Systematic Literature Review: Pain Detection in Infants Using Machine Learning

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Abstract

Detecting pain in infants is a significant challenge in the medical field because infants are unable to verbally express pain, meaning healthcare professionals must rely on subjective observations of behaviour and physiological responses. With the advancement of artificial intelligence technology, various studies have developed automated systems based on machine learning to detect pain through the analysis of facial expressions, crying sounds, and physiological signals such as heart rate and Electrodermal Activity (EDA). This study aims to identify the developments, methods, and technological trends in pain detection in infants through a Systematic Literature Review (SLR) approach. The research process followed the PRISMA 2020 guidelines, with data sources from Google Scholar, Scopus, Crossref, and OpenAlex covering the period 2015–2025. Based on the inclusion and exclusion criteria, 31 relevant studies were identified for analysis. The analysis covered data types, Machine Learning methods, and quality assessment using the GRADE approach. The results of the review indicate that the most commonly used algorithms are Convolutional Neural Networks (CNN), Support Vector Machines (SVM), Random Forests, and Recurrent Neural Networks (RNN). Overall, the application of Machine Learning shows great potential in improving the objectivity and accuracy of pain detection in infants, although further research is still required to develop a more optimal and clinically applicable system.

Keywords: *Pain Detection, Infants, Machine Learning, Facial Expressions, Systematic Literature Review.*

A. INTRODUCTION

Pain is an unpleasant sensory and emotional experience associated with, or resembling, actual or potential tissue damage (Jamal et al., 2022). Pain is a complex subjective experience and is one of the key indicators in assessing a person's state of health. In adults, pain can be communicated verbally, making the process of identifying and managing it relatively easier. However, this is not the case for infants, who, due to their developmental stage, do not yet possess the ability to communicate verbally. Consequently, the assessment of pain in infants relies sheavily on the interpretation of behavioural signs and physiological responses, such as facial expressions, crying, changes in body posture, and increased heart rate and respiratory rate. These observational methods are subjective and heavily influenced by the experience and perceptions of healthcare professionals, thereby potentially leading to inconsistencies in the assessment of pain in infants (Padila et al., 2023).

According to research in the field of nursing, a baby's cry has characteristics associated with the level of pain, and sound frequency parameters can be used as an early indicator of pain (Alpriani et al., 2022). This study established a range of crying frequencies as a standard for assessing the intensity of pain in infants during

immunisation, highlighting the importance of objective data representation for the assessment of pain in infants. In line with this, a Systematic Literature Review (SLR) conducted by Abdi Dharma et al. (2025) indicates that the development of technology-based pain detection methods utilising advanced sensors and algorithms is capable of providing more objective, rapid, and consistent detection compared to conventional manual techniques (Dharma et al., 2025).

With the rapid development of artificial intelligence technology, particularly Machine Learning (ML) and Deep Learning (DL), computational approaches are increasingly being applied in the healthcare sector to improve the objectivity and accuracy of diagnoses. ML enables systems to learn complex patterns from large volumes of data without the need for explicit programming. In the context of assessing pain in infants, ML algorithms can be utilised to process visual data such as facial expressions and audio data such as a baby's cries, thereby producing a pain detection system that is more consistent and minimises subjectivity. Deep Learning is a form of Machine Learning that uses artificial neural networks to teach computers to perform human-like behaviours, such as classifying images, text, or sounds directly (Christnatalis et al., 2024).

Research in Indonesia has demonstrated the potential for applying machine learning to the detection of pain in infants. A study on the implementation of Convolutional Neural Networks (CNNs) to detect pain in infants through facial images using the You Only Look Once (YOLO) approach has demonstrated that CNN models are capable of classifying infants' facial expressions into several emotional categories, including pain, although there remain challenges in improving classification accuracy under varying lighting conditions and facial angles (Tomy et al., 2021). In addition to visual approaches, the use of audio data has also shown promising results. Yusdiantoro & Sasongko (2023) applied the Mel-Frequency Cepstral Coefficients (MFCC) method to extract features from infant crying sounds, combined with a CNN to classify the meaning of the cries. The results of this study demonstrated a high level of accuracy, indicating that the patterns of a baby's cry can be utilised as a relevant data source in ML-based pain detection systems (Yusdiantoro & Sasongko, 2023).

Nevertheless, the results of these studies remain scattered across various publications, employing diverse approaches, algorithms, datasets and evaluation metrics. These differences make it difficult for both researchers and practitioners to gain a comprehensive understanding of the most effective methods, current research trends, and the challenges and opportunities for developing machine learning-based infant pain detection systems. Some studies emphasise visual approaches, whilst others focus on audio or multimodal data; however, there is as yet no systematic synthesis summarising the strengths, limitations, and research gaps of these various approaches, particularly within the context of research in Indonesia.

