Sound Analysis System of Newborn Cry during Blood Draw with Cerebral Oximetry Monitoring

Flaviu Feier*, Ioan Silea*, Claudiu Angelescu, Ioan Stefan Sacala***, Mihnea Alexandru Moisescu*****

**University Politehnica Timisoara, Department of Automation and Applied Informatics, Timisoara, Romania, (Tel: +40 356 086 849; e-mail: flaviu.feier@aut.upt.ro; ioan.silea@aut.upt.ro)*
***Victor Babes" University of Medicine and Pharmacy Timisoara, Department of Neonatology Street Address, Timisoara, Romania, (e-mail: angelescu.claudiu@ymail.com)*
**** University Politehnica of Bucharest, Faculty of Automatic Control and Computers Science, Romania, (e-mail: sacalaioan@yahoo.com, mamihnea@gmail.com)*

Abstract: Newborns' cry is one of the few signals that can be obtained without invasive tests. Latest studies performed mostly in the last 25 years show that through feature extraction from the cry signal relevant information can be found in order to classify different pathologies such as asphyxia, hypothyroidism, hypoxia, autism or other disorders. The study of pain cries has even a longer history, due to the fact that it clearly states an inner suffering that the newborn is vocalizing in his language which must be decoded and given a medical meaning. In order to perform the studies on the newborn cry, besides the cry signal in some researches medical instruments have been also utilized in order to correlate between physiological parameters and some cry features. In this study, cerebral oxygenation was measured during routine blood draws from the scalp, arm or heel while also recording the pain cries. The goal of this study was to analyze the cry signal while performing these common tests in order to compare the fluctuations of the cerebral oxygenation with features from the cry signal. An e-Health platform is proposed in order to carry out the study across multiple hospitals, which have the required medical equipment used to gather information about the cerebral oxygenation of the newborn at blood draw.

Keywords: informatic system for cry acquisition, dominant frequency, cerebral oximetry, cry at blood draw, INVOS

1. 1. INTRODUCTION

Crying represents the first form of communication that the newborn provides after birth with his surroundings. This is the only way in which he manifests his inner state until learning the first words. Although nowadays pregnancies are closely monitored and facts about the newborns health are known even before their birth, there is the possibility of several affections that can be found only long time after birth when parents notice different health issues or their baby's inability to start expressing in basic words. Knowing about a medical condition is essential in order to cure it or at least stop certain illnesses progression.

Unfortunately most of the medical tests that can be done after birth are invasive and consist in multiple blood draws from the infant which are done only when there is a hint of a certain affection so that these tests can be targeted and treatment applied correspondingly. Therefore, the usage of an indicator such as features from the cry can be a non-invasive method to determine the likelihood of pathologies or physical state.

The idea of studying the newborn cry in order to determine the state of health is originating in the 1960s when the first cry spectrograms have been generated. With the latest technical developments that allow professional sound acquisition and in depth sound feature extraction and analysis, studies on this topic have evolved consistently and show visible progress (Orozco et al., a), b), 2003; Michelsson et al., 2007; García et al., 2009). The goal of studies performed on the newborn cry is to find a set of parameters that can be used as pointers to determine a relationship between them and certain medical conditions such as: hypothyroidism, hypoxia, hearing disorder, asphyxia, autism or others (Sahak et al., a) 2012)

Some of these pointers or indicators used in most of the studies are represented by the fundamental frequency (F0) (Mima et al., 2006; Balou, 2008) (Figure 2), the melody of the cry (the changing of the pitch, F0) (Várallyay et al., a), b), 2007), the first three formants (F1, F2, F3) (Ismaelli et al., 1994), noise or vocal tract resonance frequency (Orlandi et al., 2012) are most commonly used in analysis from the audio signal point of view. These are coupled in some of the studies with birth characteristics and/or physiological measurements.

Most of the recent studies focus on investigating elements from the cry signal consisting in vocalizations of 1 to 3 seconds. Signal processing techniques are applied to these elements in order to extract Mel frequency cepstral coefficients (MFCCs). The method of extracting these coefficients is presented in Fig. 1, with the operations that are undertaken in order to obtain these coefficients:

- **Windowing** operation over the cry signal (usually Hamming with an overlapping of 10%-50%);
- Fourier transformation applied over the windowed signal (**FT**);
- A **Filtering on Mel Scale** of the Fourier coefficients with the use of triangular band pass filter banks (most commonly 26 filters are used);
- A logarithmic function (**Log**) over the Mel scaled coefficients
- A Discrete Cosine Transform (**IFT**) applied over the logarithm of the resulting filtered frequency response from the previous phases (IFT).

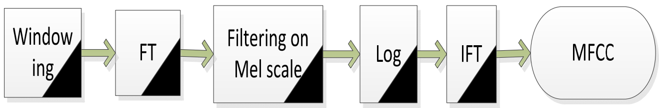

Fig. 1. Mel Frequency Cepstral Coefficients extraction.

These coefficients are then reduced by using methods that consider only the most significant ones, like the *Principle Component Analysis* method or *Orthogonal Least Square*. Based on the resulting coefficients, different methods, like *Support Vector Machines or Multilayer Perceptron Networks*, among others are proposed, in order to do a classification between healthy newborns and ones diagnosed with different sufferings. (Sahak et al., a), b), 2010, c), d) 2012).

