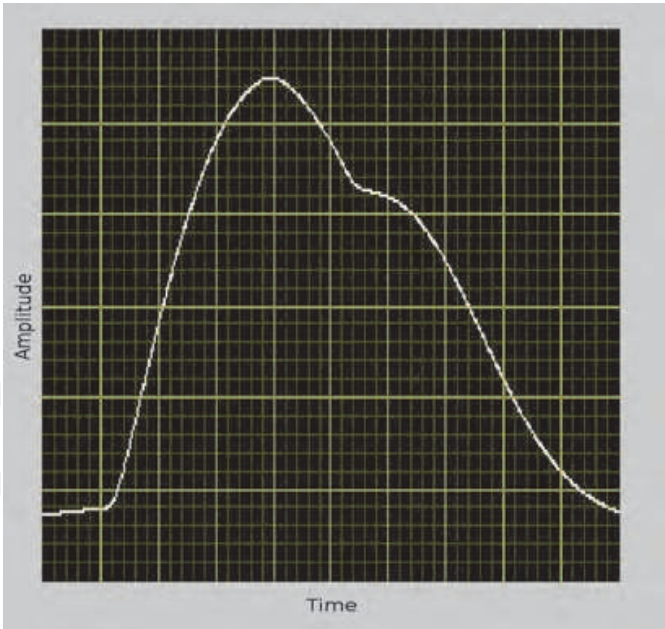


Fig. 6. Synthetic Pulse signal

4.1.3 Arterial pressure

*Morphology of the signal*

Blood pressure is the force that blood exerts against the arteries’ walls. This variable depends on the volume of blood in the vessels and the distensibility of the walls. If the



volume of blood that enters the arteries equals the exiting volume in a period of time, the arterial pressure remains constant. Nevertheless, during the ventricular systole (contractions of the ventricles) a high volume of blood enters the arteries while only a third is expelled towards the arterioles. During diastole (heart relaxing after a contraction) there is no blood entering the arteries although there is a continuous amount of blood going out caused by the elastic recoil of the blood vessel walls. The maximum pressure exerted on the arteries while the blood is expelled during systole is called "systolic pressure". The minimum pressure on arteries when the blood is drained to the rest of vessels during diastole is called "diastolic pressure". The pulse pressure is the difference between the systolic pressure and the diastolic pressure; finally, the mean pressure is the average of the pressure during the whole cardiac cycle (Sherwood, 2010) (see Figure 7).

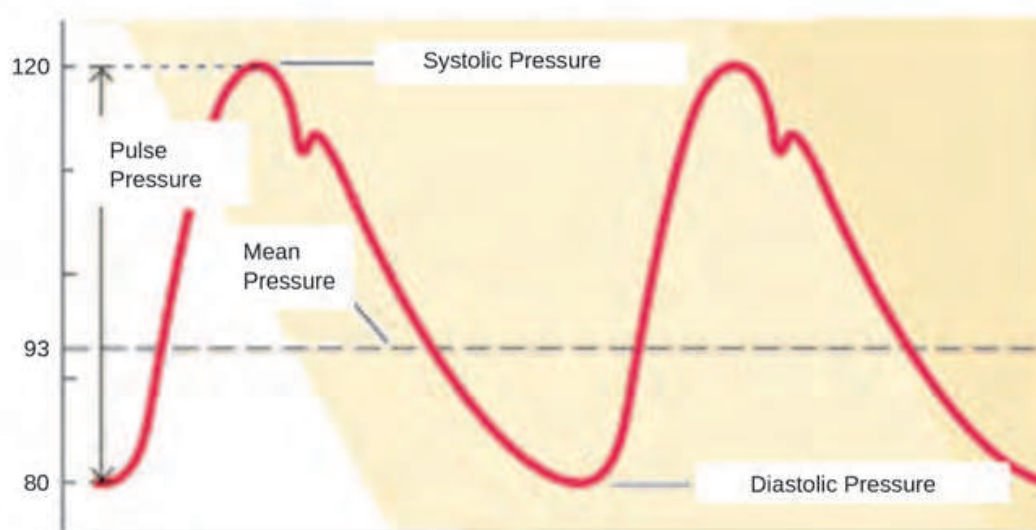


Fig. 7. Components of the arterial pressure wave (Sherwood, 2010)

In practice, arterial pressure is expressed as the systolic pressure over diastolic pressure. Values produced by those measurements and their limits (meaning hyper or hypotension) are relative and depend on each patient and their inherent factors; nevertheless, it is established that a normal reading for an adult patient could reach up to 135/90 mmHg. In contrast between 140/90 mmHg and 160/110 mmHg there would be mild hypertension. If the result is above these values, it would indicate a severe hypertension. On the contrary, values under 100/60 mmHg would represent hypotension or low arterial pressure. Values of arterial pressures in newborns vary significantly compared to those of the adults and are defined by variables such as gestational age, weight and postnatal age, among others.

#### *The implemented mathematical model*

In order to obtain the blood pressure signal, the linearized and improved cardiovascular physiology model presented by Beneken has been used (Beneken, 1965). This hydraulic model of 10 compartments describes: **systemic and pulmonary circulation** (see Figure 8). The model accepts changes in blood volume and intrathoracic pressures as inputs, and generates the pulmonary and systemic pressures as outputs. Blood pressure is calculated for the model of each compartment (Equation 14), the input flow (Equation 15) and the volume

changes (Equation 16). Equations of the compartments adjust with each other as the input flow of one compartment depends on the pressure of the previous one and the changes in volume depend on the input and output flows. The expressions use elastance, resistance and volume variables.

$$p(t) = E(v(t) - UV) \tag{14}$$

$$f(t) = \frac{p_{in}(t) - p(t)}{R} \tag{15}$$

$$\frac{dv(t)}{dt} = f(t) - f_{out}(t) \tag{16}$$

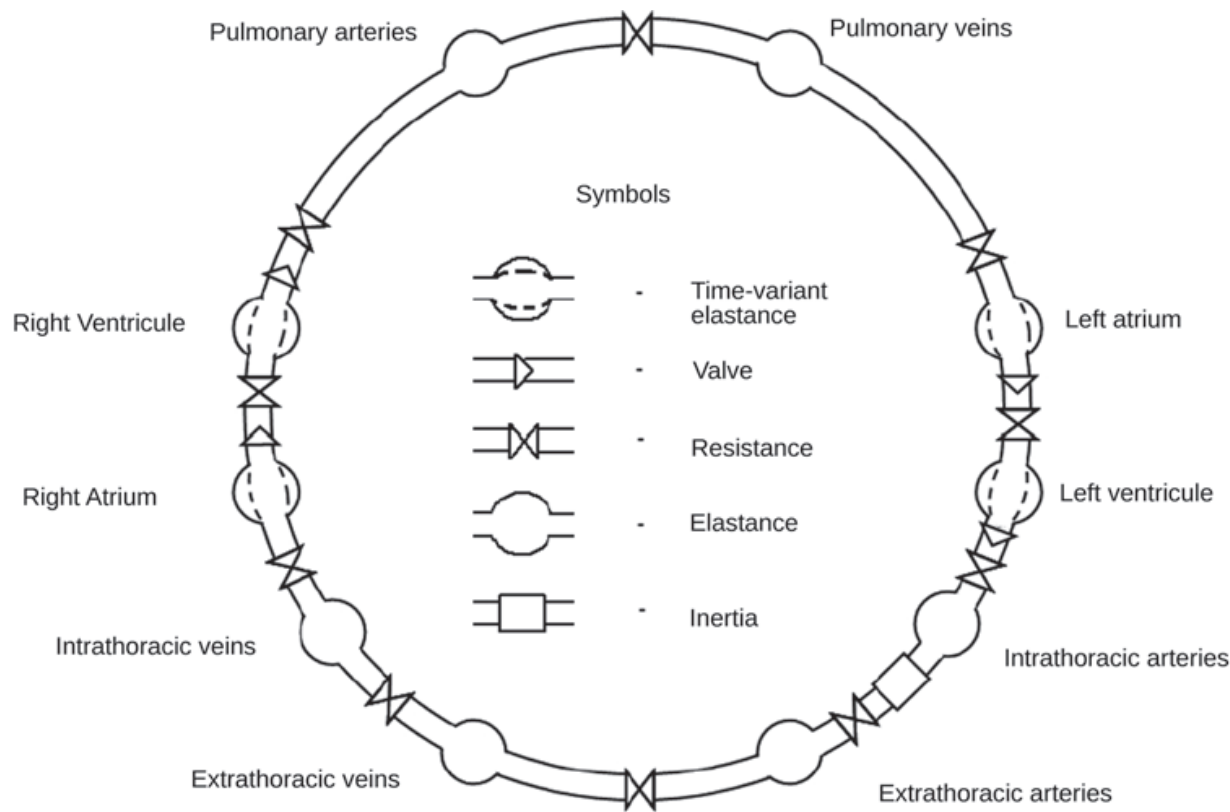


Fig. 8. Physiology Cardiovascular Model (Beneken, 1965).