In this context, a Systematic Literature Review (SLR) is a relevant research method for identifying, evaluating and synthesising research findings on pain detection in infants using machine learning. Through the SLR approach, this study

aims to present a systematic mapping of the research, identifying the most widely used algorithms, the types of data analysed, model performance, and the challenges still faced. Consequently, the results of this SLR are expected to provide a strong scientific foundation for further research development and the implementation of ML-based infant pain detection systems in clinical settings.

The novelty of this study lies in the use of infant facial images to detect pain by applying a YOLO-based Convolutional Neural Network (CNN). This study classifies infant facial expressions into several categories, such as pain, sadness and neutral. Test results indicate that the CNN approach is capable of recognising patterns of infant facial expressions associated with pain; however, it remains dependent on static images and controlled data collection conditions within a clinical setting (Tomy et al., 2021). Meanwhile, this study conducted a systematic literature review of various machine learning methods used in the detection of pain in infants based on facial images, video expressions, sounds and physiological signals, thereby providing a more comprehensive overview of the development of these methods and their performance. Research by Kristian et al. (2020) used videos of infants' facial expressions to detect pain by combining a Deep Convolutional Neural Network (DCNN) and Long Short-Term Memory (LSTM).

This approach utilised visual and temporal information from the video to improve the accuracy of infant pain classification. Although it demonstrated better performance compared to static images, this study focused solely on one type of data, namely video footage of infants' faces (Kristian et al., 2018). The study presents a systematic review of various video-based and multimodal machine learning approaches for detecting pain in infants, thereby identifying the trends, strengths and limitations of each method employed. Research by Arafat et al. (2023) developed a system for classifying infant crying using machine learning based on Artificial Neural Networks (ANNs) and MFCC features. This study emphasised that the choice of algorithm and features significantly influences the system's performance in recognising an infant's condition based on their crying sounds. However, that study focused solely on a single algorithm and a single type of data. In contrast to that study, this research presents a novel approach by mapping and comparing various machine learning algorithms, such as ANN, CNN, LSTM, and other deep learning approaches used in the detection of pain in infants based on various types of data (audio, images, and video) through a Systematic Literature Review (Arafat et al., 2023).

B. METHOD

In this study, a secondary literature review method was employed, utilising a Systematic Literature Review (SLR) approach. This approach involved analysing published scientific articles without the direct collection of primary data. The SLR method enables research to be conducted in a systematic and transparent manner, thereby providing a comprehensive overview of the topic under investigation and identifying patterns and gaps in the existing research (Khoerunnisa et al., 2022).

The research was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol as a guideline for the identification, screening and selection of literature (Rizkiyah, 2025). Articles were searched for in academic databases such as Google Scholar, SINTA, and university digital libraries in accordance with the established inclusion and exclusion criteria. The selected articles were then analysed descriptively to systematically assess the quality of the methodology and research findings.

Through this PRISMA-based SLR approach, the study is expected to provide a comprehensive overview of relevant prior research, whilst establishing a solid theoretical foundation for future research. Thus, this study does not merely describe the existing literature, but also systematically assesses the methodological quality and findings of previous studies.

A structured process was followed, beginning with the formulation of research objectives and questions focused on the application of machine learning in the detection of pain in infants. Subsequently, a literature search strategy was established by identifying relevant keywords, such as infant pain detection, infant expressions, and machine learning. Articles were searched for across various national and international academic databases, such as Google Scholar, SINTA, and relevant journal portals. The retrieved articles then undergo an initial identification and screening stage based on titles and abstracts, followed by the establishment of inclusion and exclusion criteria, such as topic relevance, year of publication, and availability of full-text articles. Article selection is carried out using the PRISMA guidelines, followed by an assessment of article quality to ensure the reliability of the methodology and research results. The selected articles were analysed descriptively based on data type, machine learning methods, and research findings, then synthesised to provide an overview of research developments, and finally organised systematically into a thesis report.

Data analysis in this study was conducted based on the results of a Systematic Literature Review (SLR) of selected articles. The analysis process involved coding and thematic grouping based on the type of data used (facial images, crying sounds, or physiological signals), machine learning or deep learning methods, validation techniques, and system performance results. Subsequently, data synthesis was carried out by summarising the findings in the form of descriptions and thematic tables to illustrate the distribution of research based on year of publication, the approaches used, model performance, and the quality of research results. The data extraction process was carried out by two reviewers independently to minimise errors and bias, with the data collected including author names, year of publication, article sources, data types, algorithms, evaluation methods, and system performance results. Where information was unclear, a thorough review of the relevant articles was conducted, and articles lacking complete data were excluded from the analysis. The entire analysis process was carried out manually without the use of automated software to ensure the precision and accuracy of the study's results.

