Original article

Noninvasive way for the detection of neonatal jaundice using GBR

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Abstract

Background: Neonatal jaundice is a common condition in newborns because of excess levels of bilirubin. The traditional method for bilirubin testing is invasive, i.e., only via blood tests, which may cause neonate discomfort. Therefore, this study used machine learning algorithms to develop a noninvasive method to detect neonatal jaundice.
Objective: This study aimed to design a computer-aided support system to detect neonatal jaundice using a machine learning algorithm.
Methods: The gradient boosting regression model was used to predict the bilirubin level. Gradient boosting is a robust boosting algorithm that combines several weak learners into strong learners, in which each new model is trained to minimize a loss function, such as the mean squared error or cross-entropy of the previous model, with gradient descent.
Results: This study involves ensemble methods, which consist of non-linear methods that can improve the system's overall accuracy. The results revealed a better correlation between the actual and predicted bilirubin levels, with an efficiency (r^2) of 0.86.
Conclusion: The hybrid approach for predicting neonate bilirubin levels offers a promising noninvasive alternative to traditional blood tests. While the current model shows a positive correlation with ground truth values, further refinement is required to address the observed discrepancies.

Keywords: Bilirubin, hyperbilirubinemia, image processing, neonatal jaundice.

Neonatal jaundice is characterized by elevated levels of bilirubin in the blood because of an immature liver, and it is a common condition that affects newborns worldwide.(1) A pathological test is the gold standard method for the measurement of bilirubin level. However, pathological testing is generally time-consuming, which may lead to a delay in treatment. Therefore, the timely and accurate assessment of bilirubin levels is required to prevent severe complications, such as kernicterus, which may lead to neonatal mortality. Recent advances in technology have led to the exploration of noninvasive approaches, integrating machine learning and computer vision to enhance predictive accuracy and reduce neonate discomfort.

A significant body of literature has focused on the development and refinement of these methods. Abdulrazzak AY, *et al*. presented a real-time jaundice detection system using machine learning models, which demonstrated high accuracy in identifying jaundice from skin images of neonates.(1) Similarly, Ahmad, *et al.* proposed a computer-aided system for the automated detection of jaundice, thus emphasizing the potential for clinical application and early diagnosis.(2) Sreedha B, *et al*. explored noninvasive diagnosis techniques using computer vision, thereby highlighting the benefits of a reduced need for frequent

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blood sampling.[3] Anggraeni MD, *et al.* investigated the use of smartphone-captured chest images to estimate jaundice levels, which provides an accessible and cost-effective alternative for remote areas.[4] Juliastuti E, *et al*. focused on skin color image analysis to estimate the risk zone for newborn jaundice and demonstrated the viability of this method in clinical settings.[5] In addition, Munkholm SB, *et al*. explored the use of smartphone cameras for transcutaneous bilirubin measurement, revealing the practicality and convenience of this approach.[6]

Sohani M, *et al*. proposed a neuro-fuzzy approach to diagnose neonatal jaundice, leveraging the strengths of neural networks and fuzzy logic.[7] Their key finding was that this hybrid method could effectively manage the inherent uncertainty and variability of medical data, thereby improving diagnostic accuracy. The method involved training a neuro-fuzzy system on clinical data, which then provided diagnostic outputs based on the input parameters such as skin color and bilirubin levels. The results indicated that the neuro-fuzzy approach outperformed the traditional methods, providing a promising tool for neonatal jaundice diagnosis and achieving 78.0% accuracy.[7] Whereas Guo G, *et al.* explored the use of the K-nearest neighbors (KNN) model in classification tasks. Their study demonstrated that the KNN model, when applied to medical datasets, could classify the cases with high accuracy. They utilized various datasets to evaluate the model, and they found that KNN's simplicity and effectiveness made it a valuable tool for medical diagnosis. These results highlighted KNN's potential in classifying neonatal jaundice cases, although its performance is heavily dependent on the choice of parameters and distance metrics. The result showed that the model achieved a reduction rate of 90.4%.[8]

