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A Systematic Literature Review of Methods and Technologies for Detecting Pain in Infants Through Facial Expression Analysis

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Abstract

Pain assessment in infants, particularly neonates, remains a challenging task due to their inability to verbally communicate pain. Therefore, pain evaluation commonly relies on indirect indicators, including facial expressions, crying behavior, and physiological responses. This study aims to review existing methods and technologies for infant pain detection through facial expression analysis using a Systematic Literature Review (SLR) approach based on the PRISMA framework. The review process involved several stages, including identification, screening, eligibility assessment, and inclusion of relevant studies, resulting in 27 articles selected for further analysis. The findings indicate that Deep Learning-based approaches, particularly Convolutional Neural Networks (CNNs), are the most frequently applied techniques for analyzing infant facial expressions in pain detection systems. Furthermore, recent studies have explored multimodal approaches by combining facial expressions with crying sounds and physiological signals to improve detection performance. Despite these advancements, several challenges remain, including limited data availability, lack of standardized public datasets, and difficulties in validating models across different clinical settings. Overall, artificial intelligence-based approaches demonstrate significant potential in supporting more objective and consistent infant pain assessment. This review provides insights into current research trends and future directions for developing reliable pain detection systems to assist healthcare professionals in neonatal care.

Keywords:
Infant Pain; Facial Expression Analysis; Deep Learning; Machine Learning; Systematic Literature Review.

1. INTRODUCTION

Pain is an unpleasant sensory and emotional experience resulting from actual or potential tissue damage. In infants, particularly neonates, pain assessment remains a complex challenge because they have limited ability to verbally communicate their discomfort. As a consequence, healthcare providers must rely on indirect indicators, including behavioral responses and physiological changes, to identify pain conditions. Accurate pain assessment is essential because inadequate pain recognition and management may negatively affect neurological, physiological, and psychological development in infants (Heiderich et al., 2023). Therefore, the development of objective and consistent pain detection methods has become an important need in neonatal healthcare.

Various pain assessment instruments have been implemented in clinical practice, including the Neonatal Infant Pain Scale (NIPS), Premature Infant Pain Profile (PIPP), and Neonatal Facial Coding System (NFCS). Although these instruments have contributed to improving pain evaluation, most approaches still depend on

healthcare professionals' observations, which may introduce subjectivity and inter-observer variability. Ben Aoun (2024) highlighted that these limitations have encouraged the development of automated pain assessment systems based on artificial intelligence (AI) to improve evaluation consistency and reduce dependence on manual interpretation. Advances in computer vision and machine learning technologies have further created opportunities for automated facial expression analysis as a non-invasive approach for infant pain detection.

Facial expression is considered one of the most important behavioral indicators in neonatal pain assessment because it reflects observable responses associated with pain conditions. Several facial characteristics, such as eye squeezing, brow bulging, nasolabial furrow changes, and mouth opening during crying, have been identified as relevant pain-related features. Orsi et al. (2023) demonstrated that infant facial expressions can provide sufficient information for pain recognition even within a short observation period. These findings indicate that facial expressions have strong potential as a primary data source in developing automated infant pain detection systems.

The development of artificial intelligence technology has brought significant changes to the field of medical image analysis, including in infant facial expression recognition. Initially, research primarily utilized rule-based approaches and manual feature extraction using the Facial Action Coding System (FACS). However, these methods required complex annotation processes and relied on observer expertise. With the advancement of deep learning technology, Convolutional Neural Network (CNN)-based approaches began to dominate research due to their ability to automatically extract facial features without the need for complex manual feature extraction processes. Al-Eidan et al. (2020) concluded in a systematic review that deep learning models performed better than traditional machine learning methods in various facial image-based pain recognition tasks.