C. RESULTS AND DISCUSSION

1. Results of the Literature Review

The literature review for this study was conducted systematically and in a structured manner using various reputable academic databases, namely Google Scholar, Scopus, Crossref, and OpenAlex, with a publication range set between 2015 and 2025. This timeframe was selected to obtain relevant and up-to-date literature in line with developments in machine learning technology within the field of pain detection. The keywords used in the search process included pain detection, machine learning, CNN, baby, and infant, as well as various variations and combinations of similar terms to broaden the scope of the search results. Based on this initial search, a total of 21,082 articles were identified as initial data, which would subsequently undergo further selection.

Initial screening was carried out to eliminate generally irrelevant articles and remove duplicate data that could affect the quality of the analysis. During this stage, 5,655 articles were identified as duplicates and systematically excluded from the selection process. In addition, 5,642 articles were eliminated because their titles and abstracts did not align with the established research focus. This process aims to ensure that only articles with good initial relevance proceed to the next stage. Following this initial screening stage, 9,785 articles remained for the subsequent selection process.

In the next stage of the selection process, a more in-depth review of the article titles and abstracts was carried out to assess their specific relevance to the research topic. During this process, 9,595 articles were eliminated for various reasons, including not focusing on infants as the research subjects, not explicitly discussing pain detection, not using an artificial intelligence or machine learning approach, being classified as review or survey articles, and the unavailability of full-text access. This stage was carried out to filter articles more selectively so that only truly relevant research was retained. The result of this process left 190 articles that were deemed to meet the initial criteria for further evaluation.

The next stage involves an evaluation of the full text of the articles to assess the appropriateness of the methodology, the clarity of the data used, and the relevance of the research findings to the study's objectives. Of the total 190 articles evaluated, 159 were eliminated as they did not meet the established criteria, such as irrelevance to the research topic, limited access to the full text, being classified as review articles, or failing to provide clear and analysable datasets. This evaluation process was conducted meticulously to ensure that only articles of high quality and relevance were used in the research. Consequently, 31 articles were identified that met all criteria and were deemed suitable for further analysis in this study. The overall results of this literature selection process were then visualised in the form of a PRISMA 2020 flowchart to provide a clear and systematic overview of the selection stages undertaken.

