An Intelligent System for Infant Cry Detection and Information in Real Time

Pruthvi Raj Myakala[1], *Rajasree Nalumachu*[2], *Shivam Sharma*[3] *and V. K. Mittal*[4]
Indian Institute of Information Technology Chittoor, Sri City, A.P., India[1,2,3]
CEO, Ritwik Software Technologies Pvt. Ltd., Hyderabad, India[4]
pruthvi.m14@iiits.in[1], *rajasree.n14@iiits.in*[2], *shivam.sharma@iiits.in*[3], *DrVinayKrMittal@gmail.com*[4]

***Abstract*—Acoustic analysis of infant cry signal can indicate the physical-emotional state of a baby and the cry-cause. Knowing it remotely is a challenge for working parents. This paper proposes an *'Intelligent Cry Detection Information System (ICDIS)'*, to automatically detect an infant's cry and alert the parents. Parents can verify whether baby is in-fact crying, by informing a care taker who can send a web/app-controlled *smart robot* to fetch live video-streaming. It also sends text/image message to the parent, with urgency-level. The proposed system consists of sensors, *Signal Processing Unit (SPU)* and *Information Transmission Unit (ITU)*. The audio-visual signals are processed in SPU. Acoustic features extracted from cry signal are analyzed. If a cry is detected then ITU automatically sends SMS to the parents. Performance of the prototype *ICDIS* is evaluated using a *'Infant Cry Signals Database'*. The proposed system has potential applications in child care centers, schools and hospitals etc.**

1. Introduction

The advent of social multimedia computing has exposed a host of possibilities, through which a sizeable portion of the functional society can be augmented with the social media, offering better access to people, entertainment, healthcare, etc. Starting from social media usage for National developments programmes through its utility for building long lasting relationships [1], this platform has reshaped the societal dynamics from its very core. Healthcare, in particular has seen surge in inter-departmental services and community benefits, with major health care providers operating through the web. In a study [1], 54 % of the patients are very comfortable with their providers seeking advice from online communities to better treat their conditions. With all this luxury of social media, still there is a wide gap between existing conventional social media and the main-stream professional health care services. With varying degrees of involvement of networked professional health care services on social networks, different heath related solutions leveraging the social multimedia computing can be contemplated.

Now a days parents are getting busy in their job profiles which is forcing them to leave their children in home or child care centers with home assistants or caretakers. On the other hand, they worry and are curious about the care and protection for the children [1]. In order to remove the guilt of the parents that they are away from their baby, we proposed an intelligent system that monitors child all the time and identifies infant cry and notifies parents with photograph of the baby and text message that their infant is crying based on emergency of the cry.

Physiological behaviour of an infant were studied in [2] to understand his/her needs. Spectrographic analysis was carried out for characterizing pitch and harmonics in [3]. F_0 analysis was done by implementing the Welch's method and FFT in [4]. F_0 and first three formants were determined using Cepstrum analysis in [5]. In depth study was done as part of [6], where primarily the short time analysis and features like MFCC were studied, followed by k-NN algorithm for the purpose of classification. The same author in [7] proposed the automatic detection of the infant cries in a domestic environment using the features like MFCCs, pitch and Formants and finally evaluated a deep learning based Convolutional Neural Network. A different method to extract F_0 was proposed in [8], where a 3D Crosscorrelogram is implemented for projecting the cross-correlation between the adjacent speech segments. F_0 analysis was done by implementing the Welch's method and FFT for hunger, sleepiness and discomfort [9].

The primary investigation of infant cry sounds was done in [10], which was analysed with respect to the behaviour of the F_0 contour values and reported in [11]. This was followed by detailed analysis comparing the characteristic behaviour of the features like F_0, Strength of Excitation (SoE) and Signal Energy for *Discomfort* vs. *Pain* Cry sounds in [12]. These were also studied along with the use of a technique called as *modZFF* in [13]. Differnt types of peculiar cry sounds were discussed in [27]. Significant study has been done on the non-verbal paralinguistics in [14] and [15] using modZFF, where the open and closed phases of the glottal vibrations are studied for characteristic behaviour of *Shout* and *Laughter* sounds, with respect to normal speech sounds. For the cry analysis, there is still need to examine other important cry cause reasons and the corresponding acoustic behaviour. This led us to collate a comprehensive database for other significant categories too, the prior ones were introduced in [16]. This not only helped towards consolidation of the previous observations, but also gave insights into some other possible detectable cry causes.

