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Technical note

AVIM—A contactless system for infant data acquisition and analysis: Software architecture and first results

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ABSTRACT

Traditional techniques for the diagnosis of neurological disorders are recently complemented by contact-less methods that provide a semi-quantitative assessment of the patient status. In this framework, the assessment of infant's behaviour based on the analysis of audio and video recordings is appealing thanks to its unobtrusiveness and to the affordable costs of the equipment.

This paper presents the architecture of a system, named AVIM, conceived for supporting clinical diagnosis in newborns with contact-less techniques. Its most innovative aspect is the ability of merging in a single tool the management of medical records and reports, audio/video data acquisition, handling and analysis, editing and filling out customized tests. Moreover, unlike other commercial or open source software tools, AVIM allows adding markers and notes while recording audio and video signals and provides detailed reports with both perceptual scores and acoustical and kinematical parameters of clinical interest computed through dedicated innovative techniques. AVIM is therefore a unique and flexible system that could successfully support the clinician during the entire process from the acquisition of the signals to the results. In addition to providing an appreciable decrease in investigation time, costs and errors, AVIM could support the diagnosis integrating clinicians' qualitative analysis, based on subjective skills, with objective measurements. To highlight its capabilities, AVIM is applied here to the management and analysis of personal and clinical data of newborns audio/video recorded in 5 time points from 10 days to the 24th week of age, according to a specific protocol. Patient data, results of customized tests, tables and plots are provided in a user-friendly environment.

1. Introduction

Traditional techniques for the diagnosis of neurological disorders are recently complemented by contact-less methods. These techniques are mainly based on the assessment of parameters obtained both from automatic and perceptual analysis of audio and/or video recordings resulting in a semi-quantitative evaluation of the patient's status [1–5]. Contact-less techniques provide advantages in terms of comfort and safety of the patient with respect to sensor-based/invasive methods, thus they are particularly well suited for vulnerable patients such as neonates and young infants. This paper focuses on this category of subjects.

The development of reliable software tools to enhance early diagnosis, especially in home environments, is highly desirable particularly for the neurobehavioural assessment of the newborn. Such tools should provide objective measures to complement clinicians' qualitative analysis that is based on subjective skills. Acoustical analysis of infant's cry and automatic motor methods may provide objective parameters indicative of neurological pathologies.

To this aim, a new system is presented, named AVIM (audio–video infant monitoring), conceived for managing data of a large set of patients. Its most innovative aspect is the ability of merging in a single tool the management of medical records and reports, audio/video data acquisition, handling and analysis, editing and filling out customized tests. Moreover, AVIM supports the

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clinical perceptual evaluation of cry and spontaneous movements of newborns and infants, which are markerless techniques of relevant clinical interest in the early assessment of neurological disorders. In fact, recently, alterations in infant crying and general movements have been identified in several neurodevelopment disorders [6–16] suggesting their role as early markers of infant disorders.

Specifically, crying is the first and primary method of communication among humans. It involves activation of the central nervous system and requires a coordinated effort of several brain regions, mainly brainstem and limbic system. Thus an accurate acoustic analysis of newborn's cry could be helpful to identify risk markers of neurodevelopmental disorders.

The most significant acoustical parameters of infant crying are the fundamental frequency (F_0) and the first two resonance frequencies of the vocal tract (F_1 and F_2). F_0 reflects the regularity of the vibration of the vocal folds while resonance frequencies are related to the varying shape of the vocal tract during phonation and thus to its control. Both are extremely relevant also in the study of language development in the infant [17]. Few papers describe the F_0 developmental pattern in the first months of life. Gilbert et al. [18] analysed the variation of F_0 (mean, median and standard deviation) in hunger cries of 4 male infants during the first 12 months of life and found an increase of F_0 median in the first 5 months and a decrease at the 12th month. Lind and Wermke [19] reported no significant difference in F_0 mean in spontaneous cries of male healthy infants in the first three months of life. Rothganger [20] found that the mean fundamental frequency of crying varied considerably from 441.8 to 502.9 Hz in 25 infants recorded at the 3rd–5th day of the 1st, 3rd, 6th, 9th and 12th month. Baeck and De Souza [21] found a 380–435 Hz range of F_0 when analysing 30 male and female healthy infants recorded at birth and every two weeks until the 6th month of life.