The dominance of CNN use in infant pain detection research is also demonstrated by various empirical studies. Semwal and Londhe (2020) reported that CNNs are able to identify pain expressions through facial analysis with a high degree of accuracy compared to conventional methods. Research conducted by Alghamdi and Alaghband (2022) demonstrated that a facial expression-based automated pain assessment system is able to effectively recognize pain characteristics through the use of deep learning algorithms. Similar findings were obtained by Zhao et al. (2024) who developed a deep learning-based neonatal pain detection system and demonstrated that the CNN model is able to automatically identify pain expression patterns from infant facial images. Furthermore, Onal Ertugrul et al. (2023) developed Infant Automated Facial Action Recognition (Infant AFAR) which enables the automatic identification of infant facial muscle movements, thus supporting a more objective pain assessment system.

In addition to static image-based approaches, several studies have begun to utilize video data to capture temporal changes in facial expressions. Kristian et al. (2018) combined a Deep Convolutional Neural Network (DCNN) and Long Short-Term Memory (LSTM) to classify pain in videos of infant facial expressions. This approach allows the system not only to recognize facial characteristics in a single frame but also to understand changes in expression that occur over time. The results of this study indicate that temporal information can improve the system's ability to more accurately distinguish between pain and non-pain expressions.

Although facial expression is the most dominant parameter used in pain detection research, some researchers argue that using a single parameter is insufficient to fully describe pain conditions. de Lucio Delgado, A., et al. (2021) demonstrated that automated facial analysis can aid in the assessment of procedural pain in infants, but its performance could be improved through integration with other indicators. Research conducted by Crispin et al. (2021) confirmed that physiological parameters such as heart rate, oxygen saturation, and respiratory rate also have a strong relationship with pain responses. Furthermore, Alpriani et al. (2022) found that infant crying frequency characteristics can be used as an additional indicator in detecting pain during immunization. These developments demonstrate a trend toward a multimodal approach that combines facial expression, crying, and physiological signals to improve the accuracy of pain detection systems.

On the other hand, research developments also show a variety of methods used to detect infant pain. In addition to CNNs, several studies utilize Support Vector Machines (SVMs), K-Nearest Neighbor (KNN), Recurrent Neural Networks (RNNs), and transfer learning to improve classification performance. However, the results of this study indicate that CNNs remain the most widely used method compared to other algorithms. This dominance indicates that facial image-based deep learning approaches remain the primary choice in developing infant pain detection systems due to their ability to automatically extract features and achieve a high level of accuracy.

Neonatal pain management has become an important concern in modern healthcare, particularly because newborns frequently experience painful procedures during hospitalization, including venipuncture, heel lance, intubation, and other invasive interventions. Repeated exposure to untreated pain during critical periods of brain development may lead to long-term consequences, including alterations in neurodevelopment, stress responses, and pain sensitivity. Despite increasing awareness regarding neonatal pain management, accurate pain assessment remains challenging because behavioral and physiological responses can vary depending on gestational age, clinical conditions, and individual characteristics of infants. Therefore, the development of reliable and objective pain detection approaches is essential to support timely intervention and improve the quality of neonatal healthcare.

Recent advances in artificial intelligence have further expanded opportunities for improving automated infant pain detection systems. In addition to conventional CNN-based approaches, emerging techniques such as transfer learning, attention mechanisms, and vision transformer architectures have been increasingly explored in medical image analysis. These approaches provide potential solutions for addressing common challenges in neonatal pain research, particularly limited dataset availability and variations in image characteristics. Transfer learning, for example, enables models to utilize previously learned visual representations from large-scale datasets, thereby improving performance when applied to relatively small medical datasets. Such developments indicate that AI-based pain assessment systems continue to evolve toward more adaptive and clinically applicable solutions.

However, despite promising results, the implementation of artificial intelligence-based infant pain detection systems in real clinical environments remains challenging. Model performance measured by accuracy alone may not guarantee clinical acceptance, as healthcare professionals require systems that are reliable, interpretable, and capable of providing meaningful clinical support. Factors such as variations in illumination, camera position, infant movement, facial occlusion, and differences in clinical environments may influence model performance. Consequently, recent research has also emphasized the importance of explainable artificial intelligence (XAI) approaches to improve transparency by identifying facial regions or features that contribute to pain classification decisions. The integration of accurate and interpretable AI systems is considered essential for bridging the gap between laboratory-based research and practical neonatal care.