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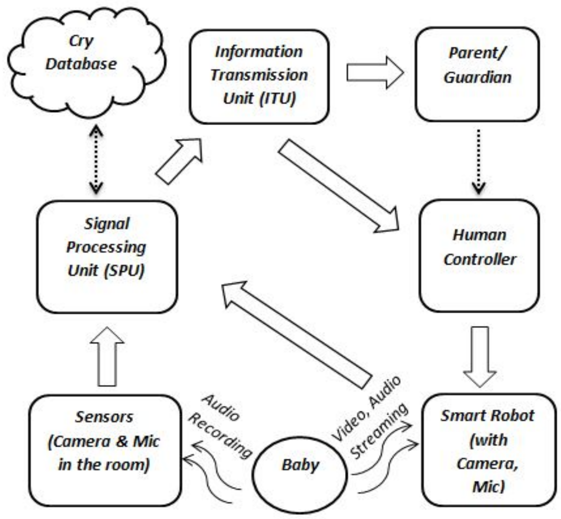

Figure 1. System Architecture of the ICDIS. Connection between the dotted lines are futuristic.

In this paper, a baby monitoring system called *Intelligent Cry Detection Intelligent System (ICDIS)*, has been proposed. This system uses speech signal techniques on hardware components to build a real time system. Proposed system processes real time audio signal by applying signal processing techniques and extracts the features and intelligently detects the infant cry signal. If it detects a cry signal, system sends a message to human controller who can remotely control the smart robot [17] through Wi-Fi communication medium. He/She can observe the surroundings of the baby through live video streaming. Mic present on the smart robot records the signal again and extracts the features to validate the infant cry. If cry is validated, system sends messages to the parent based on the emergency. Parent can be a controller in future.

This paper is organized as follows. In Section 2, it gives an overview of the design aspects of the *Intelligent Cry Detection Information System (ICDIS)* in both hardware and the software aspects. It gives an detailed explanation of *cry detection system* working and also the *smart robot* building. In section 3, Signal processing methods, features are discussed and it also describes about how the interaction between the robot and the *CDS* is carried out in the ICDIR. Section 4, describes about the experiments and the results, it also explains about the data collection and organization. The Possible applications in real-time are discussed in Section 5 and followed by summary and future scope in the Section 6.

2. Design Details of Intelligent Cry Detection Information System (ICDIS)

This section gives a detailed explaination about design of the *signal processing unit (SPU)* and the smart robotic platform that were build in ICDIS. Figure 1, gives the overall working architectural design of the ICDIS prototype.

Table 1. AT COMMANDS OF GPRS/GSM FOR SMS TRANSMISSION
NOTE: ALL COMMANDS BELOW ARE GIVEN ALONG WITH 'AT+'

(a) AT Command	*(b) Operation*
CMGS	Send message
CMMS	More messages to send
CMGR	Read SMS message
CMGC	Send command
IPR=0	Choose auto baud rate

Table 2. AT COMMANDS FOR CONFIGURING WI-FI MODULE
NOTE: ALL COMMANDS BELOW ARE GIVEN ALONG WITH 'AT+'

(a) AT Command	*(b) Purpose*
RST	Reset command
GMR	To check firmware version
CWMODE?	To check mode of operation
CWLAP	To check available Wi-Fi Networks
CIFSR	To check IP address
CWJAP	To connect to suitable Wi-Fi

2.1. Cry Detection System

In this system, raspberry pi 3, Model B acts as the *Signal Processing Unit (SPU)*, which is the heart of the entire ICDIS. Wherein, Matlab Simulink models were deployed into it. Simulink model [18] was developed for processing of signals. Signal processing techniques are applied on the signal in this part of the system i.e., SPU. Input data to the system is real time audio signal. This function of the system is done by Zebronica microphone which is in turn connected to 7 channel USB sound card, and further it is connected to the SPU i.e. Raspberry Pi. After processing of signal, this SPU will send a control command to Arduino through serial communication. Based on the control command received from *signal processing unit (SPU)*, system decides further action like whether to send alert message or not. Information transmission unit (ITU) block consists of GSM module which will send message to the controller/parent when the baby is crying. GSM module used in the ICDIS is sim900a which is on the quad band technology which includes bands of 850/900/1800/1900 MHz. Interaction between GSM and Arduino takes place through AT commands. Sending an SMS to the controller/parent when the child cries to the pre-configured number is done using the AT commands of GSM module. Table 1, consists of all required AT commands for configuration and sending SMS to parent for the GSM module [19].