Kumar SA, *et al*. developed a noninvasive biomedical system to quantify neonate bilirubin levels.[9] This system used optical sensors to measure the bilirubin concentration transcutaneously. Their key finding was that the system could provide reliable measurements that were comparable to those of traditional blood tests. The method involved calibrating the optical sensors against standard bilirubin measurements, followed by clinical testing on neonates. The results revealed that the noninvasive system significantly reduced the need for invasive blood drawings, thus improving patient comfort and care efficiency.[9] Whereas Mansor MN, *et al*. investigated a color detection method for the monitoring of jaundice in newborns. They found that analyzing skin color could effectively indicate the bilirubin levels. The method involved capturing images of the newborn's skin and processing these images to detect jaundice-related color changes. The results indicated that this approach could serve as a simple and cost-effective monitoring tool, which is particularly useful in resource-limited settings. Further refinement and validation of the color detection algorithms were suggested to enhance accuracy. Moreover, kurtosis can be used as a major feature when designing a classifier.[10] Mansor MN, *et al*. extended their previous work by combining preprocessing techniques with color detection methods to improve the jaundice monitoring accuracy. Their key finding was that preprocessing steps, such as noise reduction and contrast enhancement, significantly improved the detection accuracy. The method involved employing various image preprocessing techniques before performing the color analysis on the images. The results exhibited a marked improvement in the detection rate, thus making it a more robust solution for neonatal jaundice monitoring. They used features such as entropy, mean, standard deviation, skewness, and kurtosis energy for a classifier.[11]

Bhutani VK, *et al*. provided comprehensive global estimates of neonatal hyperbilirubinemia and its associated impairments.[12] Their study highlighted the high incidence rates and substantial health burden of severe jaundice in neonates. They used epidemiological data from various regions to estimate hyperbilirubinemia prevalence and outcomes. The findings highlight the need for effective screening and management strategies to reduce the incidence and prevent the severe consequences of untreated jaundice.[12] Laddi A, *et al*. developed a machine vision-based system for noninvasive jaundice detection, and their key finding was that machine vision techniques could accurately detect jaundice by analyzing skin images. This method involved capturing high-resolution images of the neonate's skin and using image processing algorithms to identify jaundice. The results show a variance of 89.0%.[13]

Aune A, *et al*. focused on developing a smartphone-based tool to diagnose jaundice.[14] The study found that smartphones could be used effectively to capture and analyze images to detect jaundice. The method involved using a smartphone camera to capture images of the neonate's skin, and these images were then processed with a dedicated application.[14]

de Greef L, *et al*. introduced Bilicam, a mobile phone application designed to monitor newborn jaundice.(15) The key finding was that Bilicam could accurately estimate bilirubin levels using smartphone-captured images. This method involved capturing images of the neonate's sclera, and then advanced image processing algorithms were used to estimate bilirubin concentration. The predicted bilirubin levels correlate with the total serum bilirubin (TSB) by a rank order correlation of 0.85, with a mean error of 2.0 mg/dL. These results indicated that Bilicam could serve as a practical, noninvasive tool for jaundice monitoring, thereby providing parents and healthcare providers with a convenient option for early detection.(15) Polley N, *et al*. developed a non-contact optical device for the online monitoring of jaundice.(16) Their device could continuously monitor bilirubin levels without direct contact with the neonate. The method involved the use of optical sensors to detect bilirubin levels based on the reflection and absorption of light from the skin. The results showed that the non-contact device provided accurate and continuous jaundice monitoring, thus enhancing patient comfort and reducing the risk of infection.(16)