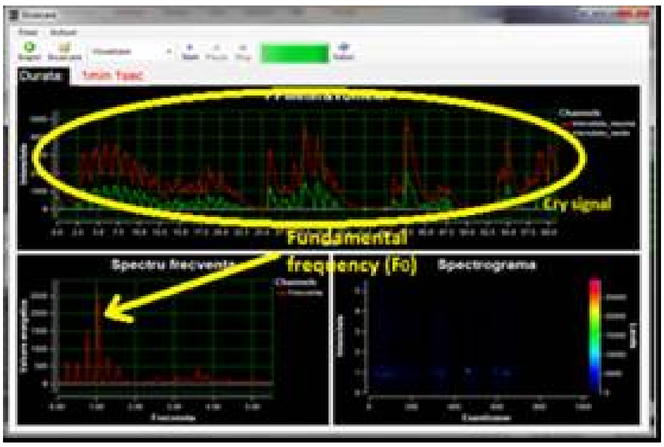

Fig. 2. Capture from the Neonat application.

The current work focuses on determining patterns in the newborn cry that can be linked to physiological measurements such as the cerebral oxygenation. Such correlations have been studied and are still of interest to different interdisciplinary groups where medical personnel works together with sound technicians or engineers to determine the impact brought to the cry signal by heart rate fluctuations, peripheral or cerebral blood oxygenation among others (Bocchi et al., 2008).

Most of the studies rely on results that define a normal cry as having the below characteristics (Várallyay et al., a), b), 2007, Ruíz et al., 2012):

- F0 from the cry varies from 400 to 600Hz;
- The melody form that prevails in rising-falling;
- There are more sound cries.

The cry with a pathological tendency is defined as having (Várallyay et al., a) , b), 2007):

- Cries with extreme values in the F0;
- The melody forms that prevail are falling, falling-rising, flat and without melody form;
- Glides and shifts happen the most.

Developments have been obtained in previous researches of the authors (Robu et al., 2011; Feier et al., 2014) by using a special developed software tool to visualize in real time the cry waveform and its spectrogram, called Neonat. First studies were conducted in order to determine the protocols for performing the later on experiments, which consisted in Data Mining analysis of several new born groups with similar affections with the intent of making a classifications between healthy newborns' and each of these groups. The results of this study showed a very good classification capability of the tool Weka (WEKA, 2015; Feier et al., 2014), when searching differences between the witness group (healthy newborns) and the group of premature born, the one with newborns' with respiratory problems due to umbilical cord strangulation at birth and a third group of newborns with Apgar score below 7 which were born on time but diagnosed with severe illnesses like neurological suffering. Decision trees (Daelemans et al., 1997; Murthy et al., 1998; Quinlan et al., 2006) and classification rules (Qiang Li et al., 2006) showed the best behaviour in order to achieve the presented results.

The current study focuses on the utilization of several equipment for the cry signal acquisition, real time visualization and post processing together with the measuring of the cerebral blood oxygenation during lab draws. A professional acquisition tool, the Olympus LS-100 PCM Multi Track Recorder was brought into the study order to do precise post processing of the cry signal. In order to determine the cerebral blood oxygenation the oximeter INVOS 5100C has been used.

2. e-HEALTH SYSTEM DEVELOPMENT

Given the fact that the activities concerning the collecting of real medical data from patients (cry signal acquisition, physiological parameters measurements, data from medical sheets) are often difficult to realize and a lot of time needs to be spent in order to gather a numerous group of subjects an e-Health system can very useful. Having such a system, and skilled teams spread in multiple hospital facilities, a bigger amount of data can be collected and shared so that considerable amounts of data can become available in a much shorter time frame, for the different undergoing studies.

In order to ensure the efficient development, deployment, integration and interoperability an e-Health Enterprise Architecture (EAeH) has been proposed. The EAeH aims at providing a framework for system, clinical process, support processes and IT infrastructure development and integration. In this context new capacities, can be identified in order to increase system performance. An Architecture can be interpreted, in accordance with ISO standard ISO/IEC/ IEEE 42010:2011, as (Costetchi et al., 2013):

> „fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution".

An Architecture Framework represents , in accordance with ISO standard ISO/IEC/ IEEE 42010:2011 (Costetchi et al., 2013):

> „conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders".

The following principles have been considered for the structuring of EAeH:

- Data Acquisition Systems are related to Data Architecture and include: Data Modelling, Data Analytics, Decision Support Systems and Knowledge Management. These are essential components for coherent clinical data and Quality of Service;
- Process Management Systems based on process modelling techniques and best practices;
- Medical Services represented as complex synchronized services. Important components that need to be addressed are related to communication, security, information processing, and interoperability.

EAeH is intended to offer an architecture framework to develop and manage e-health systems. An important focus of the architecture is represented by data acquisition, information processing and knowledge management in regard to all entities involved in the health care system.

Benefits of using the EAeH can be identified as follows, in terms of:

- Efficiency;
- Productivity;
- Safety;
- Security.