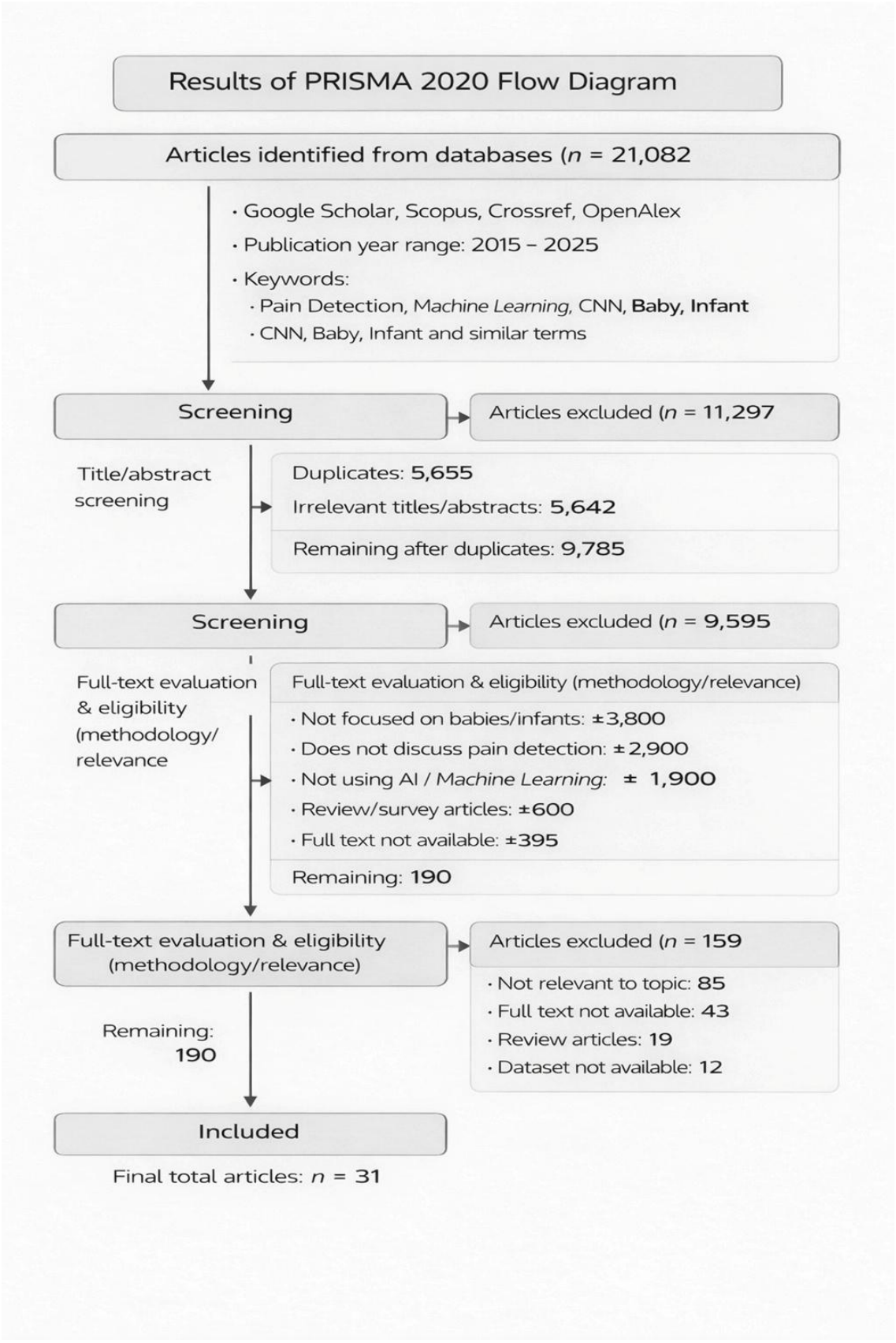

Figure 1. PRISMA 2020 Flowchart Results

2. Database Distribution in the Study

Of all 26 selected studies, the use of public databases was as follows:

Table 1. Database Used

Database	Number of Studies
Deep Learning	16
Machine Learning	15
Infant Pain Detection	12
Baby Cry Analysis	11
Audio Signal Processing	11
Facial Expression Analysis	9
Convolutional Neural Network (CNN)	7
Neonatal Pain Detection	6

The results indicate that research into pain detection in infants is dominated by the topics of deep learning and the use of machine learning. Furthermore, the analysis of facial expressions and infant crying is also widely used as a data source, making image- and audio-based approaches the most common methods in this research.

3. Sensor Modality Used

The types of sensors used in research vary depending on the experimental design and the data sources employed. The following are the most commonly used types of sensors in studies on pain detection in infants:

Table 2. The Sensors Used

Database	Number of studies
Facial Expressions	13
Baby Crying Audio	13
Heartbeat	3
Electrodermal Activity	3
Body Movement	3
Electromyography	2
Humidity Sensor	2
Electroencephalography	1
Blood Volume Pulse	1
Respiration Rate	1
SpO2	1
Temperature Sensor	1
Clinical Notes	1

The sensors used in this study vary, but the most commonly used are facial expressions and the sound of a baby's cry, as these are the clearest indicators of pain. Some studies have also incorporated body movements and heart rate to enhance the accuracy of the detection results.

4. Technologies and Methods Used

In the process of data processing and pain classification, various machine learning and deep learning methods are employed as required by the research. The following table shows the distribution of methods used in the studies analysed.

Table 3. Algorithmic Methods Used

Database	Number of Studies
CNN (Convolutional Neural Network)	34
SVM (Support Vector Machine)	10
Random Forest	5
RNN (Recurrent Neural Network)	4
Logistic Regression	2
Gradient Boosting	2
Ensemble	1
KNN	1
AdaBoost	1
Transformer	1
DNN	1
Naive Bayes	1
wav2vec 2.0	1
WavLM	1
HuBERT	1
ANN	1

Based on the analysed results, the CNN method was the most widely used and deemed the most suitable for this study, particularly for processing data on infant facial expressions. Meanwhile, SVM and Random Forest are typically used as comparison methods, whilst RNN is more suitable for audio data or time-series signals.