Singla R, *et al*. proposed a framework for jaundice detection using homomorphic filtering-based image processing, which is an image processing technique that could effectively enhance the visibility of jaundice indicators in skin images.(17) This method involved applying homomorphic filtering to improve the image contrast and clarity, followed by analysis to detect jaundice.(17) Whereas Aydýn M, *et al*. developed a comprehensive neonatal jaundice detection system using advanced imaging techniques. The method involved capturing and analyzing images of the neonate's skin using a specialized imaging device.(18) Azar AT, *et al.* introduced a hybrid system that combined bijective soft computing and neural networks for diagnosing neonatal jaundice. This hybrid system improved diagnostic accuracy by leveraging the strengths of both approaches. The method involved integrating bijective soft computing techniques with neural network models to analyze the clinical data. The results indicated that the hybrid system provided a more accurate and robust diagnosis compared to that of traditional methods, which emphasizes its potential for clinical application.(19) Santhanam R, *et al*. experimented with the XGBoost algorithm for prediction and classification tasks, including jaundice detection. XGBoost provided high accuracy and efficiency when managing large datasets. The method involved training the XGBoost model on various datasets to predict and classify cases.(20)

Outlaw F, *et al*. evaluated the use of smartphones for the screening of neonatal jaundice. The method involved using smartphone cameras to capture images of the neonate's skin and analyzing these images with a dedicated application.(21) Furthermore, Brit H, *et al*. conducted a study on the prevalence and risk factors of neonatal jaundice in a hospital setting. Their key finding was that neonatal jaundice was prevalent among healthy term neonates, with various risk factors that contributed to its occurrence. The method involved collecting and analyzing clinical data from newborns to identify the prevalence and associated risk factors of jaundice.(22) Alsaedi SA, *et al.* investigated the use of transcutaneous bilirubin measurements during phototherapy. Their key finding was that the transcutaneous measurements could reliably track bilirubin levels even during treatment. The method involved the use of transcutaneous bilirubinometers to noninvasively measure the bilirubin levels during phototherapy sessions.(23) Munkholm SB, *et al*. explored the use of smartphone cameras for the transcutaneous measurement of bilirubin. Their key finding was that smartphone cameras could provide accurate bilirubin measurements that were comparable to those of traditional devices. The method involved capturing images of the neonate's skin using smartphone cameras and processing these images to estimate the bilirubin levels.(6) Kawano S, *et al*. studied non-contact and noninvasive methods for detecting neonatal jaundice and predicting the bilirubin levels. Their key finding was that these methods could accurately detect jaundice without physical contact, thereby enhancing patient comfort. The method involved the use of optical sensors and imaging techniques to noninvasively assess the bilirubin levels. The results demonstrated the potential of non-contact methods for accurate and comfortable jaundice detection.(24)

Juliastuti E, *et al*. focused on estimating the risk zone for newborn jaundice based on skin color image analysis. The method involved capturing and processing skin color images to identify the risk levels.(5) Hashim W, *et al*. developed a computer vision system for detecting neonatal jaundice. The method involved using image processing algorithms to analyze skin images and detect jaundice indicators.(25) Anggraeni MD, *et al*. explored the use of smartphone-captured chest images to estimate neonatal jaundice. This method involved capturing chest images with a smartphone and processing these images to detect jaundice.[4] Sreedha B, *et al*. investigated noninvasive early diagnosis techniques for jaundice using computer vision. The method involved the use of computer vision algorithms to analyze skin images for jaundice indicators.[3] Abdulrazzak AY, *et al*. developed a computer-aided system for automated jaundice detection. The method involved the training of machine learning models on clinical data to automate the detection process.[2] Thereafter, they presented a real-time jaundice detection system using machine learning models. The method involved training machine learning algorithms on a large dataset of clinical images and using these models for real-time jaundice detection.[1] This review of existing literature highlights the significant advancements made in the field of neonatal jaundice detection. Various methods, ranging from neuro-fuzzy systems to machine learning models, have been developed to improve the accuracy and noninvasiveness of jaundice diagnosis. Despite these advances, there remain substantial gaps in the literature. Existing studies often lack comprehensive integration of the various data sources and machine learning techniques, thus limiting their predictive accuracy and robustness. Furthermore, the generalizability of these models to diverse populations and varying clinical conditions remains underexplored. This study addresses these gaps by proposing a hybrid approach for predicting bilirubin levels in neonates. By designing an ensemble machine learning model and integrating diverse data sources, our approach aimed to enhance predictive accuracy and reliability. This ensemble model leverages the strengths of individual techniques, thereby providing a more robust and generalizable solution. In summary, this study aimed to develop a comprehensive and accurate predictive tool for evaluating neonatal bilirubin levels to potentially improve early diagnosis and intervention for neonatal jaundice.