2.2. Smart Robot and its control

Smart Robot has a micro controller (Arduino) to control it's movement [20]. Arduino is a 8-bit microcontroller with a clock speed of 16 MHz. It can control the *smart robot*

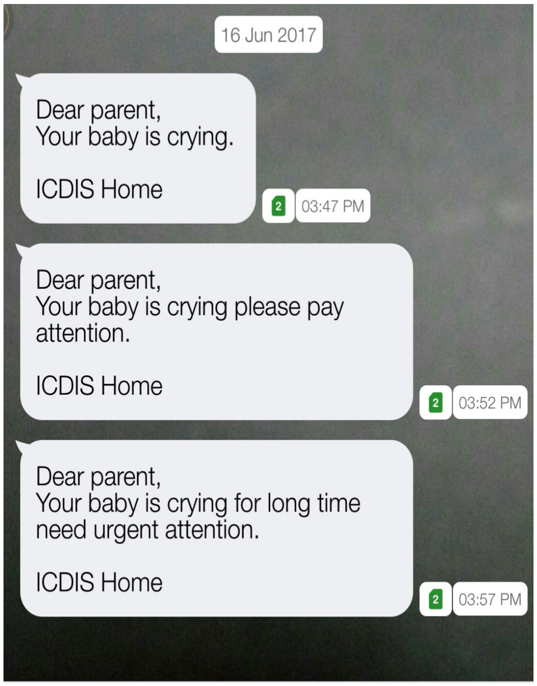

Figure 2. *Screen shot of SMS's received by the parent at different time instances based on emergency of baby cry*

through a web page. Commands given through webpage are received by the Arduino through Wi-Fi medium. Wi-Fi medium is created by ESP8266, which is a low cost miniaturized chip [21]. As a unique feature, it can be configured both as a client and server. All the necessary AT commands required to configure Wi-Fi module to the network are given in table 2. A camera module is mounted on the *Smart robot* which serves to capture the video and the mic present on it records the audio signal. *Smart robot* is made up of a metallic chassis. Wheels attached to it are connected to a dual H-bridge driver (L293D). It ampifies the low current control signal it receives from Arduino and produces high current control signal for the movement of DC motors [22].

3. Signal Processing for Cry Detection System

3.1. Signal processing methods and features

The preliminary analysis of the acoustic cry signals was done for the samples of the infants with recording of cry due to Pain and Discomfort present in pairs. This type of the pairing of cry causes, for the same infant elucidated the characterisation process vividly [12]. These observations are further cross-validated with different Signal Processing techniques [11]. The features that are found to be distinctly characterising the signals are,

(a) Instantaneous fundamental frequency (F_0)
(b) Strength of Excitation (SoE)
(c) Signal Energy

Table 3. *Infant Cry Signals Database 2 (ICSD 2) Summary*

(a) Attributes	*(b) Values*
Total # of files	181
Total # of speakers	101
Total # of session	104
Total # of cries in sessions	1587
Average # of session per speaker	1.02
Average # of cries in each session	15.26
Total duration of all sessions	1 Hr 5 min
Average duration of each session	38 sec

The F_0 contour extraction techniques evaluated are,

(a) Autocorrelation
(b) LP Residual based extraction
(c) Zero Frequency Filtering (ZFF)
(d) *modified* Zero Frequency Filtering (modZFF)

3.2. Smart Robot and Cry Detection System

Cry Detection system continuously records the real time audio signal through the external mike attached to it and sends it to the *signal processing unit (SPU)*, where MATLAB SIMULINK models were developed are deployed into. System stores the audio signal in a buffer of the required length in the form of a matrix. Once, the buffer is filled, it transmits the data to the matlab function, where signal processing techniques are applied on it and features are extracted. System validates the result with the features of infant cry (experimented and stored in the data base). If it detects it to be an infant cry signal, *Information Transmission Unit (ITU)* sends a MMS and text message to the human controller that child is crying.

In order to validate that child is crying, controller can send the *smart robot* near the child by giving control commands through web page [23]. Those instructions are generated in the form of a HTTP request and it is received by the Wi-Fi module which is mounted on the *Smart robot System*. Those signals are decoded and processed for the movement of *smart robot* [24]. For movement of the robot, forward, backward, left, right directions are written on the web page. Depending on the button operated by the user on the web page, the robot moves in that direction [25].