The inertial behavior of the blood in the arteries is defined by the differential equation (see Equation 17).

$$\frac{df_{etha}(t)}{dt} = \frac{p_{itha}(t) + PTH - RETHA f_{etha}(t) - p_{etha}(t)}{LETHA} \tag{17}$$

Where PTH represents the average intrathoracic pressure, RETHA is the resistance of the extra-thoracic arteries and LETHA represents the inertia of the blood flow in the arteries. Data of the constants of a newborn patient were obtained from (Beneken, 1965). The synthetic signal obtained to represent the pressure is presented in Figure 9.

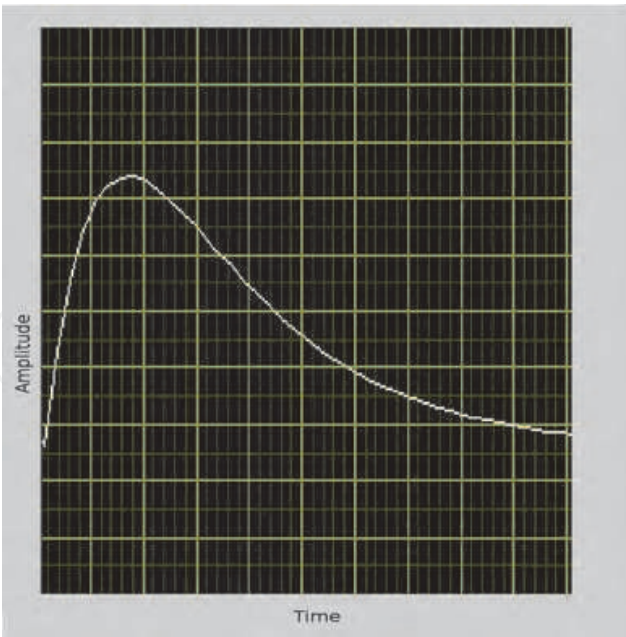


Fig. 9. Synthetic pressure signal

**4.1.4 CO<sub>2</sub> Levels and respiratory frequency**

*Morphology of the signal*

The concentration of CO<sub>2</sub> in expired gases has a close relationship with tissue metabolism, systemic circulation and ventilation. Capnography is the graphic record of instant concentration of CO<sub>2</sub> in gases expired during a respiratory cycle (Bhavani-Shankar et al, 1992). A capnogram is divided into four fundamental phases (see Figure 10).

The first Phase (A-B) represents the initial stage of breathing. In this phase, the gas occupies unused space, normally containing CO<sub>2</sub>. In point B, a strong movement is shown in the capnogram which is the Phase (B-C). The slope of this movement is determined by the uniformity in the alveolar ventilation and in the respiratory emptying. In point D, the CO<sub>2</sub> concentration shows its highest value at the end of the respiratory cycle. When a patient initiates the inspiration, fresh gas enters and there is a significant drop of the baseline. Unless there is a re-inhalation of CO<sub>2</sub> the baseline approximates to zero (Barash et al, 2009).

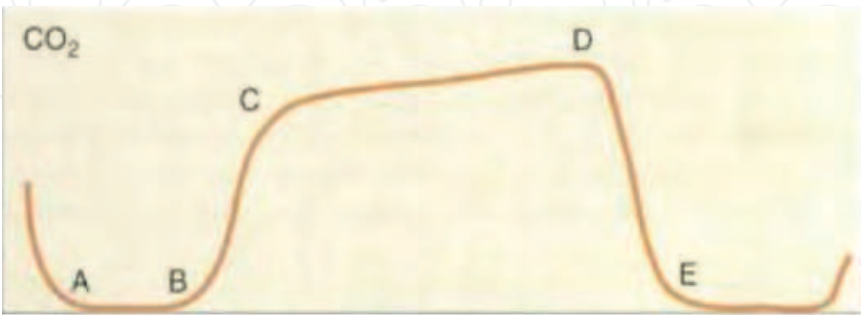


Fig. 10. Normal Capnogram (Barash et al, 2009)

The frequency of the figure above is known as the respiratory frequency or respiratory rate and corresponds to the number of respirations (inhalation and exhalation) within a period of time.

### *The implemented mathematical model*

The capnogram is divided into four fundamental phases (see Figure 10). This wave shape can be described by decreasing exponentials that model the aspiratory and expiratory processes. The frequency of this signal is related with the respiratory frequency.

The dynamic model used describes 2 first degree differential equations; the first expression describes de aspiration (see Equation 18) and the second describes all the cycle, expiration and aspiration (see Equation 19).

$$\frac{df}{dt} = \frac{1}{\tau}(-f + \Phi) \quad (18)$$

$$\frac{dN_{CO_2}}{dt} = \frac{1}{\tau_2}(-N_{CO_2} + \alpha(f(t - D))) \quad (19)$$

$\tau$  y  $\tau_2$  define the time constants of the exponentials that represent the inspiration and the expiration respectively. Besides,  $\varphi$  and  $\alpha$  define the baseline and the maximum  $CO_2$  of a respiratory cycle. Finally,  $D$  is defined as the time in which the respiratory process takes place. In the Figure 11 synthetic signal obtained is shown.

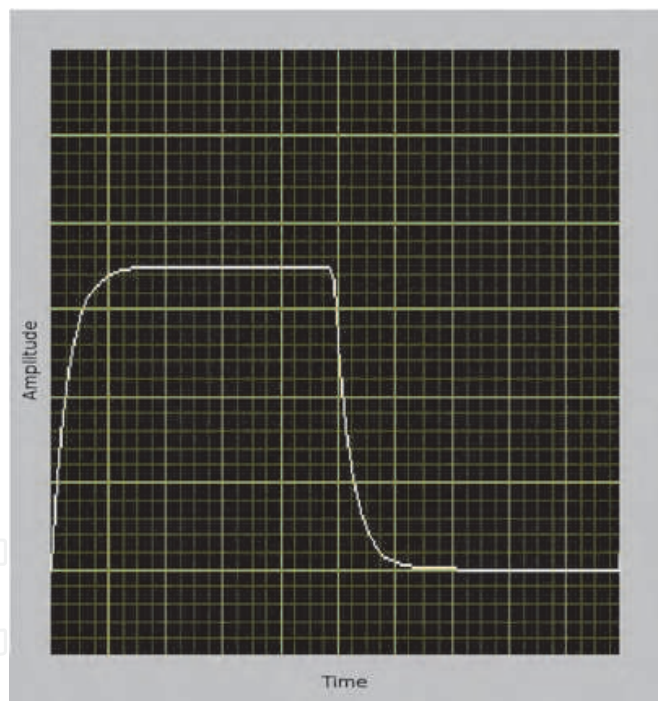


Fig. 11. Synthetic capnogram

### **4.1.5 Other variables**

#### *Temperature*

Human beings along with birds and mammals are categorized as warm-blooded animals or homeothermic beings; that is, that despite of being exposed to a variety of temperatures, homeothermic organisms keep their temperature steady. Cells in the body perform optimally within a temperature range between 35 to 38 centigrade degrees.

The center of temperature regulation of humans is the hypothalamus; this is an area in the brain above the pituitary gland that acts as a thermostat to maintain the body's internal temperature within a range between 36,1 – 37,7 centigrade degrees.

Regarding to this measured values, if the oral temperature is above 38 °C, it can be said that the individual has a fever. On the other hand, rectal temperature is always higher than the oral one by 0,6 °C whereas axillary temperature is lower than internal temperature by 1 °C. A failure in the thermoregulatory system with temperatures equal to or greater than 41 °C would lead to a malign hyperthermia, which is characterized by a failure in the mechanisms of heat loss.