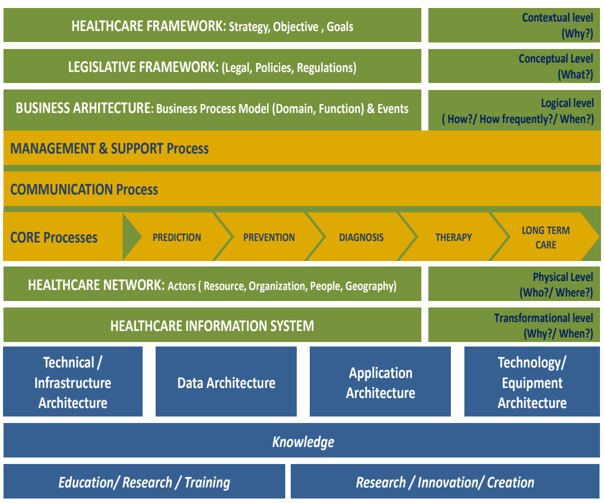

Fig. 3. Enterprise Architecture for e-Health system.

EAeH e-Health Architecture Framework dimensions address:

- The Strategy dimension including Organizational Mission, Objectives and Goals;
- The legal dimension refers to governing bodies' principles best practices and policies that apply to the healthcare system. E-health systems need to be designed by taking into consideration these aspects as system constrains;
- Organizational process management including the following components: business domains, capabilities, organizational networks, Core and Support Process Models, Process Monitoring. Core processes for a medical organization include: prevention, diagnosis, short and long term therapy. These processes usually follow strict medical protocols. Support processes include: accounting, human resources management, acquisitions strictly related to supply chain management, marketing and sales;
- Organizational networks are networks of entities: organizations or people. Networks may be organized based on Extended Enterprises, Virtual Organization or Collaborative Networks principles;
- Healthcare Information System refer to systems managed by an entity, composed of people and computer infrastructure, that process data and deliver information relevant to the healthcare system. These systems may be developed with the aid of EAeH or may be represented by legacy systems. Interoperability levels of such systems may be considered in terms of technical, syntactic and semantic interoperability and can be included in one of the following categories: isolated, connected, functional, domain and enterprise as described in "Levels of Information Systems Interoperability (LISI)";
- Technical Architecture encompasses technological solutions used for the development of such systems. These refer to both Information and Communication Technologies and Medical Technologies;
- Infrastructure Architecture refers to: Platform as a Service components, Communication networks, Data centers, Software support applications, Security Infrastructure.
- Data Architecture has the following components: Data Model and Semantic Model.
  Data Models must include acquisition of both unstructured and structured data associated with heterogeneous terminology. Data is processed in relation to predefined Taxonomies and Ontologies. Data acquisition can be performed indirectly by medical staff and directly with the aid of sensors, grouped in Sensor Networks. Network topology is an important factor in ensuring Data Acquisition efficiency.
- Application Architecture includes: Legacy Software, user interfaces and interfaces to other applications.
- Technology / Equipment Architecture refers to medical equipment that is connected to the e-health care system.

The architecture component is related to the Cyber Physical Systems paradigm. This refers to the integration of both cyber and physical components of an organizational environment and relates to emerging technologies such as:

- Wireless Sensor Networks including network topologies, routing protocols, low-powered devices. WSN will enable sensor self-organization;
- Internet of Things as an evolution of internet, enabling devices interconnection through the internet;
- Semantic Web as a component of the Web addressing semantic annotation, data and business objects and semantic query languages.

Knowledge management is an essential dimension of the proposed framework. Knowledge management refers to information analysis and summarization in order to synthesis knowledge and support decision making.

Educational/Research/Training and Research / Innovation/ Creation are the basis for the long term sustainability of the healthcare system and must be addressed in the development of new such systems.

In association with the EAeH, the authors propose the following elements related with methodology for system development (Fig. 4):

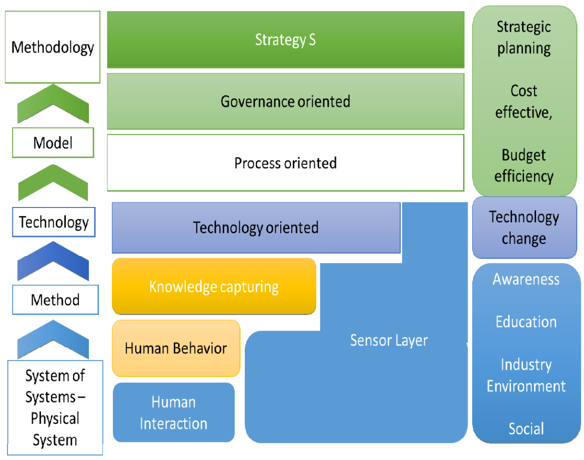

Fig. 4. Methodology for system development.

1. Analysis of the system components including: social, educational, health specific, environment and awareness;
2. Identifying Legislative constrains of the Health System;
3. Identifying and modelling processes, both clinical and support, specific to the proposed case
4. Selecting stakeholders including the main actors and organizations.

