Point of Care Detection of Anemia in Non-Invasive Manner by Using Image Processing and Convolutional Neural Network with Mobile Devices

by

Md. Nafis Nakib Rahman - 16101195
Saif Abdullah Sadik – 16101222
Anindya Biswas – 16101185
Ratul Bin Tazul - 16101201

A thesis submitted to the Department of Computer Science and Engineering
in partial fulfillment of the requirements for the degree of
B.Sc. in Computer Science

Department of Computer Science and Engineering
BRAC University
April 2020

Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing degree at BRAC University.

2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.

3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.

4. We have acknowledged all main sources of help.

Student's Full Name & Signature:

Nafis

Md. Nafis Nakib Rahman
16101195

Sadik

Saif Abdullah Sadik
16101222

Anindya

Anindya Biswas
16101185

Ratul Bin Tazul
16101201

Approval

The thesis/project titled "Point of Care Detection of Anemia in a Non-Invasive Manner by Using Image Processing and Convolutional Neural Network with Mobile Device" submitted by

1. Md. Nafis Nakib Rahman (16101195)
2. Saif Abdullah Sadik (16101222)
3. Anindya Biswas (16101185)
4. Ratul Bin Tazul (16101201)

In Spring, 2020 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of B.Sc. in Computer Science on April 18, 2020.

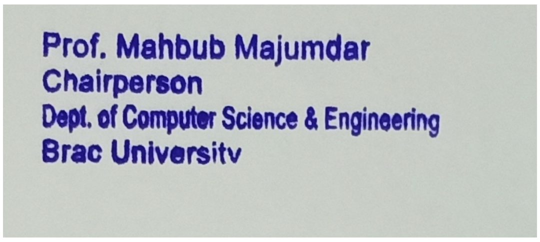
Examining Committee:

Supervisor:
(Member)

Rabiul

Dr. Golam Rabiul Alam
Associate Professor
Department of Computer Science and Engineering
BRAC University

Head of Department:
(Chair)



Dr. Mahbubul Alam Majumdar
Professor
Department of Computer Science and Engineering
Brac University

Ethics Statement

Hereby, We, Md. Nafis Nakib Rahman, Saif Abdullah Sadik, Anindya Biswas and Ratul Bin Tazul consciously assure that for the thesis "Point of Care Detection of Anemia in a Non-Invasive Manner by Using Image Processing and Convolutional Neural Network with Mobile Device" the following is fulfilled:

1. This paper is the authors' own original work, which has not been previously published elsewhere.
2. The paper is not currently being considered for publication elsewhere.
3. The paper reflects the authors' own research and analysis in a truthful and complete manner.
4. The paper properly credits the meaningful contributions of co-authors and co-researchers.
5. The results are appropriately placed in the context of prior and existing research.
6. All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference.
7. All authors have been personally and actively involved in substantial work leading to the paper and will take public responsibility for its content.

The violation of the Ethical Statement rules may result in severe consequences.

We agree with the above statements and declare that this submission follows the policies of BRAC UNIVERSITY as outlined in the Guide for Authors and in the Ethical Statement.

Corresponding Authors' Full Name Signature:

Nafis

Md. Nafis Nakib Rahman
16101195

Sadik

Saif Abdullah Sadik
16101222

Anindya

Anindya Biswas
16101185

Ratul Bin Tazul
16101201

Abstract

A medical procedure is described as non-invasive if there is no necessity for incision into the skin. Invasive methods can often be risky because there is a high chance of infection. That is why the medical sector is constantly trying to shift its momentum into non-invasive methods. The traditional method of detecting Anemia is by testing blood samples taken from the patient's body. Anemia is a medical condition when the human body suffers from a lack of RBC. RBC is the carrier of oxygen to the blood. If not checked regularly, this may lead to kidney failure or even premature births. The situation gets worse in the rural areas of developing nations, where medical equipment is often unavailable. This study proposes a non-invasive point of care solution using images captured from mobile phone videos. Image processing is a vastly used technique around the world. Mostly because it allows various algorithms to be applied and reduces the build-up of noise and deformation during image processing. Usually, an Anemic patient's blood contains less hemoglobin. Anemic blood transmits more light compared to normal blood, so the severity of anemia can be measured by analyzing the color of blood. Using the flashlight, the capturing of blood color was made possible without drawing blood. Hence, this paper tried to analyze the sample using python image processing that will enable the chances of a low-cost point of care solution for the detection of Anemia.