Robot can stream live video which helps the controller in viewing the child's surroundings. Live streaming is done using the Internet Protocol (IP) Camera that is mounted on the *smart robot*. In addition, mic present on the smart robot records the data and sends it through Wi-Fi [21] communication medium (established through ESP8266) to

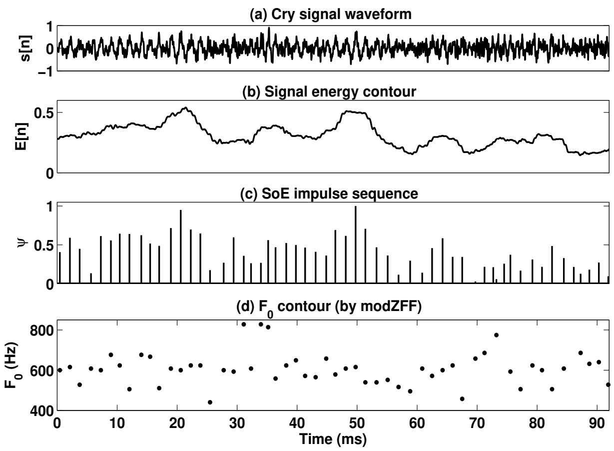

Figure 3. *Illustration of features for pain cry signal: (a) cry signal waveform, (b) signal energy contour, and (c) SoE impulse sequence and (d) F0 contour derived using the modZFF method, for (pain) cry signal of infant #S02 (male).*

signal processing unit, wherein processing of the audio signal takes place in a manner similar to the prior processing and once again validates weather child is crying or not based on the features extracted from the audio signal. If it matches it sends a message to the parent to let them know that their child is crying. System sends message to parent based on the criticality. It notifies the parent with an interval of 5 minutes when baby continues to cry for long duration. Screen shot of different notifications received by the parent based on criticality is shown in figure 2. There is a flexibility for the parent to watch the live stream of the video on smart phone or in a web browser.

4. Experiments and Results

4.1. Data Collection and Organization

The data was collected from a Paediatrics clinic. The room temperature was maintained at 16^oC. Although, people in the room were asked to maintain silence to get the cry sounds in pure form, but any additional perturbations in the sound recordings were taken care of by an attached noise screen accessory. Zoom H4n, a handy recorder, with built in X/Y stereo mics was used to record the cry voices from a distance of 10-20 cm. The recordings were made at 48 KHz sampling rate with bit coding rate of 16 bit. Care is taken that only the cry parts clean enough for a reliable analysis were considered for study. The cry sounds were recorded for a total of over 100 subjects (50 Male and 50 Female) for a period of 5 days (Refer Table 3 for detailed summary). The average session duration is 38 sec, which provided sufficient core cry information needed for analysis. The ages of the infants whose data is recorded lies in range from 2 days to 6 years, with majority of the samples falling in the range 1-15 months. The causes for the babies crying during recordings were mostly, as attributed by the doctors were due to vaccination pain, or some discomforting situation. Other interesting categories that were noted were Stranger's Anxiety and Environmental Changes. Overall, there were 7 distinct categories that were defined and set forth, by the Doctors concerned, for all the cry sounds collected namely: Ailment, Discomfort, Emotional Need, Environmental Factors, Hunger Thirst, Pain and Stranger's Anxiety. The relavant cry sample details including these ground truth cause labels are collated in the form of metadata [16].

Table 4. RESPONSE DELAY TIME FOR VARIOUS OPERATIONS

(a) Operation	***(b) Delay-Time***
SMS transmission (ITU)	1.2 sec
Video streaming (ITU)	2 sec
Control commands (ITU/Robot)	1.01 sec
Signal Processing (SPU)	0.2 sec

4.2. Observations

4.2.1. Infant cry charactersation. It was observed [12] that the cries due to discomfort have flat spectral characteristics, in that the variations in the F_0 and the Harmonics with time, were minimal for each cry event whereas, the cries due to Pain were observed to have peculiar cyclic spectral patterns. These patterns within the Pain cry signals have continuous volleys of inverted-cup shaped Fundamental frequency and harmonics.

These observations were further examined by doing the features analysis using SoE impulse sequences, Signal Energy and F_0 contour [10]. The observed behaviour with respect to these features gave the empirical proofs for the characteristic behaviour described above. The short-term fluctuating changes in the Signal Energy contour, SoE impulse sequence and F_0 contour, in the case of Discomfort cries were very less, as compared to those in Pain cries. The changes in these features for Pain cry, as can be seen in Fig. 3 [24], had significant variations frequently.

4.2.2. Latency measure of various operations:. Delays of various operations are tabulated in Table 4. This table consists of an average value, whereas the experimentation is carried out for 50 times. It is observed that if network is not good near the ICDIS, then the SMS will not be sent. On the other hand for ICDIS, the signal processing on the Raspberry Pi is slightly faster compared to all other platforms. Also, the deleay reported is highest for the Video Streaming.

4.3. Results and Discussion

The parameters used for quantifying the behaviour of the outputs of these different features are Mean (μ), Standard Deviation (σ) and Normalised Standard Deviation ($\sigma_N = \sigma/\mu$) [12]. In general, σ_N in F_0, SoE and Energy obtained for the cries due to Pain were much larger than those obtained for the Discomfort category.