5. Study Quality Assessment (GRADE)

The quality assessment of the studies was conducted by adapting the GRADE system to the context of machine learning-based research into pain detection in infants. This assessment aimed to ensure that each article analysed met the criteria for topic relevance, methodological clarity and accountable reporting of results. The assessment criteria used in this study are as follows:

Table 4. Study Quality Assessment (GRADE)

No	Assessment Criteria	Assessment Details
1	Methodological Clarity	Assessing the extent to which the study describes the research design, experimental procedures, data processing techniques and the analysis process in detail and systematically.
2	The Relevance of Pain Detection	Assessing the relevance of research to the topic of pain detection, whether through physiological

		sensors, analysis of infant behaviour, facial expressions, crying sounds, or the application of machine learning.
3	Database Compatibility	Assessing the suitability of the datasets used in relation to the research focus, such as the BioVid Pain Database, iCOPEvid, UNBC-McMaster, or the Donate-A-Cry Corpus.
4	Algorithm Accuracy	Assessing whether the algorithm or model used is appropriate for the research objectives and capable of producing valid and meaningful results.
5	Research Replicability	Assessing the research's replicability by other researchers, including the availability of data, algorithms and clear documentation of methods.
6	Innovation and Contributions	Assessing the extent to which the research offers new approaches, innovative techniques, or insights that broaden our understanding and practice of pain detection in infants.
7	The Power of Validation and Evaluation	Assessing methods for validating research results, such as the use of cross-validation, testing with different datasets, or comparison with previous methods.
8	Clarity in the Writing and Presentation of Results	Assessing readability, writing structure, and the quality of the presentation of research findings, including tables, graphs and supporting visualisations.

Each study was evaluated against these eight criteria, with scores of 1 (met), 0.5 (partially met) and 0 (not met) assigned for each criterion. The scores for all criteria are then totalled to determine the study's quality level. With a maximum score of 8, articles scoring 6–8 are categorised as High, 4–5.5 as Moderate, and below 4 as Low.

Based on the evaluation of 31 articles, 5 studies were classified as High, 11 as Medium, and 5 as Low. Studies classified as High generally featured clear methodology, the appropriate use of datasets and algorithms, and comprehensive validation and presentation of results. Studies in the Moderate category still had some limitations, such as a lack of detail regarding validation or methodological documentation. Meanwhile, studies in the Low category generally did not adequately explain the analysis and evaluation processes. Overall, these results indicate that the majority of the analysed literature is of good quality and can support the discussion in the following section.

The results of the study quality assessment are as follows:

Table 5. Results of the Study Quality Evaluation

Quality Categories	Number of Studies
High	15
Moderate	11
Low	5

Most studies are of high quality, as they employ appropriate sensors, sound validation methods and clear reporting of results. Studies classified as moderate or low quality generally lack detail in their description of pain labelling or the validation process, as well as the sample size used.

