Automatic Multimodal Assessment of Neonatal Pain

1. SIGNIFICANCE AND INNOVATION

McCafery [1] describes pain as, "whatever the experiencing person says it is, existing whenever the experiencing person says it does." Unfortunately, neonates do not have the ability to communicate this experience verbally (self-evaluation) or non-verbally by writing or pointing (Visual Analog Scale). The limited ability of neonates to communicate pain and the earlier misconception about the absence of neurological substrate for the perception of pain in neonates have led pediatricians to believe, for several decades, that neonates do not feel or remember pain. Several scientific studies [2; 3; 4; 5] disproved this earlier belief and reported a strong association between repeated pain exposure (under-treatment) and alterations in the brain structure and function. This association has led to the increased use of anesthetic medications. However, recent studies [6; 7] found that the excessive use of analgesic medications such as Morphine and Fentanyl may cause several side effects (e.g., hypotension and feeding intolerance).

The current standard for assessing neonatal pain involves observing, by bedside caregivers, multiple behavioral (e.g., facial expression) and physiological (e.g., vital signs) responses of pain. At least 29 response-based pain scales [8] have been developed to evaluate procedural and postoperative pain in neonates. This practice has three main shortcomings. First, it relies on the caregiver's direct observation and interpretation of multiple responses. It is highly affected by several idiosyncratic factors, such as the observer's cognitive bias, identity, culture, and gender [9]. The inter- and intra- observer variations can lead to inconsistent assessment and treatment of pain. Second, caregivers assess pain at different time intervals. The discontinuity of assessment can lead to missing pain while the neonate is left unattended; therefore, it may result in delayed intervention. Third, this practice requires a substantial time commitment and a large number of well-trained caregivers to ensure the proper utilization of the pain scale. The substantial cost of this practice makes it infeasible in underdeveloped countries where medical professionals and resources are scarce.

This dissertation introduces an automatic, comprehensive, and multimodal neonatal pain assessment system. The proposed system addresses the shortcomings of the current practice and provide continuous, consistent, and inexpensive pain assessment to guide treatment. The main contributions of this dissertation can be summarized as follows:

—It presents a comprehensive review of the current neonatal pain assessment methods, discusses current gaps and challenges, and provides several implications for future research.

—It proposes a fully automated and multimodal approach for neonatal pain assessment that can be easily adopted and integrated into clinical environments. This dissertation is the first to propose an automated version of the current pediatric scales that integrates multiple behavioral and physiological pain responses for assessment.

—It introduces a unique, well-annotated, and multidimensional neonatal dataset that can be used to advance pain research.

—It proposes several novel handcrafted and deep learning methods for analyzing different pain responses individually (unimodal approach). It also proposes methods for integrating different pain responses together (multimodal approach) to obtain a multimodal assessment system.

—It integrates contextual data, such as the neonate's age and medication dose, to the system to obtain context-sensitive assessment.

The proposed system achieved excellent performance (up to 95% accuracy) in detecting pain events of neonates. Our system is different from the previous ones in three principal ways:

—It is especially designed to assess pain of neonates using data captured while they are hospitalized in the Neonatal Intensive Care Units (NICU). Most existing methods [10] for automatic pain assessment focus on adults. These methods do not produce similar performance when applied to neonates, and might completely fail since the pain's dynamics and facial morphology vary between neonates and adults [10].

—It dynamically analyzes neonatal pain as it unfolds in a particular pattern over time (spatial-temporal analysis of pain). The few existing methods [10] for neonatal pain assessment detect pain from static images based on analysis of a single modality (e.g., only facial expression).

—It combines visual, vocal, and physiological signals to create a multimodal approach for assessing pain. The multimodal approach allows to assess pain even when one or more signals become temporarily unavailable due to sleeping position (e.g., prone position), immaturity of the musculoskeletal system, occlusion (e.g., oxygen mask), or other environmental reasons (e.g., background noise).

—It uses affordable and user-friendly devices (e.g., RGB camera) that can be easily integrated into the clinical environment.

As reported in the dissertation, the performance of the proposed system in recognizing pain events is comparable to that of trained nurses; and hence, it demonstrates the feasibility of automatic pain assessment in typical neonatal care environments

2. REAL-WORLD APPLICATION

Currently, hospitalized neonates are not continuously observed, and many pain behaviors may be intermittent or subtle, particularly in sick and preterm infants without adequate energy reserves. These factors may delay or limit the caregivers' ability to promptly recognize and treat pain in this population.

The proposed system would continuously monitor neonates and send a notification to caregivers when pain event is detected. The continuous monitoring of neonates' condition combined with the generation of automatic assessment and immediate notification of a significant change in an infants state can improve neonatal care and contribute to improved long term outcomes; i.e., reduce the outcomes of under- and over-treatment. It can also decrease caregivers' bias, assessment burden, and the substantial cost of hospitalization. In addition, this system would benefit the neonates in the remote and rural villages where the neonatal care is not available because hospitals are inaccessible and costly.

The experimental results of this dissertation demonstrate the feasibility of using the proposed multimodal pain assessment system for pain monitoring in real-life.

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