Materials and methods

This study included 192 neonates from Acharya Vinoba Bhave Rural Hospital (AVBRH), Wardha, between July 2019 and December 2020. This study was reviewed and approved by the Institutional Ethics Committee of Datta Meghe Institute of Medical Science (approval no. DMIMS(DU)/IEC/2019/7863). A Google Pixel camera was used to capture the images of all neonates under a controlled environment. A manually designed color calibration card was used while capturing the image. The color calibration card consisted of twelve colors. Image quality was rigorously assessed by applying a threshold to the standard deviation of pixel values for each color patch on the color calibration card. **Figure 1** shows the sample input image captured with a color calibration card.

Figure 1. Sample input image.

The objective of this study was to develop a decision support system for the early detection of jaundice in neonates. Neonatal jaundice can be characterized by the discoloration of the skin and sclera, and for the detection of skin discoloration, this study converted the original RGB (red, green, blue) color values into YCbCr and Lab color spaces.

Conversion equations for YCbCr are as follows:

$$Y = 0.257\,R + 0.504\,G + 0.098\,B + 16 \quad (1)$$
$$Cb = -0.148\,R - 0.291\,G + 0.439\,B + 128 \quad (2)$$
$$Cr = 0.439\,R - 0.368\,G - 0.071\,B + 128 \quad (3)$$

To train the regression model, twelve features were considered, including the means of the RGB channels, YCbCr, and Lab color spaces, and three features derived from the linear gradient of the RGB plane. These features, along with the TSB values, were used to train the gradient boosting regression model. Several weak learners were combined to form the strong learners. For training of the new model, gradient descent was employed to minimize the loss function. For every iteration, the algorithm computed the gradient descent of the loss function with respect to the predictions of the current ensemble, and a new weak model was then trained to minimize this gradient. The predictions of the new model were then added to the ensemble, and the process was repeated until it met the stopping criterion.

Results

The individual regression algorithms performed similarly in terms of correlation with the traditionally measured TSB values. However, it was observed that the algorithm performed differently on individual samples. When the actual bilirubin values were > 12 mg/dL, the linear method predicted an underreported bilirubin level. This study involves an ensemble method that consists of non-linear methods that can improve the system's overall accuracy. **Figure 2** illustrates the comparison between TSB levels obtained from traditional blood tests and the bilirubin levels predicted using a noninvasive approach based on the skin color of neonates. The scatter plot reveals a positive correlation between the ground truth TSB levels and the predicted bilirubin levels.

Discussion

These results suggest that this noninvasive method can potentially estimate bilirubin levels, although there are instances of deviation where the predicted values