6. Risk of Bias in Studies

Based on the ROBINS-I assessment

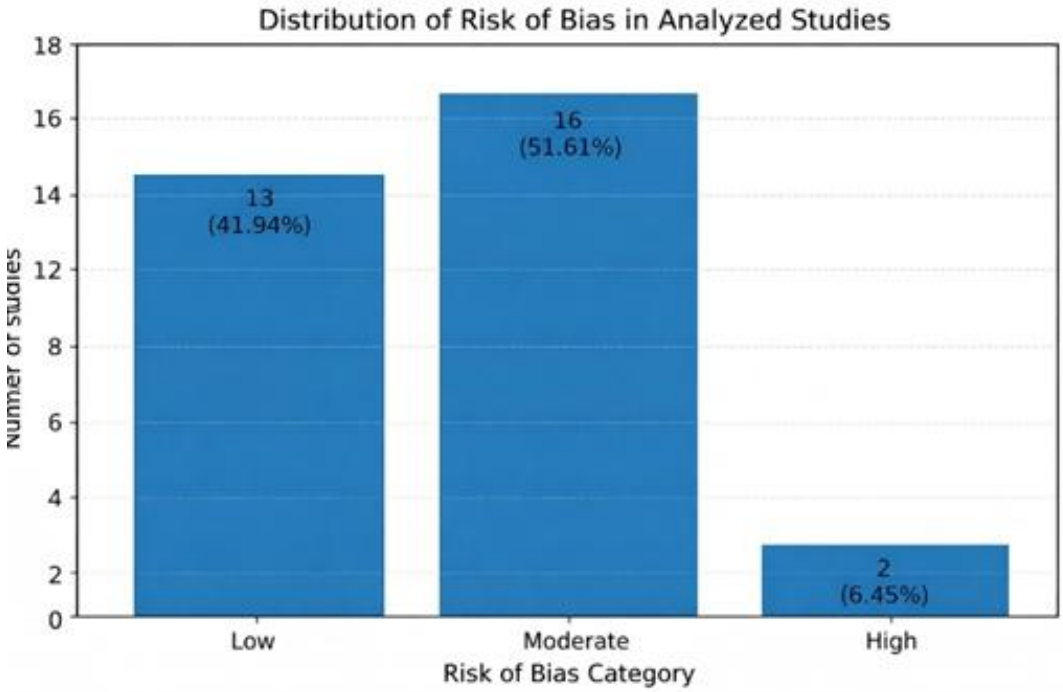

Figure 2. Bias Risk Diagram

The study focused on a synthesis analysis of 31 selected articles that had undergone a systematic screening process based on the PRISMA method, as described previously. The selection process was carried out in stages, from identification to the final inclusion stage, ensuring that the analysed articles were truly relevant to the topic of machine learning-based pain detection in infants. The results of the risk of bias analysis showed that the majority of studies fell into the moderate (51.61%) and low (41.94%) categories, whilst only 6.45% were classified as high. These findings indicate that the majority of studies possessed reasonably good methodological quality, although limitations remained regarding pain labelling, sample size, and cross-dataset validation.

Based on the findings of the review, the facial expression-based approach is the most commonly used method for detecting pain in infants. The study 'Neonatal Pain Detection from Facial Expressions Using Deep Learning' shows that CNN models are

capable of automatically recognising patterns in infants' facial expressions and producing better classification results than manual feature-based methods (Zhao et al., 2024). This finding is supported by the study 'Automatic Detection of Pain from Spontaneous Facial Expressions', which states that spontaneous facial expressions are strongly correlated with clinical pain intensity (Meawad et al., 2017). This explains why the visual approach has become dominant, as facial expressions are a non-invasive indicator that is easy to observe in a clinical setting.

Other studies have also developed more complex models. The study 'Camera-Based Discomfort Detection Using Multi-Channel Attention 3D-CNN' demonstrates that the use of 3D-CNNs is capable of capturing both spatial and temporal information simultaneously, making the system more sensitive to changes in infants' micro-expressions (Sun et al., 2021). Additionally, the study 'Automatic Infants' Pain Assessment by Dynamic Facial Representation' explains that factors such as gestational age and the angle at which the image is captured can affect the system's performance (Zhi et al., 2018). This is consistent with the findings of the risk of bias analysis, in which several studies of moderate quality did not describe the subjects' characteristics in detail.

The analysis of a baby's cries is also an important alternative to visual approaches. The study 'Automated Infant Pain Detection from Acoustic Features of Baby Cries' found that acoustic features such as pitch and sound energy exhibit different patterns between painful and non-painful conditions (Di et al., 2024). The study 'Infant Cry Classification Using CNN–RNN' shows that the combination of CNN and RNN is able to improve accuracy because it can capture both the spectral and temporal patterns of crying sounds (Nadia Maghfira et al., 2020). In the meantime, a comparative study based on MFCC concluded that algorithms such as SVM and Random Forest produce more stable results than other simpler methods (Riadi et al., 2024). This indicates that the choice of feature extraction methods and techniques has a significant impact on system performance. In the context of direct application in a clinical setting, the study 'Employing the Artificial Intelligence Object Detection Tool YOLOv8 for Real-Time Pain Detection' demonstrates that YOLOv8-based models are capable of real-time detection with a fast response time (Cascella et al., 2024). This capability is particularly important for monitoring in neonatal intensive care units.

Recent developments point towards a multimodal approach, which involves combining more than one type of data. The study 'Multimodal Automatic Assessment of Acute Pain through Facial Videos and Heart Rate Signals Utilising Transformer-Based Architectures' shows that combining facial and heart rate data yields better performance than a single-modality approach (Gkikas et al., 2024). The researchers behind the study 'Enhanced Multimodal Physiological Signal Analysis for Pain Assessment Using Optimised Ensemble Deep Learning' also reported that combining several deep learning architectures with physiological signals can improve the system's accuracy and stability (Gasmi et al., 2025). These findings suggest that a multimodal approach holds great promise, as it is capable of capturing pain responses from various aspects simultaneously.

Based on an analysis of 31 articles, the risk of bias distribution shows that the majority of studies fell into the moderate (51.61%) and low (41.94%) categories, whilst only 6.45% were classified as high. This indicates that the methodological quality of the research is generally quite good, although there are still limitations regarding dataset size, subject diversity and standardisation of assessment. Consequently, whilst the development of machine learning-based infant pain detection technology shows a positive trend, improving the quality of research design and clinical validation remains a key priority.