Hyperpyrexia takes place when the body temperature is 41 °C, taken as an isolated reading, or if there is an increase of 1 °C every 2 hours. This could be originated by fever or hyperthermia. On the contrary, hypothermia is the decrease in central body temperature (rectal reading) below 35° C. The most common cause is the accidental exposition to extremely low temperatures which may take place during winter, accidents in mountains and immersion in cold water.

#### *Cardiac output*

Cardiac output is composed by two main factors: the “ejected volume”, which is the blood volume expelled by the heart in each heartbeat and the “cardiac frequency”. The multiplication of both factors expresses the cardiac volume per minute or, what has been called “cardiac output”.

Cardiac output normally decreases during normal sleep as well as under general anesthesia. Some anesthetics such as the halothane can reduce the cardiac output excessively as it reduces the sympathetic discharge in the cardio vascular system. In particular, a strong circulatory insufficiency is characterized by an abnormally low cardiac output. In chronic cardiac insufficiency, the cardiac output can be limited only during intense physical activity; nevertheless, after certain time, the reduction also takes place even during rest limiting the physical capacity .

During physical exercise, incremental cardiac output takes place; likewise, cardiac output can be greater than 50% by the end of pregnancy as well as under certain pathological conditions such as hyperthyroidism or arteriovenous fistula.

#### *Oxygen saturation*

Oxygen saturation is defined as the relationship between the amount of oxygen combined with hemoglobin present in a particular location and the maximum amount of oxygen that could be combined with the hemoglobin in the same setting. In this way, oxygen saturation indicates the amount of oxygen that is being transported by the plasma.

Under controlled conditions and constant monitoring, the saturation needed to reach and keep proper blood oxygenation can reach levels of 97% in infants; similarly, at altitudes such as that of Bogota, saturation can fluctuate between 88 to 92 % with a maximum range between 85% and 95%.

## **4.2 Selecting medication and dose**

Once vital signs of newborns have been simulated to create different scenarios, the medicines that will be used by the simulator have to be selected in order to stabilize vital signs in case the trainee finds a pathological scenario. The following substances that are of common use in neonates were initially considered (Taketomo, Hodding, 2010):



- Cardiovascular: Adenosine, Digoxin , Dobutamine, Dopamine, Indomethacin, Terbutaline.
- Respiratory System: Aminophylline, Dexamethasone, Salbutamol.
- Central and peripheral nervous system: Phenobarbital, Phenytoin, Fentanyl, Midazolam.
- Miscellaneous: Adrenaline, Atropine, Human albumin 20%, Atropine, Sodium Bicarbonate, Furosemide, Calcium Gluconate 10%, Crystalline Insulin, Physiological Serum 0,9%, Pulmonary Surfactant, Vitam K1, Vecuronium.

From the previous list some medicines that are administered via intravenous route were selected. Similarly, those that can be administered via umbilical vein were chosen since this is one of the most common ways used during the neonatal period and also because this is the place in where the identifier will be located (See Figure 1). According to these parameters, the selected medications are: Adenosine, Adrenaline, Atropine and Terbutaline. Each of them has a different purpose but physically they have a similar effect in the patient. Table 3 summarizes the selected medications with their corresponding uses and their side effects.

Medication	Use	Side effects
Adenosine	Convert tachycardia in to a sinus rhythm	Arrhythmias Redness - Flushing Bradycardia Hypotension Apnea
Adrenaline - Epinephrine	Increase heart rate	Tachycardia Cardiac arrhythmia Sudden death Hypertension
Atropine	Sinus bradycardia	Arrhythmia Fever Flushing Tachycardia
Terbutaline	Increase heart rate bradycardia	Tachycardia Arrhythmias Flushing Hypertension

Table 3. Table of medicines, their uses and side effects.

It was also important to determine the proper dose for each of the selected prescriptions. In order to find this information, the following guidelines have to be taken into account:

- Concentration in Vaccine Bottle: it is the ratio between the amount of solute (mg) and the amount of solvent (mL). It has to be specified how many milligrams of the vaccine bottle need to be administrated to the neonate according to his/her weight.
- Necessary dilutions: Dilution is the process by which the concentration of a solution is reduced by adding a solvent. Vaccine bottles containing pure medication or initial concentrations are not used in newborns due to their cardiovascular, respiratory and immune systems would not tolerate them.

- Neonate’s weight: This parameter is relevant to know the dose to be administered by taking into account the weight in kilograms (Kg); along with this information, the proper dose to be given to the newborn can be determined. The proper dose has to be calculated accurately since in case of administering a wrong amount the newborn can suffer undesired side effects.

In Section 5.1.2 the appropriate dose is presented for each medicament according to the newborns’ weight.

## 5. Implementation of the system

All the information referenced in the previous section was considered when implementing the virtual and physical interactive simulator. Vital signs simulated in a virtual way allow the instructor to recreate different medical scenarios; medications allow trainee to choose the treatment that will be applied. The mannequin reflects the health condition of the neonate which indicates the student whether the right medicament and dose have been selected. Taking these mentioned elements into account and in order to design and implement the simulator, the main system blocks and the data flow are shown in Figure 12. Each of these system blocks will be explained in this chapter along with the implementations obtained in each of them.

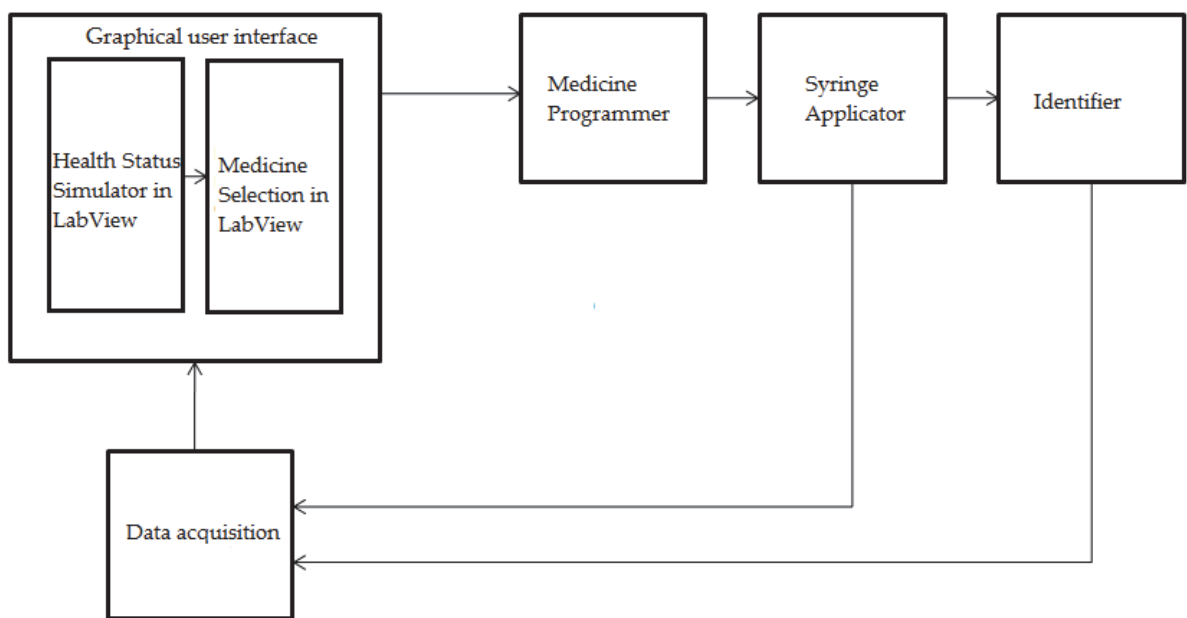


Fig. 12. System block diagram of the neonatal virtual and physical simulator

### 5.1 Implementing the graphic interface

Observing the vital signs on a screen is very important for both doctors and nurses during their training process because specific problems can be found through their traces, shapes, curves and their numeric values. Usually these specific problems cannot be found only by hearing the heart beats, checking the temperature or by chest auscultation. In the software application developed, different vital signs can be read and the patient can be treated according to the diagnosed pathology.

5.1.1 Simulating the health condition of a neonate in LabView ®

The models explained in the previous section are implemented and visualized in a graphic interface developed in LabView®. The result of this process can be seen in Figure 13. The interface allows the modification of the different parameters in order to obtain a wide diversity of medical scenarios; nevertheless, the feedback variables from the mannequin are: the cardiac frequency, the respiratory frequency, the rectal temperature and skin flushing. The interface is used, mainly, to train students of the healthcare area for acquiring diagnostic skills.