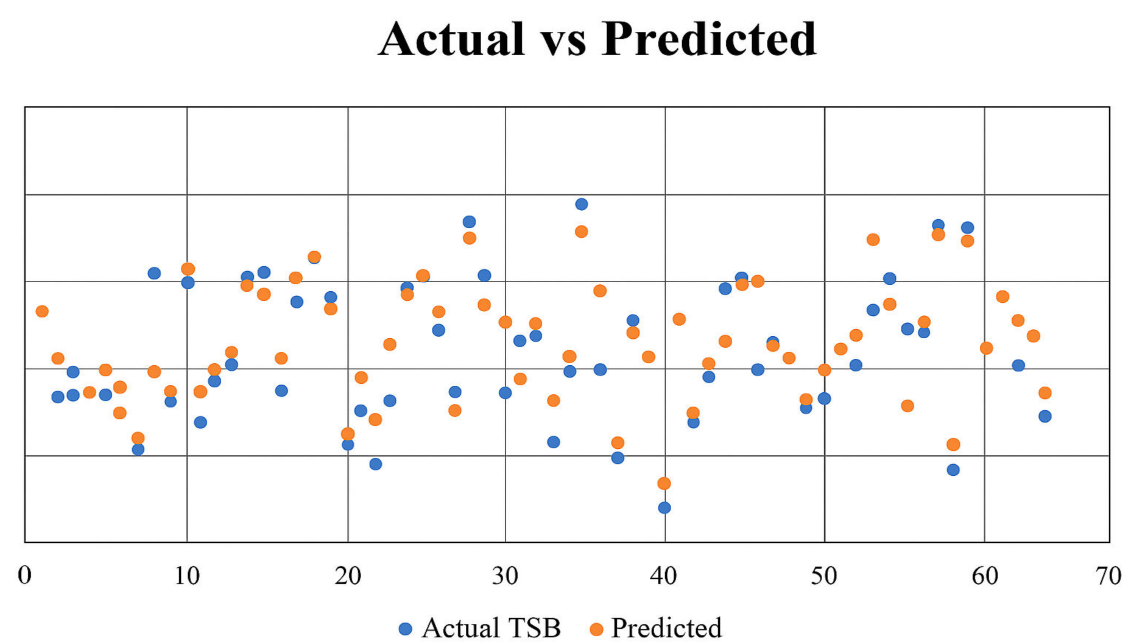

Figure 2. Comparison of TSB ground truth and predicted bilirubin level.

do not align perfectly with those of the ground truth. While our approach exhibits a reasonable alignment with the ground truth, there are notable discrepancies. These discrepancies may be due to several factors, including varying skin tones among neonates, lighting conditions during image capture, and the inherent variability of the noninvasive measurement process. Similar challenges were discussed by de Greef L, *et al*. [15], where the Bilicam system also faced difficulties in achieving perfect accuracy because of similar factors. Outlaw F, *et al*.[26] demonstrated that using smartphones for screening neonatal jaundice could be a feasible alternative to traditional methods, albeit with certain precision limitations. The scatter in our results echoes these findings, thus highlighting the trade-off between noninvasiveness and accuracy. The root mean square error and mean absolute error could be further calculated to quantify these discrepancies, as suggested by Abdulrazzak AY, *et al*. [2] in their study on automated jaundice detection systems. Despite these discrepancies, the noninvasive method demonstrates promise for initial screenings and continuous monitoring of bilirubin levels, which can be particularly advantageous in resource-limited settings or for home monitoring. By reducing the need for frequent blood draws, this approach can minimize discomfort and risk for neonates. Moreover, the convenience and potential for real-time monitoring, as discussed in the studies by de Greef L, *et al*. [15] and Outlaw F, *et al*. [26], support the integration of such hybrid approaches into clinical practice. The flow of execution of the methodology is shown in **Figure 3.** Future improvements could focus on enhancing the accuracy of the prediction model by incorporating additional parameters, such as skin tone classification, and improved image processing algorithms and machine learning techniques. More comprehensive datasets spanning a wider range of neonate demographics would also refine the model. In addition, integrating this approach with clinical workflows and validating it in diverse clinical settings are crucial steps toward its broader adoption.

Conclusion

Classification of jaundice using image processing has emerged as a vital noninvasive approach to diagnosing neonatal jaundice, which is characterized by the yellowing of the skin and sclera because of elevated bilirubin levels. This method focuses on advanced digital image processing and machine learning techniques to enhance diagnostic accuracy while minimizing neonate discomfort.