The behavior of excitation source features for the cry causes being considered here became more prominent with visual inspection of Spectrograms of the SoE impulse sequences than for the acoustic signal. The frequent cyclic changes with larger fluctuations within contour of the F_0 and Harmonics for the Pain cry can be attributed to the psychological aspects of the infant responsible for inspirations and full expirations for brief cry outbursts. On the other hand, the reason behind relatively stable characteristics of the Discomfort cry could be less agitated mental state of the infant, reflecting as stable excitation source characteristics for the majority of the cry signal. The standard deviation based paramteric characterization of the cry signals, for the features discussed yield insightful results when considered independently.

In other set of experiments in [28] where over 70 cry cases have been analysed giving definitive characteristics for the cry melody contour using F0, in terms of the short-time F0 deviations. This led to the distinctive characterization of the cry signal for the causes Discomfort, Environmental Change, Pain and Stranger's Anxiety. The quantitative analysis of the feature parameters stated previously, are effected significantly due to various cry sound types like Shrill, Growl, Squeak, etc [27]. The results for these give insights towards not only the cause category, but also infant's age and pathological condition.

5. Possible Applications

The developed *Intelligent Cry Detection Information System (ICDIs)* has wide area of applications in day to day life. Few important key applications are discussed in this section.

5.1. Infant Cry Analysis

Infant cry as it is also an audio signal carries some meaningful information, which can be analyzed by using signal processing techniques. The information obtained from the features extracted can be used to identify the reason for baby cry, that is analyzing the cause of cry like pain, discomfort, anxiety, hunger etc. Analysis can also be helpful to identify the baby who is crying from among many babies in a child care center or a play school . In addition we can identify the severity of baby cry and caution the parent or the respective person.

5.2. Baby Care Centers

Most of the parents are forced to leave their children in baby care centers or with a nanny or with a relative in their absence, because of their tight scheduled work. But, they are panic and are curious about their child, they don't have any idea whether the person with whom they left their baby are able to take care of their child. In addition they always worry whether their child is crying or is he/she fine. The proposed system can to help parents to get free from their worries. The system can be modeled to monitor babies and detect the child cry and alert the parent. It can even analyze the cry of the baby and find the reason behind their cry, which helps the parents and the care takers to take care of the baby accordingly. System can detect the environmental changes around the baby and notify the parent about the situation, it can also try to calm down the baby by playing light music or blinking different lights

5.3. Child abuse prevention

Physical maltreatment of children is present in all corners of the world, it disturbs the children mentally and physically. In some nations it is even considered as a crime. In most of the scenarios children may not be able to convey their pain to their parents, may be because of fear or any other reason. This case is more in children below age of 5. The proposed *ICDRS* can be modified to solve these kind of issues, where the system detects the child cry and tries to find the reason behind the cry, identify the maltreatment like beating scenario and notify the parents or to the respective people to notify them about the situation for further reaction.

6. Summary and Conclusion

An *Intelligent Cry Detection Intelligent System (ICDIS)* for infant cry monitoring and real time information is developed in this paper. This system mainly consists of two parts, *Cry detection system* and *Smart robot*. *Cry detection system (CDS)* captures the real time audio signals and detects the cry signal by applying signal processing methods on the signal.

Smart robot can be controlled remotely through the Wi-Fi communication using the ESP8266 (Wi-Fi module) mounted on the robot. This paper also explains how the signal processing is embedded into the microcontroller for identifying the cry detection. The developed system will record the signals and process them in the *signal processing unit*. If the system encounters the cry signal it would then trigger the arduino and generates an MMS and text message to pre-configured number using the GSM [28] module to the controller and later to the parent after validating it to be a cry signal. This paper also gives an overview of the IIITS ICSD, which was specially collected for the infant cry analysis. Infant cry signals are analyzed using various signal processing methods like Autocorrelation, LP Residual, ZFF and mod ZFF, have been discussed along-with the features SoE, Signal Energy and F_0 contour. Along-with the Spectrogram analysis of the cry signals with respect to different causes, establishing the analytical aspects of the infant cry characterisation is also discussed in the paper.

Another limitation of the system is the Information sending functionality (through MMS, text messages), which is constrained by the availability of good strength mobile networks in the vicinity of the system and all the experiments were done in a silent room. The paper also provides comprehensive view of embedding the MATLAB Simulink models into the microcontroller and Wi-Fi technologies for the connectivity between the robot and the user. This research could provide some insights towards scaling up the functionality for a real-time Infant monitoring and *cry detection system*.

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