Considering the rapid development of artificial intelligence-based infant pain detection technologies, a comprehensive evaluation of existing studies is necessary to understand the current direction of this research field. Individual studies commonly focus on specific datasets, algorithms, or evaluation metrics, making it difficult to determine which approaches provide consistent performance and demonstrate potential for clinical application. A systematic review can provide a broader understanding by comparing research methodologies, datasets, parameters, algorithms, performance outcomes, and limitations across different studies. This approach is important for identifying research gaps and establishing future directions for the development of objective, accurate, and clinically applicable infant pain detection systems.

Although research in this field is progressing rapidly, several challenges remain. Heiderich et al. (2023) noted that most infant pain detection research still faces limitations in dataset size, a lack of standardized public datasets, and minimal validation in real-world clinical settings. Furthermore, Ben Aoun (2024) highlighted the lack of uniform evaluation standards, making direct comparisons of results from different studies difficult. This situation makes the generalizability of models to broader populations a pressing issue.

Based on a review of previous research, most studies have focused on developing specific models or algorithms for detecting infant pain. However, relatively few studies have systematically mapped the development of methods, parameters, algorithms, and technologies used in pain detection through infant facial expressions. Furthermore, recent developments toward multimodal approaches and the use of modern deep learning technologies require more comprehensive study. Therefore, there is a need for a literature synthesis that can describe research trends, dominant methods used, the quality of available research, and the future direction of infant pain detection technology development.

Based on these issues, this study aims to conduct a systematic review of the methods and technologies used to detect pain through facial expressions in infants. This study is expected to provide a comprehensive overview of research developments, identify the most widely used methods, evaluate the quality of available studies, and identify research opportunities for future development. The results of this study are expected to serve as a reference for researchers and healthcare practitioners in developing a more objective, accurate, and widely applicable pain detection system in clinical practice.

2. RESEARCH METHOD

This study used a Systematic Literature Review (SLR) design to identify, evaluate, and synthesize research findings related to methods and technologies used in detecting pain through facial expressions in infants. The SLR approach was chosen because it provides a comprehensive overview of research developments, methodological trends, and the direction of technological development used in the field of neonatal pain detection. The research implementation process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, which provide systematic procedures for the identification, screening, selection, and synthesis of scientific articles to enhance research transparency and replication (Page et al., 2021).

The research methodology was developed based on a predefined review protocol to ensure consistency throughout the systematic review process. The protocol included the formulation of research objectives, search strategies, eligibility criteria, article selection procedures, data extraction methods, and synthesis approaches. The research questions were formulated systematically to define the scope of the review and guide the literature analysis process. This study focused on identifying the methods and algorithms applied in infant pain detection based on facial expressions, the parameters and datasets commonly used in automated pain detection systems, as well as the performance, limitations, and future development opportunities of existing approaches.

The research phase began with the formulation of research questions focused on identifying methods, algorithms, parameters, and technological developments used to detect infant pain through facial expression analysis. Based on these research questions, a literature search strategy was conducted in several reputable scientific databases widely used in health and information technology research. Data sources were indexed international and national journal articles discussing neonatal pain detection, facial expression analysis, machine learning, deep learning, and artificial intelligence-based pain assessment systems. Article selection was carried out using a combination of keywords such as infant pain detection, neonatal pain assessment, facial expression recognition, pain recognition, machine learning, deep learning, and artificial intelligence. The search strategy was designed to obtain a broad literature coverage while remaining relevant to the research objectives.