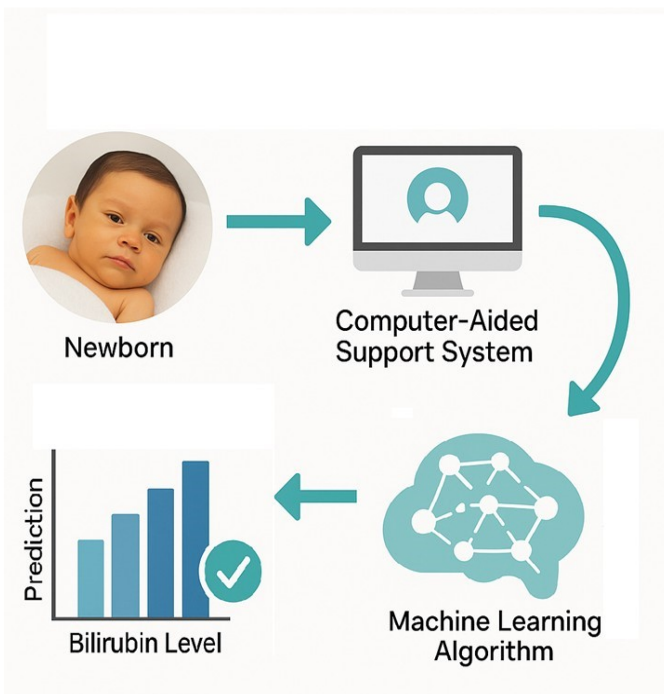

Figure 3. The flow of execution of methodology.

This gradient boosting regression model for predicting neonate bilirubin levels offers a promising noninvasive alternative to traditional blood tests. While the current model shows a positive correlation with the ground truth values, further refinement is required to address the observed discrepancies. While advances in image processing for jaundice classification are promising, there are challenges, such as the need for extensive datasets and potential variability in image quality across different devices. Nonetheless, these methods represent a considerable step toward improving neonatal care. Continued research and development, as well as drawing on insights from previous studies, will be essential in advancing this technology for its effective clinical use.

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Conflict of interest statement
The authors declare that they have no conflicts of interest.

Data sharing statement
All data generated or analyzed in the present study are included in the published article. Further details are available for non-commercial purposes from the corresponding author upon reasonable request.