Keywords: *Anemia, Point of Care, Image Processing, Non-Invasive, Python, OpenCV, TensorFlow, Keras*

Dedication

Firstly, this research work is dedicated to our parents, without whom we would not have been here today. Through their sacrifices and meaningful lessons about life, they made us work hard and dedicate ourselves to achieve ultimate goals.

It is also dedicated to our beloved supervisor, who believed in us throughout this journey and always motivated us to keep looking for a solution. Without his guidelines and teachings, this would not have been possible.

Lastly, we dedicate this work towards BRAC UNIVERSITY, which as a standout institution of Bangladesh, is continuously giving support to its students for becoming a global citizen. Because of this platform, we were able to share the knowledge we gathered over time.

Acknowledgement

First and foremost, praises and thanks to the **Almighty Allah**, for His gift of knowledge and good health that he bestowed upon us throughout our research. Our greatest and most sincere gratitude goes towards our research supervisor Dr. Golam Rabiul Alam for giving us the opportunity and immensely providing us with his invaluable guidance throughout the research. In addition to being an outstanding teacher his vision, integrity, resilience, and sincerity have deeply inspired all of us. He has always challenged us to think outside the box and push ourselves to our absolute limit. Without his counsel, our thesis would not have turned out as we had hoped it would be. It was an outright privilege and honor to work under his guidance.

We would also like to thank our respected BRAC University for always providing us with the necessary facilities, equipment, and resources during our research period. We would like to extend our deepest thanks to all the faculty members of the CSE department. Without their precious lessons, they taught us throughout our entire undergraduate period, we would not have been here today.

Last but certainly not the least, we are beyond grateful and indebted to our beloved parents for their love, compassion and all the sacrifices they went through to give us a fighting opportunity in life and preparing us for the future. We are exceedingly thankful to all our peers and fellow classmates for their love, support and getting us through all the tears and hardship. Life wouldn't have been the same without their presence.

Table of Contents

List of Figures

Nomenclature

The next list describes several symbols & abbreviation that will be later used within the body of the document

API Application Program Interface

APS Active-Pixel Sensor

CBC Complete Blood Test

CNN Convolutional Neural Network

CO Carbon Monoxide

COHb Carboxyhemoglobin

D Dimension

EIS Electrical Image Stabilization

FPS Frames Per Second

GA Genetic Algorithm

Hb Hemoglobin

HbO_2 Oxygenated Hb

HDR High Dynamic Range

JPEG Joint Photographic Experts Group

KNN K-Nearest Neighbour Algorithm

LED Light Emitting Diode

MCC Matthews correlation coefficient

metHb Methemoglobin

ML Machine Learning

MMD Minimum Mean Distance

OIS Optical Image Stabilization

PNG Portable Network Graphics

POC Point of Care

RBC Red Blood Cells

RGB Red, Green and Blue

SpO_2 Oxygen Saturation

SVM Support Vector Machine

Chapter 1

Introduction

1.1 Background

In the modern world, Anemia is considered as one of the worldwide phenomena of diseases. Yearly it affects over 1.62 billion people, which is about 24.8 percent of the world population.[39] In medical terms, anemia is a physical condition, when blood doesn't contain adequate RBC, which helps to carry oxygen to different parts of the human body. Without oxygen, people may feel weak or exhausted. Anemia often is not considered a sole disease but a symptom that may lead to other fatal conditions. However, anemia can be often deadly by considering the fact that anemia has a solid association with the heart. Out of all the types, iron deficiency anemia is the most well-known condition of anemia all over the world. It often occurs in pregnant women. During pregnancy, the female body needs a lot of nutrient components, Iron is one of them. Iron helps to supply the increasing demand for blood as well as Hb for mother and fetus.[28] Because of iron deficiency anemia, many premature deaths happen. Even it impacts the mental development of a child and may cause underweight babies. Thus, constant monitoring of Anemia is a must for pregnant women.