The results of the review indicate that deep learning methods, particularly CNNs and their variants, are the most widely used in research on pain detection in infants. This is because CNNs are capable of automatically recognising patterns in facial images and crying sounds. However, the results obtained in each study have not always been consistent. Differences in dataset quality and model testing methods are the main factors influencing accuracy levels. Therefore, consistency in data and evaluation methods remains crucial for improving the reliability of infant pain detection systems.

D. CONCLUSION

Based on the results of a Systematic Literature Review (SLR) using the PRISMA approach, covering 31 studies published between 2015 and 2025, it can be concluded that research into machine learning-based pain detection in infants has shown significant progress in recent years, with an increasing trend in publications peaking in 2024. In terms of research quality, the risk of bias analysis indicates that 51.61% of studies fall into the moderate category, 41.94% into the low category, and 6.45% into the high category; thus, overall, the majority of studies possess a reasonably good level of reliability with a low to moderate risk of bias. From a methodological perspective, deep learning approaches, particularly Convolutional Neural Networks (CNNs), have become the most dominant method used in detecting pain in infants, primarily through the analysis of facial expressions and crying sounds, whilst other methods such as Support Vector Machines (SVMs), Random Forests, and Recurrent Neural Networks (RNNs/LSTMs) have also been utilised in several studies.

Furthermore, a multimodal approach that integrates various types of data, such as facial images, crying audio and physiological signals, has been shown to improve system performance with a higher level of accuracy compared to a unimodal approach. Nevertheless, there remain a number of challenges that need to be addressed, including the limited availability of public datasets specifically for infants, variations in pain expressions, data imbalance, and the lack of consistent standardisation in pain annotation. Therefore, further research is recommended to focus not only on literature reviews but also on the direct development and testing of systems using real-world data, utilising larger, more diverse, and representative datasets to ensure the resulting models are more stable and generalisable. The development of multimodal approaches needs to be continuously improved as they

have proven to yield more optimal results, whilst testing implementation in clinical settings is a crucial step to ensure that the developed technology can be practically utilised to assist healthcare professionals in monitoring infants' conditions more objectively and accurately. As a direction for further development, future research could focus on the analysis and implementation of multimodal deep learning methods for pain detection in infants to produce systems that are more adaptive, reliable, and applicable in clinical practice.

REFERENCES

1. Abuzairi, T., Widanti, N., Kusumaningrum, A., & Rustina, Y. (2021). Implementasi convolutional neural network untuk deteksi nyeri bayi melalui citra wajah dengan YOLO. *Jurnal RESTI (Rekayasa Sistem dan Teknologi Informasi)*, *5*(4), 624-630.
2. Alpriani, S. L., Novayelinda, R., & Woferst, R. (2022). Validitas gelombang frekuensi tangisan bayi sebagai alat ukur nyeri saat penyuntikan imunisasi. *Jurnal Ners Indonesia*, *13*(1), 72-80.
3. Arafat, A. M., Priharti, W., & Rahmawati, D. (2023). Sistem Klasifikasi Tangisan Bayi Menggunakan Machine Learning. *E-Proceeding of Engineering*, *10*(3), 2132–2136.
4. Cascella, M., Shariff, M. N., Bianco, G. Lo, Monaco, F., Gargano, F., Simonini, A., Ponsiglione, A. M., & Piazza, O. (2024). Employing the Artificial Intelligence Object Detection Tool YOLOv8 for Real-Time Pain Detection: A Feasibility Study. *Journal of Pain Research*, *17*, 3681–3696. https://doi.org/10.2147/JPR.S491574
5. Christnatalis, C., Sozaro Lase, C. D., Sitompul, T. H., & Hondro, A. P. (2024). Klasifikasi Penyakit Pada Baglog Jamur Tiram Menggunakan Metode Convolutional Neural Network. *Jurnal Pendidikan dan Teknologi Indonesia*, *4*(11), 359–367. https://doi.org/10.52436/1.jpti.480
6. Dharma, A., Wijaya, J., Valentino, B., & Wijaya, V. (2025). Tinjaun Literatur Sistematis Terhadap Teknologi Kecerdasan Buatan untuk Deteksi Nyeri (2020-2024). *Metik Jurnal*, *9*, 2025. https://doi.org/10.47002/metik.v9i1.1068
7. Di, C., Magistrale, L., & Bioingegneria, I. N. (2024). *DIPARTIMENTO DI INGEGNERIA DELL ' INFORMAZIONE RIABILITAZIONE "Automated Infant Pain Detection from Acoustic Features of Baby Cries" Relatore: Dott.ssa Rubega Maria ANNO ACCADEMICO 2023-2024*. 1–71.
8. Gasmi, K., Hrizi, O., Aoun, N. Ben, Alrashdi, I., Alqazzaz, A., Hamid, O., Altaieb, M. O., Abdalrahman, A. E. M., Ammar, L. Ben, Mrabet, M., & Necibi, O. (2025). Enhanced Multimodal Physiological Signal Analysis for Pain Assessment Using Optimized Ensemble Deep Learning. *CMES - Computer Modeling in Engineering and Sciences*, *143*(2), 2459–2489. https://doi.org/10.32604/cmes.2025.065817
9. Gkikas, S., Tachos, N. S., Andreadis, S., Pezoulas, V. C., Zaridis, D., Gkois, G., Matonaki, A., Stavropoulos, T. G., & Fotiadis, D. I. (2024). Multimodal automatic assessment of acute pain through facial videos and heart rate signals utilizing transformer-based architectures. *Frontiers in Pain Research*, *5*(March). https://doi.org/10.3389/fpain.2024.1372814