References

1. Abdulrazzak AY, Mohammed SL, Al-Naji A, Chahl J. Real-time jaundice detection in neonates based on machine learning models. BioMedInformatics 2024; 623-37.
2. Abdulrazzak AY, Latif Mohammed S, Al-Naji A, Chahl J. Computer-aid system for automated jaundice detection. J Tech 2023;5:8-15.
3. Sreedha B, Nair PR, Maity R. Non-invasive early diagnosis of jaundice with computer vision. Procedia Comput Sci 2022;218:1321-34.
4. Anggraeni MD, Fatoni A, Rahmawati E. Nartiningsih I, editors. Estimation of neonatal jaundice from the chest images captured with a smartphone. Proceedings of the Soedirman International Conference on Mathematics and Applied Sciences (SICOMAS 2021); 2022 May 25; Dordrecht, The Netherlands:Atlantis Press; 2022. p. 23-6.
5. Juliastuti E, Nadhira V, Satwika YW, Aziz NA. Zahra N, editors. Risk zone estimation of newborn jaundice based on skin color image analysis. 2019 6th International Conference on Instrumentation, Control, and Automation (ICA); 2019 31 July-2 Aug; Bandung, Indonesia: IEEE;2019. p.176-81.
6. Munkholm SB, Krøgholt T, Ebbesen F, Szecsi PB, Kristensen SR. The smartphone camera as a potential method for transcutaneous bilirubin measurement. PLoS One 2018;13:e0197938.
7. Sohani M, Kermani KK, Makki B, Riazati A, Sadati N, editors. A Neuro-Fuzzy approach to diagnosis of neonatal jaundice. Proceedings of the 1st international conference on Bio inspired models of network, information and computing systems; 2006 Dec 11-13; Cavalese, Italy: Association for Computing Machinery; 2006. p. 16-es.
8. Guo G, Wang H, Bell D, Bi Y, Greer K. KNN model-based approach in classification. Lect Notes Comput Sci 2003;2888:986-96.
9. Kumar SA, Bhadri PR, Beyette FR, Clark JF, Wurster W. Non-invasive biomedical system for the quantification of bilirubin in neonates. MWSCAS 2005;2:1778-81.
10. Mansor MN, Yaacob S, Hariharan M, Basah SN, Jamil SHFSA, Khidir MLM, et al. Jaundice in newborn monitoring using color detection method. Procedia Eng 2012;29:1631-5.
11. Mansor MN, Hariharan M, Basah SN, Yaacob S. New newborn jaundice monitoring scheme based on combination of pre-processing and color detection method. Neurocomputing 2013;120:258-61.
12. Bhutani VK, Zipursky A, Blencowe H, Khanna R, Sgro M, Ebbesen F, et al. Neonatal hyperbilirubinemia and Rhesus disease of the newborn: incidence and impairment estimates for 2010 at regional and global levels. Pediatr Res 2013;74 Suppl 1:86-100
13. Laddi A, Kumar S, Sharma S, Kumar A. Non-invasive jaundice detection using machine vision. IETE J Res 2013;59:591-6.
14. Aune A, Vartdal G, Jimenez Diaz G, Gierman LM, Bergseng H, Darj E. Iterative development, validation, and certification of a smartphone system to assess neonatal jaundice: Development and usability study. JMIR Pediatr Parent 2023;6:e40463.
15. de Greef L, Goel M, Seo MJ, Larson EC, Stout JW, Taylor JA, et al. Bilicam: using mobile phones to monitor newborn jaundice. Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing. Seattle, Washington: Adjunct Publication; 2014. p. 39-42.
16. Polley N, Saha S, Singh S, Adhikari A, Das S, Choudhury BR, et al. Development and optimization of a noncontact optical device for online monitoring of jaundice in human subjects. J Biomed Opt 2015;20: 067001.
17. Singla R, Singh S, editors. A framework for detection of jaundice in new born babies using homomorphic filtering based image processing. 2016 International Conference on Inventive Computation Technologies (ICICT); 2016 Aug 26-27; Coimbatore, India: IEEE; 2016.
18. Aydın M, Hardalaç F, Ural B, Karap S. Neonatal Jaundice Detection System. J Med Syst 2016;40:166.

19. Azar AT, Inbarani HH, Kumar SU, Own HS. Hybrid system based on bijective soft and neural network for Egyptian neonatal jaundice diagnosis. Int J Intell Eng Inform 2016;4:71-90.
20. Santhanam R, Uzir N, Raman S, Banerjee S. Experimenting XGBoost algorithm for prediction and classification of different datasets. Int J Control Theory Appl 2016;9:651-62.
21. Outlaw F, Meek J, MacDonald LW, Leung TS, editors. Screening for Neonatal Jaundice with a Smartphone. Proceedings of the 2017 International Conference on Digital Health; London, United Kingdom: Association for Computing Machinery; 2017. p. 241–2.
22. Brit H, Adendorff J, Huisamen D, Beukes D, Botha K, Herbst H, et al. The prevalence of neonatal jaundice and risk factors in healthy term neonates at National District Hospital in Bloemfontein. Afr J Prim Heal Care Fam Med 2018;10:e1-e6
23. Alsaedi SA. Transcutaneous bilirubin measurements can be used to measure bilirubin levels during phototherapy. Int J Pediatr 2018;2018:4856390.
24. Kawano S, Zin TT, Kodama Y, editors. A study on non-contact and non-invasive neonatal jaundice detection and bilirubin value prediction. 2018 IEEE 7th Global Conference on Consumer Electronics (GCCE); 2018 Oct 9-12; Nara, Japan: IEEE; 2018. p. 204-5.
25. Hashim W, Al-Naji A, Al-Rayahi IA, Alkhaled M, Chahl J. Neonatal jaundice detection using a computer vision system. Design*s* 2021;5:63.
26. Outlaw F, Nixon M, Odeyemi O, MacDonald LW, Meek J, Leung TS. Smartphone screening for neonatal jaundice via ambient-subtracted sclera chromaticity. PLoS One 2020;15:e0216970.