3. MATERIAL AND METHODS

In order to perform the on-site collection of patient data both medical and sound acquisition/processing tools have been utilized.

As mentioned in the begining, in order to obtain values of the cerebral blood oxygenation the INVOS oximeter was used. This medical equipment helps to determine in a non-invasive way the ischemic risk (the local deficit of blood) at the brain level or vital organs by measuring the hemoglobin level right under its sensors on the monitored area of the scalp (in this study). The measured parameter is represented by the regional hemoglobin oxygen saturation (rSO_2) which is the value at tissue level of the oxygen from the hemoglobin which is left after tissue irrigation (Covidien, 2015). The device also allows for the peripheral blood saturation to be measured with the usage of its somatic sensors, but this was not a goal for the present study.

The device is one of the four cerebral oximeters approved by the FDA (U.S Food and Drug Administration – the central U.S control organization). The device also provides somatic oximetry but this has not been used in this study and therefore not detailed.

Cerebral oximetry has a quite recent history, and the clinical usage has begun only in the last two decades. The measurement are based on the ability of light to penetrate the scalp and determine de hemoglobin oxygenation based on the quantity of light absorbed by the hemoglobin, process called Near Infrared Spectroscopy (NIRS). The information about the rSO_2 parameter is localized, in real time and continuous. Therefore it allows the possibility to correlate its values with features from the cry signal which are as well in real time and continuous. In order to collect the rSO_2 values the device has an extension cord where the sensors are present and which have been placed on the newborns forehead by the medical staff. This extension contains a light emitter in near infrared, and the two sensors which receive the light reflected after passing through the cranium and cerebral tissue (Fig. 5).

The formula for calculating the cerebral oxygenation, used by the cerebral oximetry tools can be expressed as following (Heather et al., 2011):

$$\text{Cerebral oxygenation } [\%] = HbO_2 / (Hb + Hb\,O_2)$$

where:

- Hb is represented by the deoxygenated hemoglobin level
- $Hb\,O_2$ corresponds to the oxygenated hemoglobin level

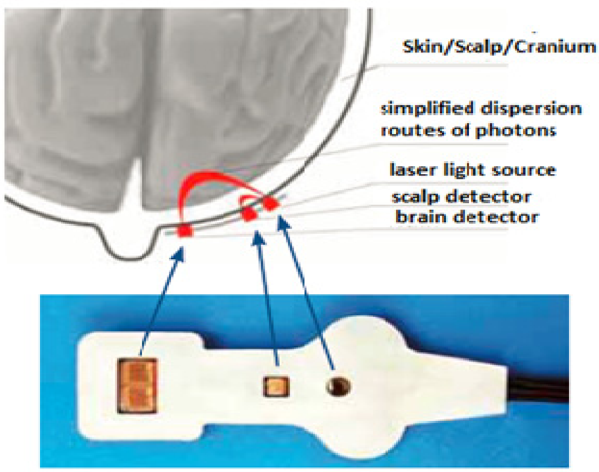

Fig. 5. INVOS sensors and placement on scalp.

The decrease of the rSO_2 parameter indicates a high ischemic risk due to the insufficient perfusion of the brain while the high increase over a baseline (set for each patient) can lead to a flooding of the tissue which can cause the deterioration of certain nervous termination.

Beside the arguments offered so far for the usage of the rSO_2 parameter in the study, there is another important aspect for its usage. This parameter has a very week dependency with other physiological parameters. This aspect has a very big importance in clinical studies where each individual has its own particularities and it is very hard to find a considerable number of subjects which fit a certain number of characteristics. More precisely, the rSO_2 value is considered as being independent of:

- Gender;
- Weight;
- Height;
- Cephalic cavity dimensions.

The INVOS device comes with a dedicated software for exporting and presenting the results consisting of the rSO_2 acquired values and of the events (lab draw, patient baseline setting) that were marked during the whole procedure and given timestamp values.

The main goal of the study that was performed was to follow the modification of the blood saturation at cerebral level when medical personnel performs blood draws from the newborns and correlating this information with features extracted from the pain cry as result of the invasive intervention. The cry signal was visualized in real time with the Neonat application and acquired for post processing with the Olympus LS-100 recording device. The usage of the Neonat application was required in order to visualize in real time, characteristics of the cry signal as:

- The signal amplitude measured with the 2 emulated devices (Volume Unit Meter and Peak Program Meter);
- The spectrum for a frame of the signal;
- The spectrum of the entire cry signal in a waterfall representation.

The study of the evolution of cerebral oxygenation during blood draw was performed exclusively on newborns' which required blood tests for medical reasons with the clear indication coming from their doctors. Invasive procedures are avoided as much as possible when dealing with neonates due to the harm that can be inflicted when over stressing the newborn. One of the goals of the study has been to point out the potential harm that excessive blood draws have on the newborn when considering the ischemic risk highlighted by the cerebral oxygenation parameter (rSO_2) when severally decreased.

This study will also present an example of a severe decrease of saturation at a newborn during the blood draw, which can cause permanent lesions. The blood draw from each of the newborns has also been performed by specialized nurses from the clinic.