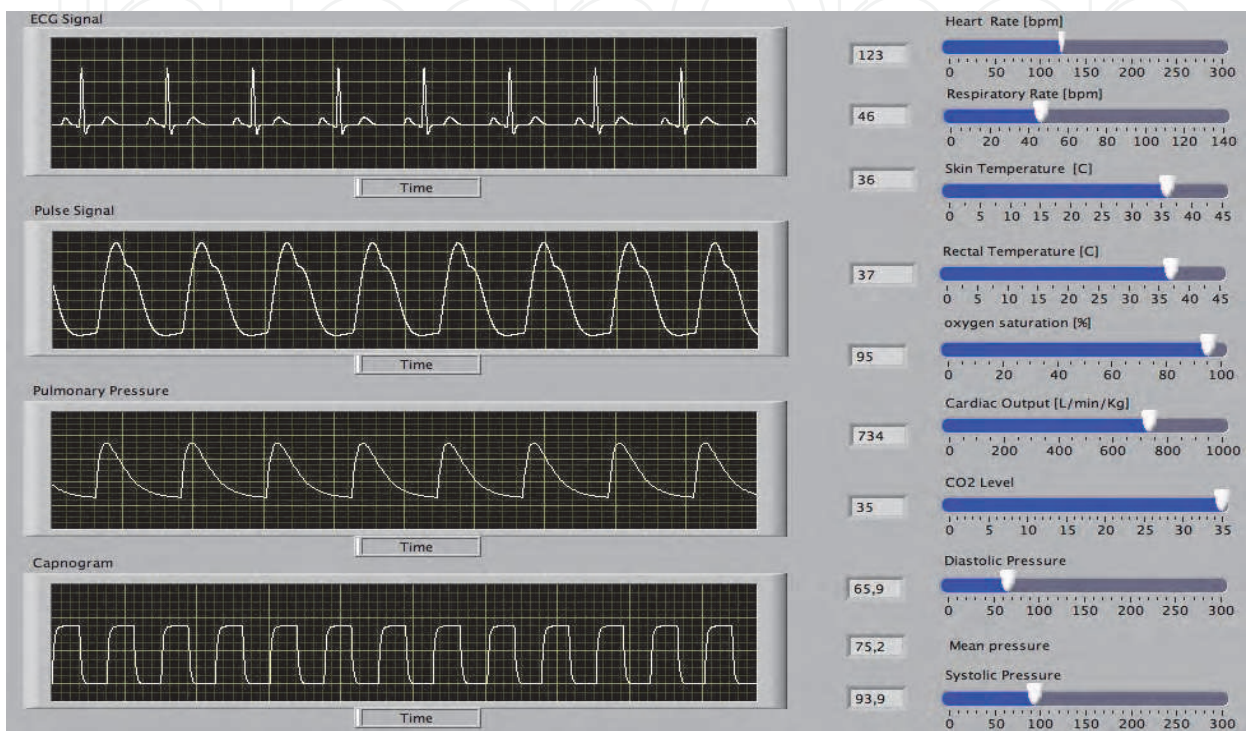


Fig. 13. Graphic interface developed in LabView ®

5.1.2 Selection of the medication in LabView ®

The correct dose is calculated for each medicament according to the drug main information. Table 4 shows the concentration of each vaccine bottle, the dilution and the dosage according to the neonate’s weight. These 4 medications are available in the graphic interface of the computer according to the pathological scenario that also includes the neonate’s weight that is also selected on screen. The interface of the medication programmer can be seen in Figure 14. (Young & Magnum, 2008)

	Concentration (mg/mL)	Drug Dilution	Dosage mL by weight			
			1 Kg	2 Kg	3 Kg	4Kg
Adenosine	3	1:9	0,17	0,33	0,5	0,67
Adrenaline	1	1:9	0,1	0,2	0,3	0,4
Atropine	1	1:9	0,2	0,4	0,6	0,8
Terbutaline	0,5 or 1	1:9	0,1 or 0,05	0,2 or 0,1	0,3 or 0,15	0,4 or 0,2

Table 4. Correct dosage according to the neonate’s weight

As shown in Table 4, the scenarios that can be generated by the instructor are created in the virtual interface where the neonate’s weight and medication are selected throughout a dropdown menu for each item; for weight selection purposes there are four options: 1Kg, 2Kg, 3Kg and 4Kg. The medications implemented are: Adenosine, Adrenaline, Atropine and Terbutaline. The selection of the dose is detailed below.

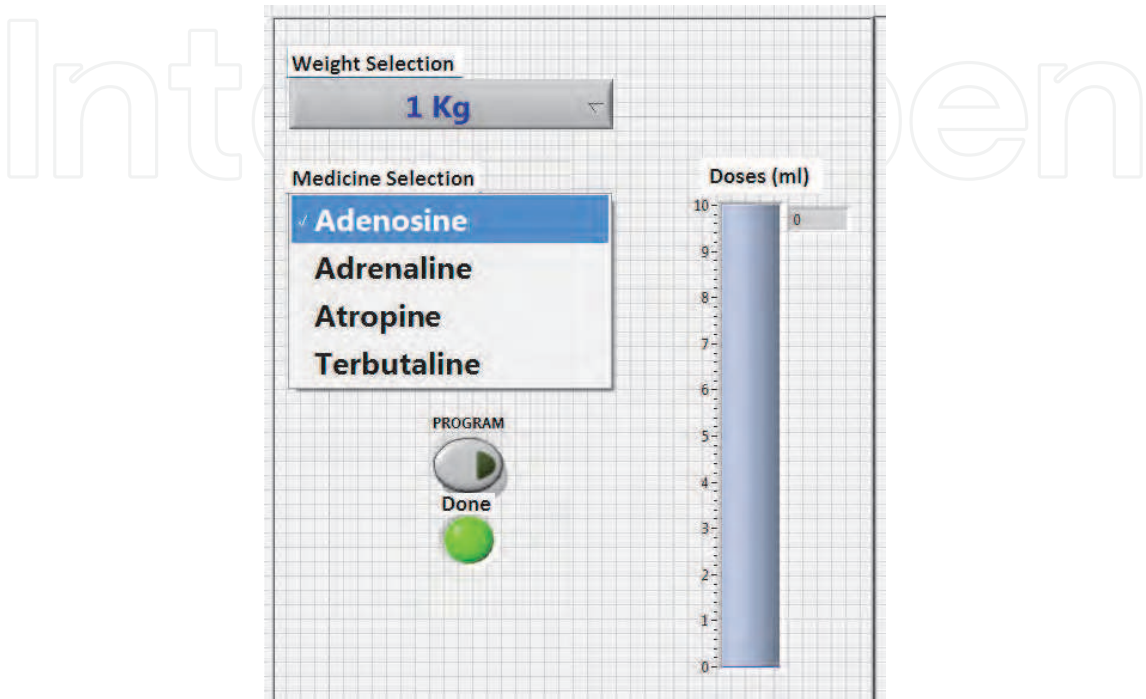


Fig. 14. Snapshot of the interface to select medication and neonate’s weight

**5.2 Implementation of the syringe applicator and selection of the dosage**

The dosage is selected by the trainee when he or she takes the syringe or applicator and makes the load up movement. To determine the dose, a Hall Effect sensor (UGN3503) is strategically located in the rubber plunger tip while a magnet is placed in the bottom of the syringe barrel in order to measure the magnetic flux density changes while the load up movement is simulated. The sensor is a transducer that varies its output voltage when detecting a change in the magnetic field. An ATmega8 microcontroller is in charge of converting the data from analogue to digital and then codification is made. Data are sent wirelessly to the data acquisition module in the computer by using the serial communication transmitter TLP434 connected to the ATmega8 microcontroller.

The wireless communication is unidirectional. The transmitter operates in a frequency of 433,92MHz which belongs to the Ultra High Frequency (UHF) band. The receiver RLP434 is connected to an ATmega8 microcontroller that is in charge of the signal decoding. The decoded byte is sent to the Data Acquisition card of LabView ® (ADQ Labview®) (See Figure 15).

Once the data are in the computer, the information is processed and the amount of medication is shown in the screen. Dose may fluctuate between 0 mL to 1 mL with a resolution of 0,02 mL. Once the medication and the neonate’s weight have been selected and the trainee has loaded up the medicament in the syringe, the information is programmed in the Tag that is attached to the syringe.