The literature search was conducted using several electronic databases, including PubMed, Scopus, IEEE Xplore, ScienceDirect, and Google Scholar, to capture studies from both healthcare and computer science perspectives. The search was limited to articles published within a predetermined period to ensure that the reviewed studies represented recent technological developments in artificial intelligence and medical image analysis. The search process was conducted using Boolean operators such as AND and OR to combine keywords and improve search accuracy. The complete search strategy was documented to ensure transparency and allow future researchers to replicate the literature identification process.

The article selection process was conducted in stages based on the PRISMA 2020 guidelines, consisting of identification, screening, eligibility, and inclusion. In the identification stage, all articles obtained from the search process were collected and checked for data duplication. Next, in the screening stage, a selection was made based on the title, abstract, and keywords to ensure their relevance to the research topic. Articles that passed the screening stage were then evaluated more thoroughly through a full-text review during the eligibility stage. The inclusion criteria used included articles discussing pain detection in infants or neonates, using facial expressions as a primary or supporting parameter, published in a fully accessible scientific journal, and containing information on the methods or technologies used. Conversely, articles that did not focus on infants, did not discuss pain detection, or did not provide adequate methodological information were excluded from the analysis process. Through this process, 27 articles were obtained that met all criteria and were used as primary sources in the research synthesis.

The screening and selection process was performed systematically to minimize selection bias. During the screening stage, articles were evaluated based on their relevance to the research objectives, while the eligibility assessment involved a detailed examination of the full-text content. Any articles that did not provide sufficient information regarding the dataset, methodology, algorithm, or evaluation results were excluded. The final selection process resulted in a collection of studies that provided adequate information regarding the development and evaluation of infant facial expression-based pain detection systems.

The subjects in this study were not individuals or respondents directly, but rather scientific articles that met the established inclusion and exclusion criteria. Therefore, the research analysis unit was scientific publications discussing the development of methods and technologies for pain detection in infants. The selected articles were analyzed based on several important characteristics, including the year of publication, the research objectives, the type of data used, the methods or algorithms applied, the pain detection parameters analyzed, and the results and system performance reported by each study. This approach allowed researchers to obtain a comprehensive overview of research developments in the field of facial expression-based neonatal pain detection.

Data collection was conducted through a systematic data extraction process using an extraction sheet prepared based on the research objectives. The extracted information included the article's identity, research location, research method, data processing technique, type of algorithm used, dataset used, and model evaluation results. Furthermore, the approaches used in the research were identified, such as machine learning, deep learning, computer vision, facial action recognition, and multimodal approaches that combine facial expressions with physiological signals and infant cries. This data extraction stage aims to ensure that all relevant information can be collected consistently and systematically.

The extracted data were organized into a structured evidence table to facilitate comparison between studies. The extraction process focused on identifying similarities and differences among research approaches, including artificial intelligence models, input characteristics, preprocessing techniques, classification strategies, and evaluation metrics. Particular attention was given to accuracy-related indicators, such as accuracy, precision, recall, F1-score, sensitivity, specificity, and area under the curve (AUC), when reported by the included studies. This approach enabled a comprehensive evaluation of the effectiveness of different methods used in infant pain detection research.

Data analysis was conducted using qualitative descriptive analysis techniques and narrative synthesis. Descriptive analysis was used to identify the distribution of studies based on the year of publication, the methods used, and technological development trends found in the literature. Meanwhile, narrative synthesis was used to compare, categorize, and interpret findings from various studies to gain a deeper understanding of the strengths, limitations, and development opportunities of each method. The narrative synthesis approach is widely used in systematic review research because it allows for the integration of research findings with diverse methodological characteristics (Page et al., 2021).

The synthesis process was conducted by grouping studies based on several analytical categories, including artificial intelligence approaches, facial analysis techniques, data modalities, and evaluation strategies. Studies applying machine learning, deep learning, computer vision, and multimodal approaches were compared to identify dominant trends and technological advancements in the field. This categorization allowed the review to highlight the evolution of infant pain detection systems and identify methodological approaches with greater potential for future clinical implementation.