In current medical practice there is only one invasive test that must be performed on each newborn if there is no indication of other illnesses. This test, called the Guthrie test, consists of heel pinching with a needle in order to gather four blood drops. Heel pinching or pricking is considered the most painless practice when dealing with newborns. Other tests require the blood draws to be made from the scalp or arm, which are painful for the newborn, and unfortunately more and more of these are done, due to the performant technologies that allow blood analysis and the constant fear of illnesses that in many cases are unprompted.

4. DATA ACQUISTION

The INVOS device has its main role in the study by providing modification of the rSO_2 parameter values. The collecting of these values is being done at each 5 seconds. The total duration of the monitoring for each of the investigated newborns is in the interval of 2 to 3 minutes. In this timeframe vocalization is recorded with the Olympus device and visualized real time with the Neonat application.

In Fig. 6 an example of a newborn considered in the study is presented. The newborns' cerebral saturation is measured via the sensors strapped to its forehead that collect the rSO2 values and show them on the INVOS screen. During the blood draw, the audio signal amplitude and frequency spectrum are showed on the Neonat application, that does this collecting with the help of a microphone next to the newborn. Finally, a professional audio recording is done with the help of the Olympus tool, which is placed next to the microphone of the Neonat application. The newborns' face has been blurred in order to keep the confidential nature of the study, in terms of newborns' names and images.

Fig. 6. Experiment with INVOS, Neonat and Olympus PCM at newborn blood draw.

Given the usage of multiple devices, the synchronization of all these equipment is imperative in order to be able to make connections between the saturation values and the cry emissions. To reach this goal, a work protocol was developed after performing a couple of test cases.

This protocol consists of several steps that have been followed for each of the newborns present in the study, and are detailed as follows:

Step 1: Synchronization of the Olympus device and the Neonat application.

This is achieved by starting the Neonat application in the same time with the setting of the baseline value of the rSO_2 parameter for patient.

1. Setting the timestamp for these actions (date, hour, minute, second)

Step 2: Marking of the blood draw (lab draw)

1. Setting the lab draw event on the INVOS devices display
2. Short acoustic signal to have a marker in the sound at both the acquisition tool and the visualization tool
3. Setting a time stamp for this action
4. Marking of the lab draw type (heel pinch, scalp draw or arm draw)

Step 3: Stop synchronization

Simultaneous stop of the INVOS acquisition, Olympus recorder and the Neonat application.

5. RESULTS

The total number of subjects present in this study was 35, but due to different problems that were encountered, only 21 could be considered relevant. The nature of the problems consisted in:

- Faulty equipment handling that led to an out of sync between all the utilized equipment;
- Missing of the cry signal (no cries were noticed at newborns that had been undergoing numerous medical test and had developed a low sensitivity level to needle stings;
- Noises over the cry signal from equipment or medical personal as this study was carried out mostly in the intensive care unit.
- Very small variations of the saturation parameter (+/1 %)

In Fig. 7 the modification of saturation is shown for 21 of the investigated newborns'. For most of the newborns' the saturation value after the blood draw decreases with an average of 15% (red columns) with respect to each individual's baseline saturation value. Each newborns' baseline saturation has been set in normal conditions, without any distress that could inflict a cry. A normal baseline, for a healthy newborn is considered to be around the value of 90%, which can decrease to 70% for a short time period. If the baseline value is already at a low level (around 70%-80%) and it decreases at a value of 45% and remains at that value for more than 20-30 seconds, it is considered to be in the situation of a high risk of cerebral injury of the newborn.

There are some situations which were encountered, when the saturation increased after the blood draw. At this moment a definite explanation for this situation cannot be provided, as it is still under investigation by the authors. There is the possibility of acquisition errors or possibly another phenomenon which will be presented in future works.

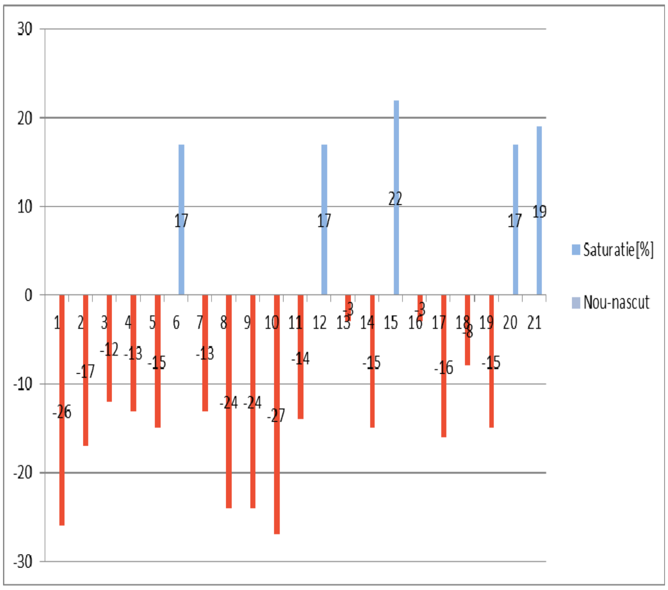

Fig. **7.** Maximum increase/decrease of the rSO_2 for each newborn considered relevant for the study.