This not exhaustive list shows the noticeable scientific interest for the analysis of infant cry. Unfortunately, the variety of cries (feeding, anger, and pain), the lack of dedicated software for infant crying recording and analysis and the difficulties of recruiting a large number of subjects did not allow defining normative values for F_0. One reason is that this study requires standardized and appropriate recording settings and a preliminary perceptual analysis of the waveform to extract relevant sequences, the so-called crying episodes or cry units (CUs). However, the workload of clinicians is often incompatible with this analysis as it requires the manual selection of a large number of cry units and the removal of moans, breath, background noise, from recordings lasting up to several minutes. Moreover, the acoustical analysis is commonly performed through commercial or open source software tools like MDVP [22] or Praat [23,24] which however were developed for the analysis of adult's voice. Thus their proper use with infant high-pitched quasi-stationary cry signals requires manual setting of some parameters and thus some technical skill.

To the authors' knowledge only two software tools exist specifically designed for the automatic analysis of infant crying. The first one is BioVoice [4,5,17,25], based on an innovative and robust parametric approach for F_0 and formants estimation [10], successfully tested against other software tools [12,26] and a software tool recently proposed by Reggiannini et al. [27] that estimates F_0 by means of a cepstrum approach. However, both methods perform only the audio analysis and are not an integrated audio/video system such as the one proposed in the present paper.

Besides cry, great interest is paid to newborn spontaneous (i.e. not induced or stimulated) movements, known as general movements (GMs). Regular GMs are gross movements, involving the whole body with a variable sequence of arm, leg, neck and trunk movements rising and waning in intensity, force and speed. They begin and end gradually and may last from a few seconds to several minutes. The majority of sequences of extension and flexion of arms and legs is complex, with superimposed rotations and often slight changes in direction. These added components make the movements fluent and elegant and give the impression of complexity and variability [28–31].

At the end of pregnancy and during the first two months after childbirth, GMs are known as writhing movements and are characterized by an elliptic shape of small to moderate amplitude and by slow to moderate speed [32]. At the age of 6 to 8 weeks of life infants' movements undergo a change in form and a new pattern, called fidgety, emerges [31]. Fidgety movements, commonly observed until 20 weeks of age, are elegant circular movements of small amplitude and moderate speed and variable acceleration of neck, trunk and limbs in all direction. They are persistent when the infant is awake, except during focused attention. Recently, some studies proved that spontaneous motility in infants affected by different brain lesions/pathologies loses elegance, fluency and complexity [30,31].

In the last decades Prechtl's method [30] was proven to be a highly accurate and specific marker-less diagnostic tool for the qualitative assessment of GMs, preventing discomfort for the baby without interfering with other measures. To date GMs are commonly assessed by expert clinicians (paediatrician/neurologist/child psychiatrist), scoring their variety and complexity according to strict protocols but solely through a perceptive examination.

Beside perceptual evaluation, marker-based techniques have been applied to the analysis of GMs [33,34]. In addition to quite expensive equipment, (building three-dimensional models requires at least two high-speed cameras), marker-based techniques require the application of markers in well-defined anatomical landmarks (often the joints) that, although of reduced invasiveness in adults, can make the newborn movements less spontaneous or even hinder them. Despite these drawbacks, marker-based techniques allow to obtain very reliable models thanks to accurate data processing. Marker-based analysis for the study of the infants' movements was performed by Coluccini and colleagues [33] with the aim of assessing movements at different stages of development (7, 10, 12 weeks). Other applications concerned the evaluation of signs of spasticity in newborns at risk [35] or the analysis of spontaneous movements in control cases [36].On the other hand, marker-less techniques can be applied on movies recorded with any good quality camera under an appropriate and standardized protocol. Adde et al. [37] assessed fidgety movements identifying the centroid of motion of the subject by a video processing software tool for the diagnosis of cerebral palsy. The centroid of motion is plotted on a diagram called motiongram (motion diagram). In a sample of 140 subjects, the method has shown a sensitivity of 81.5% and a specificity of 70.0%. A similar approach is proposed in the present paper.

Though the perception of the clinical specialist is undoubtedly the most accurate method to assess infants' crying and movements, the procedure of finding and analysing crying episodes and video frames of interest out of the whole recording is operator-dependent. Moreover, the huge amount of recorded data makes a detailed analysis often prohibitive in daily clinical practice being highly time consuming even for trained and qualified clinicians. Finally, clinicians make use of several acquisition devices and software tools not specifically designed for clinical use: that is, they have to use different hardware and software tools and even resort to pen and paper to manage patient data, record and process audio and video signals to obtain parameters of interest, collect and save results, fill tables with diagnostic indexes, scores, etc. Thus, the lack of a unique software tool that aids the clinician in the many different steps from data acquisition to clinical results makes this approach not yet widespread.