To maintain the quality of the study results, each selected article was also evaluated based on its methodological quality through a risk-of-bias assessment process. This evaluation was conducted to identify potential biases that could impact the validity of the study results, such as limited dataset size, model validation procedures, or unclear methods used. The results of the quality assessment were then used as a basis for interpreting the findings and formulating conclusions. The methodological quality assessment was conducted using a scoring approach based on several evaluation criteria, including clarity of research objectives, dataset description, methodological explanation, validation procedures, and reported performance evaluation. Each criterion was assigned a score according to its fulfillment in the selected studies. The total scores were then categorized into three quality levels: high quality (score 8), moderate quality (score 5–7), and low quality (score ≤4). This assessment process was performed to evaluate the reliability of the included studies and support the interpretation of the systematic review findings. With this approach, the study results are expected to provide an objective overview of the development of pain detection methods and technologies through facial expressions in infants and can serve as a basis for further research in the development of an artificial intelligence-based neonatal pain detection system.

The quality assessment process was conducted using a structured evaluation framework adapted from previous systematic review methodologies. The assessment considered several methodological aspects, including dataset characteristics, research methodology clarity, model development procedures, validation strategies, and reliability of reported evaluation results. Each criterion was assessed consistently to determine the overall methodological quality of each included study. The quality assessment results were considered during the interpretation process to ensure that conclusions were based not only on reported performance but also on the reliability of the research methodology.

3. RESULTS AND DISCUSSION

3.1. Results

This study applied a Systematic Literature Review (SLR) approach to identify and analyze the development of methods, parameters, and technologies used for infant pain detection through facial expression analysis. Based on the PRISMA 2020 framework and the established inclusion and exclusion criteria, 27 articles were selected for further analysis. The included studies covered various approaches involving computer vision, machine learning, deep learning, and multimodal techniques for supporting automated infant pain assessment.

The analysis of the selected studies indicates that research on infant pain detection has increasingly shifted from conventional observation-based assessment toward artificial intelligence-assisted approaches. The reviewed studies demonstrate that facial expression analysis remains the most frequently utilized parameter because facial responses can be captured non-invasively and provide direct visual indicators associated with pain conditions. The distribution of parameters used in the reviewed studies is presented in Table 1.

Table 1. Results of the parameters used

No	Parameters	Amount
1	Facial expressions	20
2	Physiological Parameters	3
3	Baby Crying	2
4	Multimodal	2

Based on Table 1, facial expressions represent the most frequently used parameter, with 20 studies (74.07%) utilizing facial features as the primary or supporting indicator for infant pain detection. This dominance indicates that facial expression remains an important behavioral marker because it can be obtained through image-based approaches without requiring additional physical sensors. Meanwhile, physiological parameters and infant crying were less frequently explored, although several studies indicate that these modalities provide complementary information for improving pain recognition. These findings suggest that current research is increasingly moving toward combining multiple data sources to achieve more comprehensive pain assessment systems.

Table 2. Methods Used

No.	Algorithmic Method	Number of Studies
1	Convolutional Neural Network (CNN)	15
2	Long Short-Term Memory (LSTM)	3
3	Support Vector Machine (SVM)	2
4	K-Nearest Neighbor (KNN)	2
5	Systematic Literature Review (SLR)	2
6	Recurrent Neural Network (RNN)	1
7	Random Forest	1
8	Transfer Learning	1

Among the identified computational methods, CNN was the most frequently applied approach, appearing in 15 studies (55.56%). The dominance of CNN indicates its strong capability in automatically extracting relevant facial features from image data without requiring extensive manual feature engineering. Several studies also combined CNN with sequential models such as LSTM to analyze temporal changes in facial expressions, particularly in video-based pain detection. Other approaches, including SVM, RNN, KNN, Random Forest, and transfer learning, were also applied, demonstrating the diversity of computational strategies developed for infant pain recognition. The dominance of CNN shows that this algorithm has excellent capabilities in automatically extracting facial features and produces a high level of accuracy in image classification tasks. Several studies also combine CNN with other methods such as Long Short-Term Memory (LSTM) to analyze changes in facial expressions in video data. The use of other methods such as Support Vector Machine (SVM), Recurrent Neural Network (RNN), and YOLO shows the variety of approaches used to improve the performance of infant pain detection systems.