In Fig. 8 is an example from the INVOS software, showing the variation of a newborns' cerebral oxygenation. This example shows a very big decrease in saturation which can be very dangerous for the newborns' state. Such a heavily decrease can cause brain leisure and is a very unfortunate situation when no monitoring is performed.

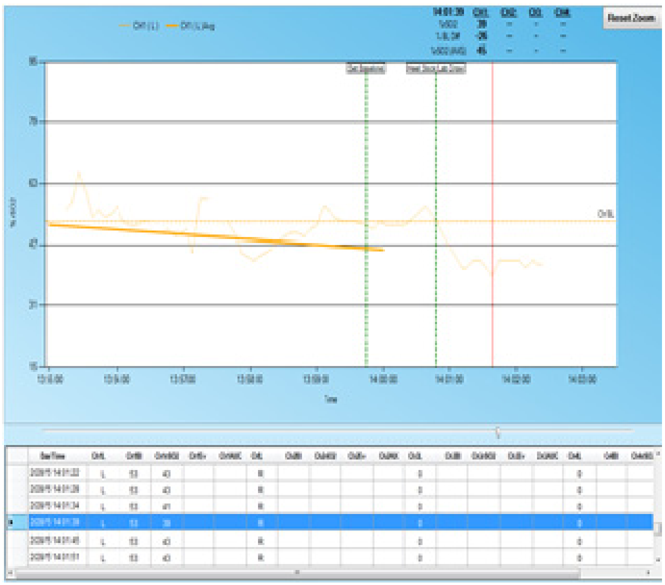

Fig. **8.** Capture from the INVOS recording for a newborn.

Since cerebral oxygenation monitoring is not usually performed given the costs that it implies, and without an indication of its necessity, cry analysis can be a very viable alternative. Fig. 9 shows a spectrum of the cry during the blood draw and in parallel with the oximeter measurements. The arrow points out the first cry after the invasive intervention which is also the trigger for the falling of the saturation parameter rSO_2.

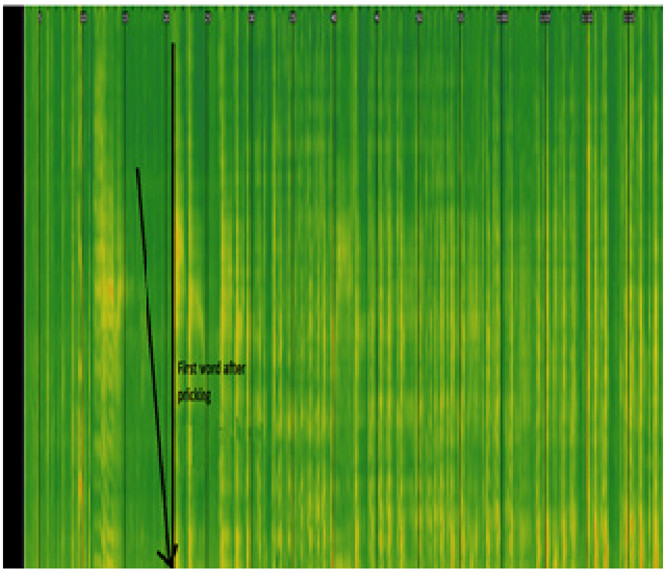

Fig. 9. Cry signal spectrum for the newborn example Fig. 8).

In Fig. 10 is highlighted the value of the dominant frequency in this first vocalization of the pain cry. The value of this is around the value of 920 Hz, which is double the amount of a normal cry fundamental frequency (Várallyay et al, a), b), 2007). The possibility of identifying the cry segment corresponding to the lowest saturation is favored by the synchronization performed between all equipment involved in the study, detailed in the protocol for the study.

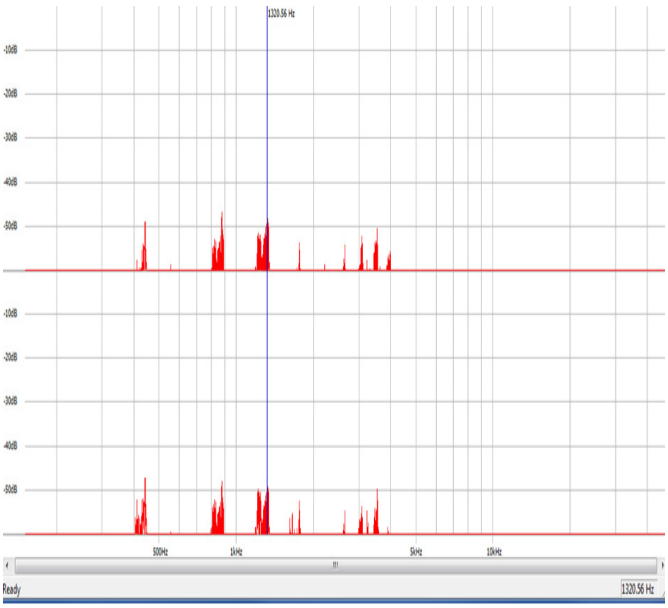

Fig. 10. Frequency spectrum of the first word from the spectrum in Fig. 9.