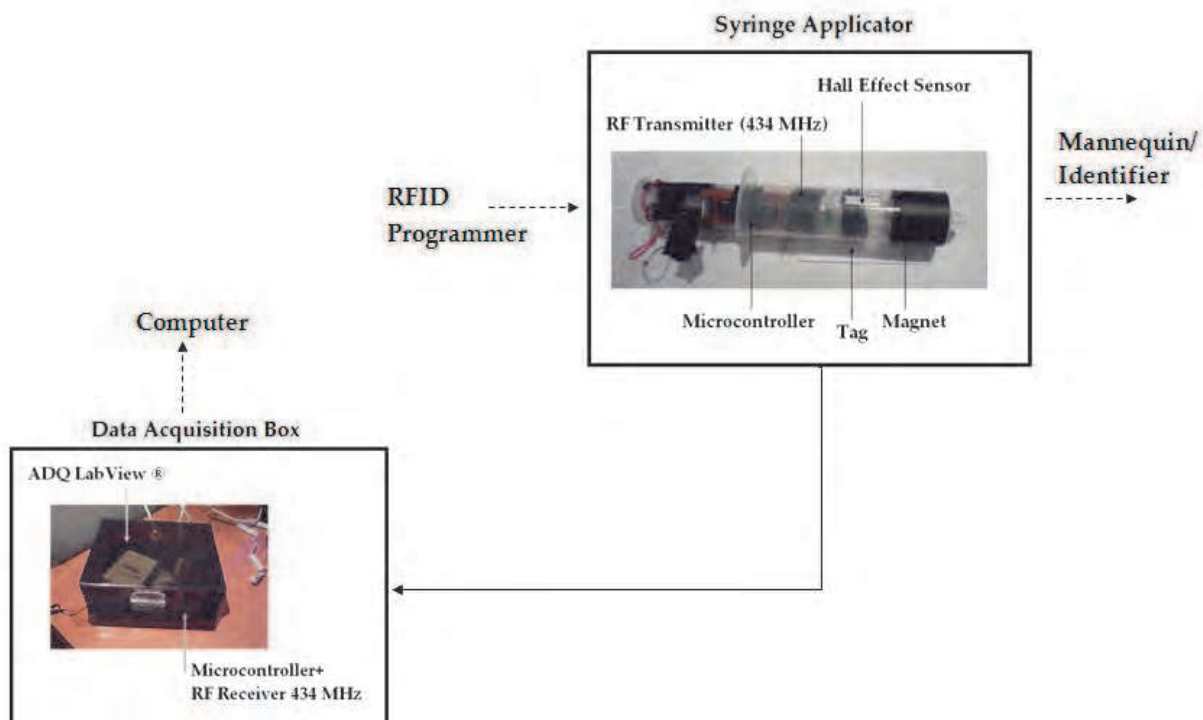


Fig. 15. Syringe applicator and wireless signals sending to the Data Acquisition Module

### 5.3 Implementation of the medicine programmer to write the RFID tag

Tag is programmed in order to store the information related to: the medicine chosen, the neonate's weight and dosage that will be applied to the mannequin with the intention of stabilizing its vital signs. Figure 14 shows the "Program" button that needs to be clicked to save the data in the Tag. To achieve this task, an RFID read/write device is used; this device allows writing (no contact) several types of RFID smart cards. The one used in this project belongs to the Mifare® family based upon the ISO 14443A standard.

The device has an RS232 interface which is used to establish the communication with the computer where medication, neonate's weight and dosage are selected. In order to have an adequate communication between the computer (by means of LabView®) and the writing device to program the Tag, a protocol that depends on the predetermined communication parameters of the ACG HF Mifare Easy Compact Plug and Play needs to be adjusted. Some of the device's features are: the transmission speed is 9600b/s, with 8 bits; it does not require a parity bit or handshake and it requires a stop bit. See Figure 16.

In order to access the Tag, it is necessary to send some control words by means of the reading/writing device (Three pass Authentication). The integrated circuit that is embedded in the electronic Tag has an EEPROM memory of 8192 Kbit; this circuit is organized into 16 sectors with 4 blocks of 16 Bytes each. An authentication procedure needs to be carried out for each sector to change the value of each block in the Tag. Three blocks in sector 2 are used in this particular project: block 8 stores the information about the medication, block 9 is used to store the information about dosage and block 10 stores the information about the neonate's weight. (See Table 5).

The Tag has a built-in PCB antenna that provides the typical reading range of 90 mm which implies that when the programming needs to be done, it has to be within the detection



range; therefore, it is necessary to place the syringe or applicator (with the Tag attached) near the programmer so data can be sent properly from the writing device. This process is carried out when the student loads up the medication into the syringe; in that moment the applicator or syringe needs to be near the vaccine bottle where the RFID programmer is located. Simultaneously, the instructor, who should be in front of the computer at that moment, has to click on the “Program” button on the screen and the information is transmitted and stored in the Tag.

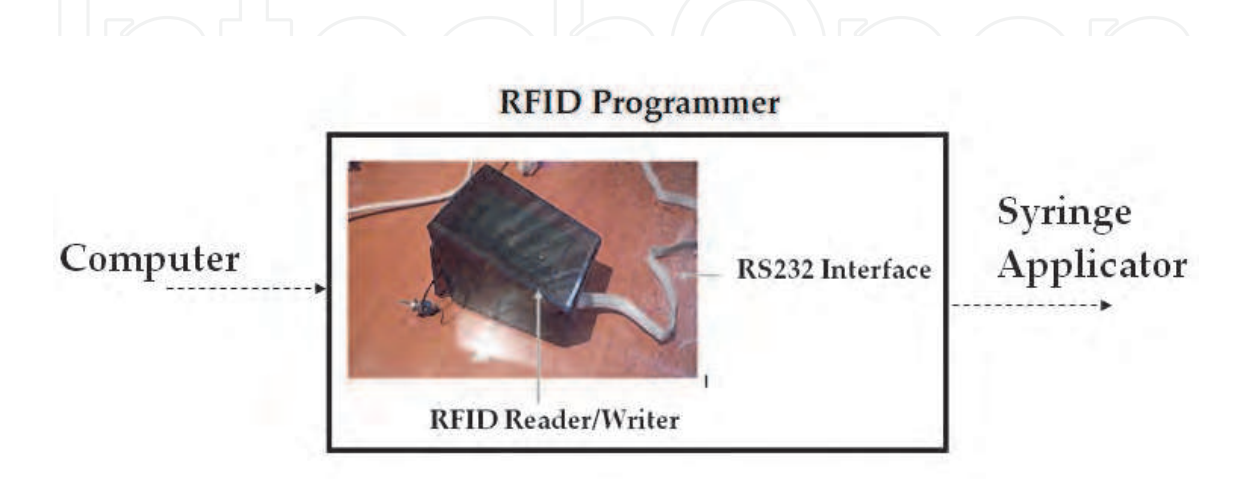


Fig. 16. Programmer of medications RFID

It is worth to mention that the memory capacity of the Tag allows the storage of a high number of medications, turning this module into a scalable project.

Tag Information				
Sector	Block	Data	Byte Value	Means
2	8	Medicine type	000000002	Adenosine
			000000003	Adrenaline
			000000004	Atropine
			000000005	Terbutaline
	9	Dosage	00000000<Byte<00110010	0 mL < dose < 1 mL
	A	Newborn's Weight	00000001	Weight=1Kg
			00000002	Weight=2Kg
			00000003	Weight=3Kg
			00000004	Weight=4Kg

Table 5. Tag information and memory uses

5.4 Implementation of the identifier (Mannequin)

As soon as the data have been stored in the Tag, the trainee has to approach to the identifier or mannequin simulating the injection of the medicine by umbilical vein catheterization, and meanwhile the Tag is read to determine whether the action carried out was the indicated one or not. In that moment, the decisions of the medicine or nursery

student are evaluated. Even though the graphic interface can also be used to judge the trainee's choice by using its virtual simulation models, the physical evaluation of the patient confronts the student with reality. It is necessary to install an RFID reader/writer device in the abdomen that allows reading the information in the Tag in order to make the neonate react according to the decoded data. A microcontroller is specially programmed to receive the information from the Tag right at the moment when the trainee is about to inject the mannequin.