10. Jamal, F. (2022). Penilaian dan modalitas tatalaksana nyeri. *Jurnal Kedokteran Nanggroe Medika*, *5*(3), 66-73.
11. Khoerunnisa, U., Sari, Y. P., & Kartika, D. (2023). Systematic Literature Review (SLR) Tentang Kinerja Keuangan Perbankan di Indonesia. *Jurnal Ekonomi dan Pendidikan*, *20*(2), 27-45.
12. Kristian, Y., Purnama, I. K. E., Sutanto, E. H., Zaman, L., Setiawan, E. I., & Purnomo, M. H. (2018). Klasifikasi Nyeri pada Video Ekspresi Wajah Bayi Menggunakan DCNN Autoencoder dan LSTM. *Jurnal Nasional Teknik Elektro Dan Teknologi Informasi (JNTETI)*, *7*(3), 308–316. https://doi.org/10.22146/jnteti.v7i3.440
13. Meawad, F., Yang, S. Y., & Loy, F. L. (2017). Automatic detection of pain from spontaneous facial expressions. *ICMI 2017-Proceedings of the 19th ACM International Conference on Multimodal Interaction*, *2017*(February), 397–401. https://doi.org/10.1145/3136755.3136794
14. Nadia Maghfira, T., Basaruddin, T., & Krisnadhi, A. (2020). Infant cry classification using CNN-RNN. *Journal of Physics: Conference Series*, *1528*(1). https://doi.org/10.1088/1742-6596/1528/1/012019
15. Padila, P., Andri, J., & Andrianto, M. B. (2023). Intervensi Family Triple Support (FTS) Berpengaruh terhadap Respon Bayi pada saat Imunisasi DPT. *Journal of Telenursing (JOTING)*, *5*(2), 3258–3265. https://doi.org/10.31539/joting.v5i2.7920
16. Riadi, P. A., Faisal, M. R., Kartini, D., Nugroho, R. A., Nugrahadi, D. T., & Magfira, D. B. (2024). A Comparative Study of Machine Learning Methods for Baby Cry Detection Using MFCC Features. *Journal of Electronics, Electromedical Engineering, and Medical Informatics*, *6*(1), 73–83. https://doi.org/10.35882/jeeemi.v6i1.350
17. Rizkiyah, N. (2025). Strategi dan Tantangan Manajemen Pendidikan Tinggi: Systematic Literature Review Menggunakan Metode PRISMA. *Jurnal Ilmiah Literasi Indonesia*, *1*(2), 194–202.
18. Sun, Y., Hu, J., Wang, W., He, M., & De With, P. H. N. (2021). Camera-based discomfort detection using multi-channel attention 3D-CNN for hospitalized infants. *Quantitative Imaging in Medicine and Surgery*, *11*(7), 3059–3069. https://doi.org/10.21037/qims-20-1302
19. Yusdiantoro, S. Y., & Sasongko, T. B. (2023). Implementasi Algoritma MFCC dan CNN dalam Klasifikasi Makna Tangisan Bayi. *The Indonesian Journal of Computer Science*, *12*(4), 1957–1968.
20. Zhao, F., Zhang, C., Dudding, K. M., Sanders, A. N., Lewis-Chumley, P., & Kathryn, L. (2024). Neonatal Pain Detection from Facial Expressions Using Deep Learning. *Research Square*, 1–16. https://doi.org/10.21203/rs.3.rs-3979706/v1
21. Zhi, R., Goldgof, D., Ashmeade, T., & Sun, Y. (2018). Automatic infants' pain assessment by dynamic facial representation: Effects of profile view, gestational age, gender, and race. *Journal of Clinical Medicine*, *7*(7), 1–16. https://doi.org/10.3390/jcm7070173