The choice of this example is due to ulterior developments of the case. Such a big drop in the saturation, below the value of 40% and the high dominant frequency lead to further investigations that discovered a neurological suffering of this newborn. Although this was not the goal of the study, the result was very encouraging for the overall purpose of the newborn cry signal study in order to determine patterns for different pathologies.

The present example was the most significant from the ulterior diagnosis point of view. In Fig. 7 were shown all the cases with most of them having considerable decrease of saturation after the blood draw. Although for the rest of the cases such a situation like the one presented before was not encountered, in the sense of diagnosing a neurological suffering after noticing high decrease in cerebral oxygenation.

Most of the newborns present in the study showed similarities regarding the high decrease in the rSO_2 value and the dominant frequencies above 1kHz for the cry segment that corresponded to the lowest value of the saturation. The correlation between the value of the cerebral oxygenation and the dominant frequency of the cry segment at a particular moment was possible by applying the presented protocol accordingly. The time interval corresponding to the lowest values of the rSO_2 parameter could be linked with the help of the acoustic sound generated in the 2^{nd} step of the protocol.

The high value for the dominant frequency (over 1kHz) even for a pain cry with no energy components on lover frequencies (400Hz-600Hz) has been concluded to be consistent with the saturation decrease. This aspect highlights the importance of avoiding as much as possible invasive tests consisting in blood draws from the newborn as the ischemic risk is increased each time such a test is performed. Of course, in some cases the blood draw is necessary to be done, but the result of this research emphasizes on the need to carefully take decisions regarding invasive testing of the newborns and need to find other indicators like features from the cry signal in oder to correlate them with certain illnesses.

6. CONCLUSIONS

The current study has focused on analyzing the cry signal from newborns' while performing blood draws and also measuring the cerebral oxygenation with the specialized INVOS medical equipment. The goal of the research was to see how usual blood draw procedures carried out in every hospital unit are affecting the newborns' cerebral blood saturation level, a good indicator for a ischemic risk.

This study was carried out on 35 newborns' with the result for 21 of them being taken into consideration. The newborns that were not considered in the study were left out:

- due to faulty protocol application;
- errors that were noticed during the data acquisition;
- no modifications of the cerebral saturation;
- no cry signal.

The results of this study show a correlation between the lowest level of the cerebral saturation and a high pitched word (above 1kHz) at that particular moment. Although it was not the goal of this study, a newborn was diagnosed with neurological suffering as a result of extreme values of the rSO_2 parameter (below 40%) and a very high dominant frequency corresponding to the cry word. This observation opens other research directions, namely into the study of the neurological suffering based on cry segments extracted from the audio signal, in non-distress situations.

A protocol for performing this study was developed in order to assure correct data acquisition given the multiple devices that were used. The other aim of this protocol was to assure a clear understanding of how the experiment must be done, when doing the same procedures at a different location where the INVOS medical equipment is also available.

The architecture for a e-Health platform was also proposed in order to gather and post process the data collected from multiple hospital facilities that can participate in this study, in order to achieve more experimental data in a shorter time frame. The only constraint for the participating units is given by the existence of a local cerebral oximetry equipment, given that this tool is quite expensive. The Neonat application can be easily provided and a professional recording tool does not rise any financial challenges.

ACKNOLEDGEMENTS

This work was partially supported by the strategic grant POSDRU/159/1.5/S/137070 (2014) of the Ministry of National Education Protection, Romania, co-financed by the European Social Fund – Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132397.

REFERENCES

Balou G., *Handbook for Sound Engineers (2008), Fourth Edition,* Elsevier Inc , p.999-1005

Bocchi L., Spaccaterra L., Acciai F., Orlandi S., Favilli F., Atrei E., Manfredi C., Donzelli G.P. (2008), Non invasive distress monitoring in children hospital intensive care unit, *Advances in Medical, Signal and Information Processing*, MEDSIP 4th IET International Conference

Costetchi, N., Stanescu A.M., Moisescu M, and Sacala I.S. (2013) "A Holistic Vision of Medical Services and Information Support System Based on E-Healthcare Framework." in *Applied Mechanics and Materials*, vol. 436, pp. 497-504

Covidien Inc., "Official brochure – Oxymetry with INVOS in Neonatology" [Online]. Available: http://www.covidien.com/rms/products/cerebral-somatic-oximetry/invos-5100c-cerebral-somatic-oximeter

Daelemans W, Antal van den Bosch, Weijters T. (1997), IGTree: Using Trees for Compression and Classication in Lazy Learning Algorithms, *Artificial Intelligence Review 11*, 407-423, 1997

Feier, F., Enatescu, I., Ilie, C., & Silea, I. (2014), Newborns' cry analysis classification using signal processing and data mining. In *Optimization of Electrical and Electronic Equipment (OPTIM), 2014 International Conference on*(pp. 880-885). IEEE.