Once the Tag's information has been read, it is necessary to process the data to determine the reaction that should take place in the neonate taking into consideration its current health status, medication and dosage programmed in the syringe. The physical simulator will have the capability of changing its condition based on the effects that should be produced as a result of the decision made by the trainee.

Visual and audible reactions can be seen and heard in the mannequin according to the uses and side effects of each medicine shown in Table 3. Medications mainly affect cardiac frequency and temperature, therefore, the mannequin has a circuit that emulates the heart sounds ( $S_1$  and  $S_2$ ) at different frequencies such as tachycardia (high frequency), bradycardia (low frequency) and cardiac arrest (too low frequency or absent heart beating) or simply normal status. In order to make this possible, a circuit was implemented by using the LM555 timer that allows generating oscillations. The variation of those oscillations allows the simulation of the sound produced by the heart when it beats.

The systole and diastole are the movements that a heart performs and each of them produces a different sound. The first one – systole – is the one with the highest pitch at 60 Hz and the second one – diastole – produces a 45 Hz sound. Those sounds are intercalated to generate different cardiac rhythms; there is a long silence between the second sound and the first one of the following beat cycle. This silence lasts at least 50 ms, which coincides with the ventricular diastole.

Rectal temperature of the neonate can also be viewed on an LCD screen located by its side; this temperature can vary between 35,5° and 38,3°. Lights on the mannequin surface are located to emulate skin flushing.

If the trainee makes an inadequate choice to treat the mannequin, its health condition will be negatively affected showing a pathology that is reported to the instructor on the computer.

### **5.5 Implementing the data acquisition unit to report the mannequin's health status on the screen**

Once the effects of the medication are seen on the mannequin, the information is sent to the computer so the mannequin's vital signs update automatically every time there is a change in its health condition (See Figure 17).

Signals are sent from the mannequin to indicate its reaction according to the treatment applied. Even though the communication is wireless, it is worthwhile mentioning that the identifier's transmitter works with a frequency of 418 MHz. This means that no interferences are generated in the communications between the syringe or applicator transmitter (434 MHz) and the mannequin transmitter (418 MHz).

Data strings of 8 bits (1 byte) are transmitted from the identifier; that byte contains information about the following variables: cardiac frequency, respiratory frequency, rectal temperature and skin flushing in the neonate. The cardiac frequency is equivalent to the frequency of the pulmonary pressure signal, the pulse signal and the electrocardiogram signal (ECG) which traces can be seen on the screen. In case the respiratory frequency

changes, the frequency of the CO<sub>2</sub> concentration level is affected. Rectal temperature remains 0,5°C above body temperature under normal conditions (room temperature needs to be between 20 and 24°C). Room humidity may also fluctuate between 30% and 60% and the ideal range is 50% to 55% (Bureau of Maternal and Child Health and Resources Development, 1993).

Width, shape and other features of each graph have to be analyzed thoroughly by medical personnel and nurses because trace's anomalies shown on the screen can be a sign of problems in the neonate's health.

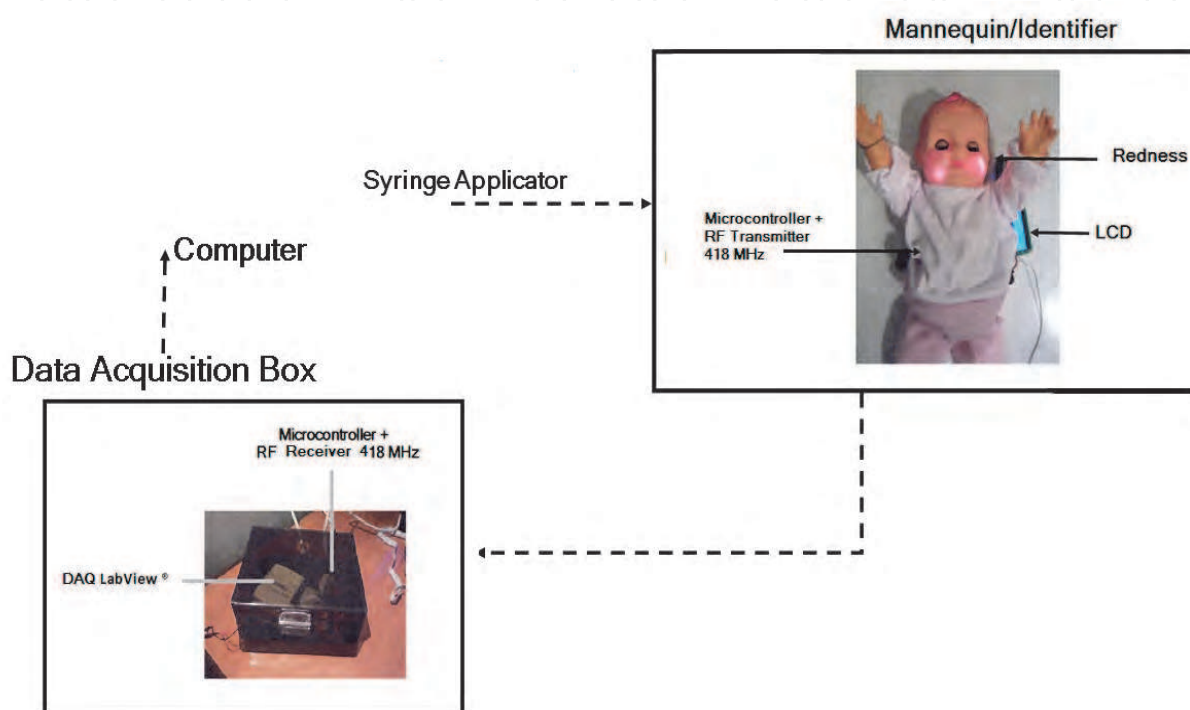


Fig. 17. Connection between the identifier and the Data acquisition Box

A noticeable message intended to catch the attention of the person who is monitoring the neonate's health condition appears on screen to report the neonate's health status.

## 6. Results

In order to present the most relevant results of this project of virtual and physical simulator, such results were classified into three aspects: medical scenarios, medical validation and cost analysis.

Four medical scenarios of special importance in the neonate's health condition are presented in Section 6.1; in addition, simulations of vital signs as well as some images of the mannequin are shown.

A review of the simulator was carried out by specialist in neonatology and the results are shown in Section 6.2. The results are presented as a percentage of experts that accept that the medical scenario modeled in the graphic interface is the correct representation of the real situation.

Finally, Section 6.3 shows a simplified and updated cost analysis of the virtual and physical interactive simulator.

### 6.1 Generating medical scenarios

The following are the four medical scenarios that can be generated in the system; different pathologies are created to try the functionality of the simulator. In addition, the way the mannequin reacts to the treatment is tested and the mannequin health status is monitored.

In order to select a medication, a student has to:

- Take the applicator
- Move the Tag near the RFID programmer
- Select the medication and neonate's weight on the screen
- Emulate the filling in of the syringe with the dosage according to the neonate's weight and pathology
- Click on the "programm" button on the screen.

In order to give the medication, the student has to:

- Move the applicator towards the mannequin's abdomen
- Wait for about 15 seconds until the mannequin reacts<sup>1</sup>
- Assess the mannequin's reaction
- Observe the different signal's graphs on the screen to evaluate the neonate's condition.

For each of the cases, a diagnostic is presented along with the suitable treatment to improve patient's health.

#### First scenario

**Diagnostic:** In the Figure 18 the neonate presents a normal status (Thompson & Crocetti, 1998). The cardiac frequency is 140 beats per minute, the respiratory frequency is 46 cycles per minute and the rectal temperature is 37,1 ° C which is slightly higher than the skin temperature.