A research quality analysis was conducted to assess the methodological validity of the included articles. The quality assessment showed that most studies were of good methodological quality.

Table 3. Summary of Study Quality

Quality Category	Number of Studies	Percentage
High (Score 8)	19	70.37%
Moderate (Score 5–7)	8	29.63%
Low (Score ≤4)	0	0%

with a percentage of 70.37%. Meanwhile, only a small portion of the studies fell into the low category. This finding indicates that research on infant pain detection has developed with relatively mature methodology and can make a significant contribution to the development of artificial intelligence-based pain detection systems.

In addition to the dominance of facial expression-based approaches, research also indicates a growing trend toward multimodal approaches. Several recent studies have begun combining facial expressions with infant cries and physiological signals to improve the system's ability to recognize pain more accurately. This approach is believed to overcome the limitations of unimodal methods that rely solely on a single type of data. This development indicates an increasingly complex research direction oriented toward more concrete clinical implementation.

3.2. Discussion

Based on the analysis of 27 selected studies, infant pain detection research demonstrates a strong tendency toward the implementation of artificial intelligence methods, particularly Deep Learning-based approaches. Among the identified algorithms, CNN showed the highest frequency of use, indicating that image-based deep learning approaches have become the dominant strategy for analyzing infant facial expressions. This finding is consistent with previous studies reporting that CNN models are capable of automatically extracting complex facial features and achieving better performance compared with conventional machine learning approaches.

The dominance of facial expression-based approaches highlights the importance of visual behavioral indicators in infant pain assessment. Facial expressions provide a non-invasive and easily obtainable data source, making them suitable for automated monitoring systems. However, relying on facial expressions alone may not fully represent the complexity of pain responses because pain involves behavioral and physiological changes. Therefore, recent research has increasingly focused on multimodal approaches that integrate facial expressions, crying patterns, and physiological signals to improve detection reliability and overcome the limitations of single-parameter methods.

The quality assessment results indicate that most included studies demonstrated good methodological quality. However, several limitations remain, particularly related to dataset availability, dataset diversity, and the absence of standardized evaluation protocols. These limitations may affect the generalizability of developed models when applied to different clinical environments or infant populations. Therefore, future research should emphasize the development of larger and more representative datasets, standardized benchmarking procedures, and validation in real-world healthcare settings.

Overall, the findings indicate that artificial intelligence-based infant pain detection systems have considerable potential to support more objective and consistent clinical assessment. Nevertheless, further improvements are required before these technologies can be widely implemented in neonatal care, particularly regarding model reliability, clinical validation, and integration with existing healthcare workflows.

4. CONCLUSION

This study conducted a Systematic Literature Review to identify and analyze the methods and technologies used for infant pain detection through facial expression analysis. The findings from 27 reviewed studies indicate that facial expression is the most frequently utilized parameter because it provides a non-invasive and direct representation of pain-related behavioral responses. Furthermore, Deep Learning-based approaches, particularly Convolutional Neural Networks (CNNs), represent the dominant computational method due to their ability to automatically extract facial features and support effective pain classification from infant facial images.

The reviewed studies also demonstrate a growing trend toward multimodal approaches that integrate facial expressions with other indicators, such as infant crying patterns and physiological signals, to improve the reliability of pain detection systems. Although current developments show significant potential for supporting more objective and consistent infant pain assessment, several challenges remain, including limited dataset availability, lack of standardized evaluation procedures, and insufficient validation in diverse clinical environments.

Future research should focus on developing larger and more representative datasets, establishing standardized evaluation frameworks, and validating artificial intelligence-based pain detection models in real-world neonatal healthcare settings. These improvements are expected to enhance the reliability, generalizability, and clinical applicability of automated infant pain assessment systems.

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