García C.A. , Cano S.D. (2009), "Fundamentos Teóricos y Prácticos del Análisis de Llanto Infantil"

Ismaelli A., Rapisardi G., Donzelli G.P., Moroni M., Bruscaglioni P. (1994), A new device for computerized infant cy analysis in the NICU, *Engineering in Medicine and Biology Society*, Engineering Advances: New Opportunities for Biomedical Engineers. Proceedings of the 16th Annual International Conference of the IEEE

Heather E. Elser, MSN, RN, NNP-BC, CNS, PhD Student, Diane Holditch-Davis, PhD, RN, FAAN, and Debra H. Brandon, PhD, RN, CCNS, FAAN (2011), Cerebral Oxygenation Monitoring A Strategy to Detect Intraventricular Hemorrhage and Periventricular Leukomalacia Duke University School of Nursing, Durham, NC. in Medscape official webpage, http://www.medscape.com/viewarticle/749603_7

Michelsson K., H. Tood de Barra and Michelsson O. (2007), "Focus Nonverbal Communication Research", vol. 2, chapter *Sound Spectrographic Cry Analysis and Mothers Perception of their Infant's Crying*

Mima Y. and Arakawa K. (2006), Cause Estimation of Younger Babies' Cries from the Frequency Analyses of the Voice - Classification of Hunger, Sleepiness, and Discomfort, International Symposium on Intelligent Signal Processing and Communication System (ISPACS), Yanago Convention Center, Tottori, Japan

Murthy S. K. (1998), Automatic Construction of Decision Trees from Data: A Multi-Disciplinary Survey, Data Mining and Knowledge Discovery, 2, 345–389

Orlandi S., Manfredi C., Bocchi L., Scattoni M.L. (2012), Automatic Newborn Cry Analysis: a Non-Invasive Tool to Help Autism Early Diagnosis, 34th *Annual International Conference of the IEEE EMBS*

Orozco J., Reyes García C.A. (2003), Detecting Pathologies from Infant Cry Applying Scaled Conjugate Gradient Neural Networks, *ESANN'2003 proceedings - European Symposium on Artificial Neural Networks*, Bruges (Belgium), ISBN 2-930307-03-X, pp. 349-354

Orozco J., Reyes García C.A. (2003), Implementation and Analysis of Training Algorithms for the Classification of Infant Cry with Feed-forward Neural Networks, *WISP* 2003, Budapest, Hungary 4-6 September, pp. 271-276

Qiang Li and Kunio Doi (2006), Analysis and minimization of overtraining effect in rule-based classifiers for computer-aided diagnosis, *Medical physiscs*

Quinlan J. R. (1996), *Induction of Decision Trees*, Machine Learning 1: 81-106

Robu, R.; Feier, F.; Stoicu-Tivadar, V.; Ilie, C.; Enatescu, I. (2011), "The analysis of the new-borns' cry using NEONAT and data mining techniques," *Intelligent Engineering Systems (INES)*, 15th IEEE International Conference on , vol., no., pp.235,238, 23-25 June 2011

Ruíz Díaz M.A., Reyes García C.A., Altamirano L.C.,, Altamirano J.E.X., Mendoza A.V (2012), Automatic infant cry analysis for the identification of qualitative features to help opportune diagnosis, *Biomedical Signal*

Processing and Control Volume 7, Issue 1, Pages 43–49 Human Voice and Sounds: From Newborn to Elder

Sahak, R., Mansor, W., Khuan, L. Y., Ihsan, A., Yassin, M., Zabidi, A. (2010), An orthogonal least square approach to select features of infant cry with asphyxia. *Signal Processing and Its Applications (CSPA)*, 6th International Colloquium on. IEEE. pp. 1-4.

Sahak R., Lee Y. K., Mansor W., Yassin A. 1. M., Zabidi A. (2010), Detection of Asphyxiated Infant Cry using Support Vector Machine Integrated with Principal Component Analysis, *IEEE EMBS Conference on Biomedical Engineering & Sciences (IECBES 2010)*, Kuala Lumpur, Malaysia

Sahak, R., Mansor, W., Khuan, L. Y., Zabidi, A., and Yassin A. I. M. (2012), Detection of Asphyxia from Infant Cry Using Support Vector Machine and Multilayer Perceptron Integrated with Orthogonal Least SquareHong Kong & Shenzhen : s.n., 2012, 2-7 January. *Biomedical and Health Informatics (BHI)*, 2012 IEEE-EMBS International Conference on (pp. 906-909), IEEE

Sahak R., Mansor W., Khuan L. Y., Zabidi A. and Yassin A. I. M. (2012), Detection of Asphyxia from Infant Cry Using Support Vector Machines, *Proceedings of the IEEE-EMBS International Conference on Biomedical and Health Informatics - BHI*

Várallyay G. Jr., and Benyó Z. (2007), Melody Shape – A Suggested Novel Attribute for the Biomedical Analysis of the Infant Cry, Proceedings of the 29th Annual *International Conference of the IEEE EMBS Cité Internationale*, Lyon, France, p.4119-4121.

Várallyay G. Jr., Benyó Z., Melody Shape (2007), A Suggested Novel Attribute for the Biomedical Analysis of the Infant Cry, Proceedings of the *29th Annual International Conference of the IEEE EMBS Cité Internationale*, Lyon, France

Weka software official website, http://www.cs.waikato.ac.nz/ml/weka/ http://www.cs.waikato.ac.nz/ml/weka/arff.html