**Treatment:** the neonate does not require any treatment.

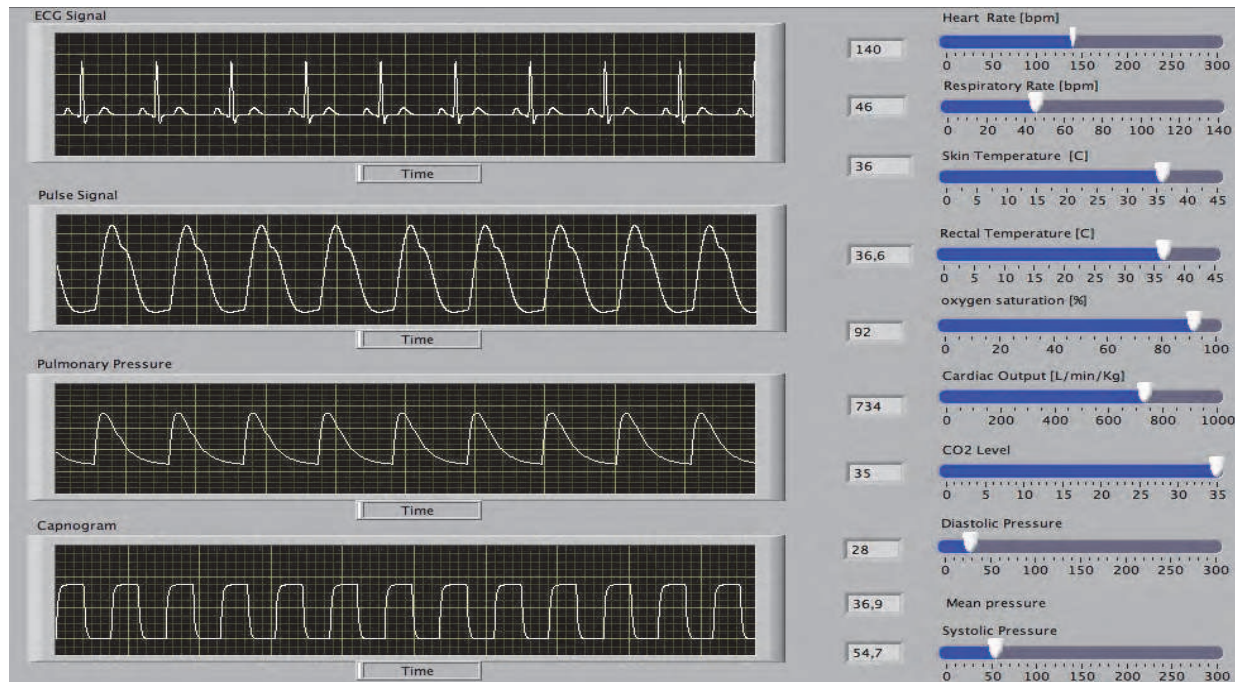


Fig. 18. Normal status

<sup>1</sup>In real life, times for choosing to re-administer the medicine might change due to the patient's reaction but for the model and data processing purposes, the student will only have to wait for 15 seconds.



*Second scenario*

**Diagnostic:** In the Figure 19 the neonate's weight is 3Kg and presents tachycardia, as shown in the cardiac frequency image that is at 220 pulses per minute. The respiratory frequency is 62 cycles per minute showing therefore tachypnea without fever as the rectal temperature is 36,8°C.

**Treatment:** The patient needs to be administered 0,5 mL of Adenosine. If after waiting for 15 seconds there is no reaction from the neonate, it is necessary to apply the medication again.

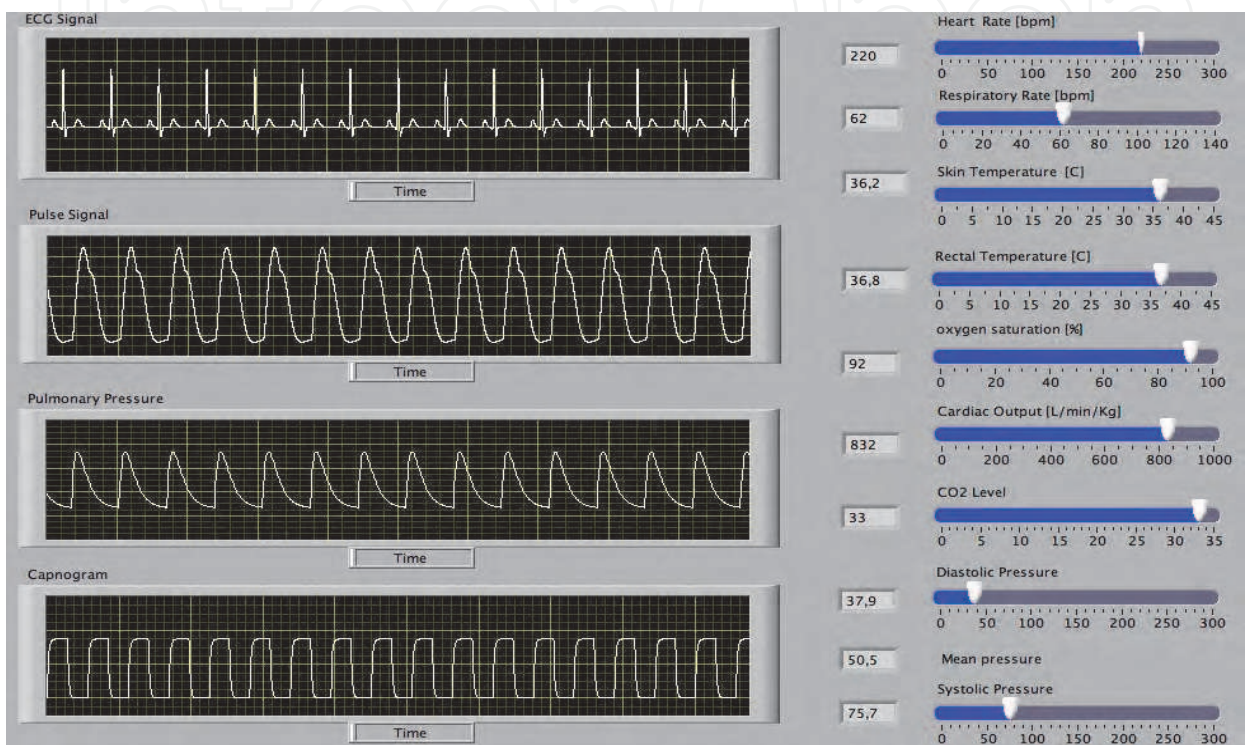


Fig. 19. Tachycardia and tachypnea

*Third scenario*

**Diagnostic:** In the Figure 20 the neonate's weight is 2 Kg. The neonate presents bradycardia as shown by the cardiac frequency of 70 bpm; the respiratory frequency is 20 cycles per minute which means there is also bradypnea and hypothermia (also shown).

**Treatment:** It is necessary to administer 0.4 mL of Atropine to reverse the severe bradycardia condition and wait for 15 seconds for the patient's response; in case the neonate does not show any reaction it is necessary to inject the medication again. The mannequin's skin may show some blush.

*Fourth scenario*

**Diagnostic:** In the Figure 21 the neonate's weight is 4 Kg and presents cardiovascular arrest (relative); the cardiac frequency is 24 pulses per minute and may continue decreasing (to a full cardiac arrest). The respiratory frequency is 12 cycles per minute meaning there is severe bradypnea as well as hypothermia.

**Treatment:** it can be administered either 0,4 mL of Terbutaline or 0,4 mL of Adrenaline, in both cases the cardiac frequency increases. If 15 seconds after there is no response from the neonate, it is necessary to inject the medication again.



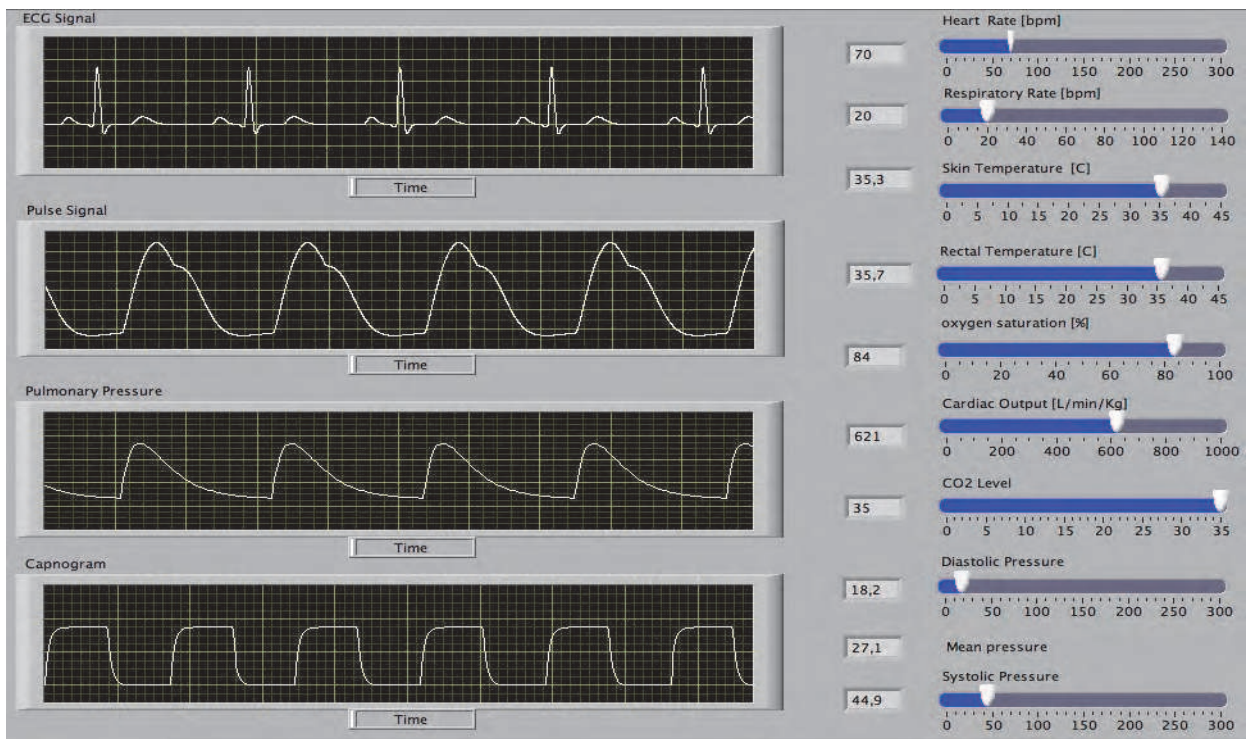


Fig. 20. Bradycardia, bradypnea and hypothermia

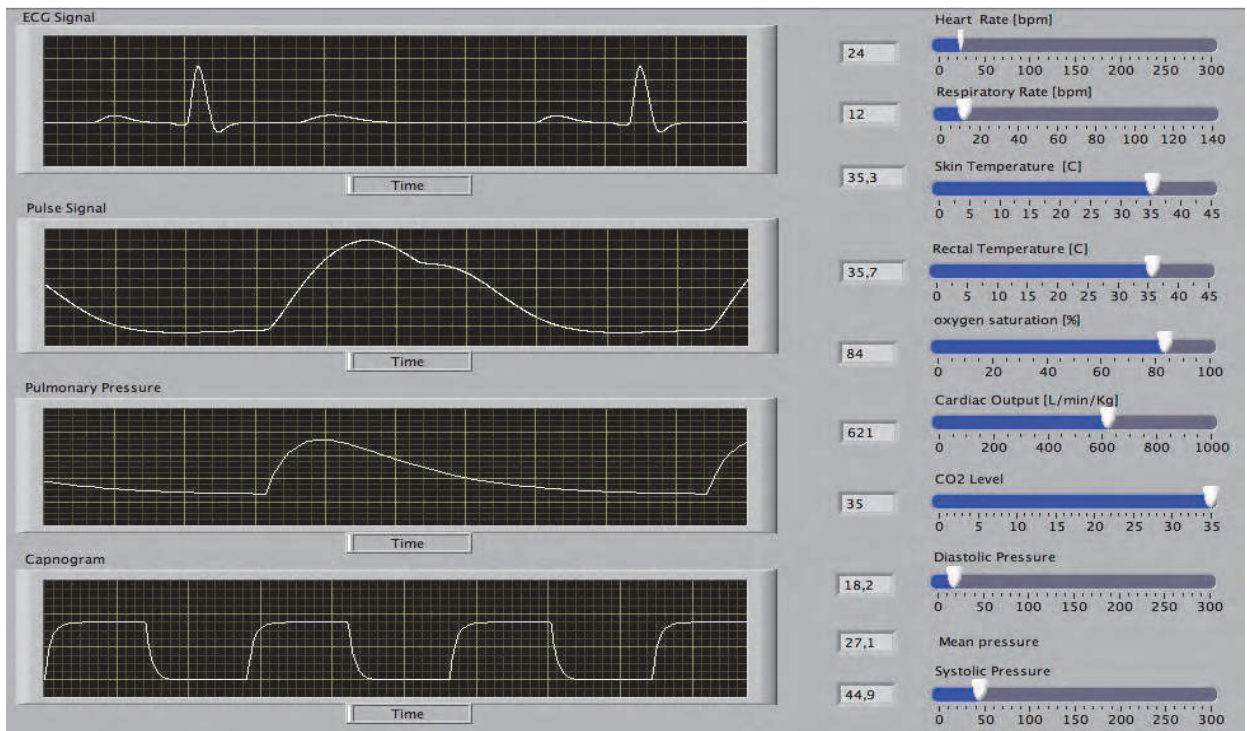


Fig. 21. Arrest (relative), bradypnea and hypothermia

6.2 Medical validation

After developing this project, a study was conducted in order to validate the usefulness of the interface in the training of personnel from fields such as Perinatology and Neonatology.

This user evaluation was a key step of this work as it allows confirmation of the veracity of the signals obtained in the interface.

A group of 16 experts in Perinatology and Neonatology was selected for this stage in order to evaluate the trustworthiness of the scenarios previously described. In this way, they evaluated the second and third scenarios described before where the neonate shows fever, tachycardia and tachypnea – second scenario – and the other where bradycardia, bradypnea and hypothermia are shown– third scenario. The constants were chosen based on expert medical advice from team members of this project.

The specialists were then presented the two scenarios in the simulator and a sheet where they wrote the set of pathologies they considered matched the represented constants.

The results (see Table 6) were highly satisfactory as the signals and, in general, the tool was considered excellent, realistic and user friendly by the consulted specialists in the healthcare area.

Fever, Tachycardia and Tachypnea		
Expected selection	100,00%	16
Unexpected selection	0,00%	0
Hypothermia, Bradycardia and Bradypnea		
Expected selection	97,00%	15
Unexpected selection	3,00%	1

Table 6. Evaluated Scenarios

7. Conclusions

The tool developed in this project consists of a neonatal monitor that shows ECG, pulse, pressure and CO2 level signals based on a physical system that simulates the use of medications with the implementation of an RFID module. This module allows wireless communication between the syringe and the dummy that cannot be found in commercial simulators.

Neonatal simulators, like the one presented in this work, are an educational tool for students of health sciences as they allow the acquisition of knowledge and skills, making faster decisions and more confidently, promoting realistic training in teams and acquiring practical clinical experience. The results of the validation of scenarios were satisfactory confirming that it is an educational tool as well as a practical and intuitive one.

The present developed tool has advantages over the commercial simulators in terms of budget needed for its implementation; the cost of the developed tool is around 7350 USD while the cost of the commercial ones, depending on their degree of complexity, range from 20000 USD to 58000 USD. This fact makes the project a viable and profitable option for training teams on neonatal care.

On the other hand, the development of a simulator that suits local training necessities provides the possibility of working in multidisciplinary research topics where knowledge from Medical Doctors, Engineers, and industrial designers, among others can be shared for successful results. In addition, it generates an environment that allows increasing the trust and experience needed in research in order to resolve multidisciplinary issues as the ones dealt with herein.

This work is the first phase of a larger project that includes a virtual simulator with the ability of generating synthetically all the signals that describe the patient's vital signs; and a physical simulator – mannequin – that exhibits the characteristics of a neonate allowing the simulation of signals that are also in the virtual simulator.

As future developments, we propose the implementation of bidirectional communication (monitor-mannequin) when transmitting all the variables that are visible in the simulator. Also, the implementation of new visible signs in the mannequin such as cyanosis, sounds, among others can be developed in the future. The simulated monitor could be enhanced with a tridimensional model of a neonate that would also allow the representation of vital signs.

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## **Deploying RFID - Challenges, Solutions, and Open Issues**

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Radio frequency identification (RFID) is a technology that is rapidly gaining popularity due to its several benefits in a wide area of applications like inventory tracking, supply chain management, automated manufacturing, healthcare, etc. The benefits of implementing RFID technologies can be seen in terms of efficiency (increased speed in production, reduced shrinkage, lower error rates, improved asset tracking etc.) or effectiveness (services that companies provide to the customers). Leading to considerable operational and strategic benefits, RFID technology continues to bring new levels of intelligence and information, strengthening the experience of all participants in this research domain, and serving as a valuable authentication technology. We hope this book will be useful for engineers, researchers and industry personnel, and provide them with some new ideas to address current and future issues they might be facing.

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