RBCs are the main components of Hemoglobin (Hb). Hb is the reason RBC gets its disc-like shapes, which help them to move freely through blood vessels. Also, Hb carries up to four molecules of oxygen. Hence, the measurement of Hb concentration in blood is an Anemia detection standard. Usually, Hb level of less than 13.5 is considered anemia among men, while less than 12.0 among women.[9] While medical checkups, mainly two things are given priority for anemia detection: patients medical and family background and CBC report. CBC tests evaluate overall blood condition by measuring the RBC, WBC and other components of blood. Through these diagnoses, the levels of the RBC and hemoglobin are accessed. But these methods are often not available in rural areas.

Traditional ways to detect Anemia require advanced medical equipment and trained personnel. Usually, the Hb level is measured in a CBC report. To perform this test, a medical professional need to collect the blood of a patient with a syringe. However, any invasive method might be a source of contagious disease. All these are costly to conduct and often none of these are available in rural areas. This research aims to find a point of care solution, which will not only help to give results immediately but also detect Anemia non-invasively. To achieve this goal, we approached by capturing videos of fingers through smartphone flashlight. This gave us access to the images of blood under the skin without piercing it. Then, we tried to calculate different color codes of blood by running various machine learning algorithms. Afterward, we trained the data against Hb data collected from CBC reports of those patients. Finally, we tested our data to find a correlation between these values.

1.2 Research Problem

Medical science has evolved so much over the years. Now for detecting any disease, several tests are done. Most of these tests take time to give a verdict. Now, the regular way of generating a CBC report requires one or two days. Whereas Hb values change over time quickly. Hence, a more reliable and frequent measurement method is required. Therefore, Point of Care (POC) detection can be an appropriate alternative. POC are those which give immediate results.

Detection of Diabetes, Oxygen saturation (SpO2), etc. are examples of POC methods. Diabetes requires drawing blood from fingers whereas oxygen saturation measurement is completely non-invasive. SpO2 is measured through a device called Pulse Oximeter. Many researches also tried to use this technique to detect Anemia. Inside the pulse oximeter, a portable sensor was designed to measure the absorption and emission of light in oxygenated Hb (HbO2) and deoxygenated Hb (Hb)Detection of Diabetes, Oxygen saturation (SpO2), etc. are examples of POC methods. Diabetes requires drawing blood from fingers whereas oxygen saturation measurement is completely non-invasive. SpO2 is measured through a device called Pulse Oximeter. Many researches also tried to use this technique to detect Anemia. Inside the pulse oximeter, a portable sensor was designed to measure the absorption and emission of light in oxygenated Hb (HbO2) and deoxygenated Hb (Hb).[36] Usually, HbO2 takes in more IR and permits more red light to pass through. Whereas, Hb permits more IR to pass through and takes in more red light. Using a sensor and a couple of LEDs, pulse oximeters measures the ratio of these emitting lights. The values are then converted into SpO2 via a lookup table using Beer-Lambert's law.

As this method deals with Hb concentration and characteristics of blood color, our initial hypothesis was, the pulse oximeter may have a relation with Hb. To justify our statement, we collected 500 SpO2 data and their corresponding CBC reports from patients of Kustho Niyontron Institute & Hospital, Mohakhali, Dhaka. The reports gave us Hb and SPO2 values to work with. For more analysis, we also evaluated data of platelets, RBC and WBC. With extensive analysis, we found very few correlations among these data. However, to detect hemoglobin, carboxyhemoglobin (COHb), methemoglobin (metHb) or other hemoglobin moieties need to be detected[1]. Methemoglobin cannot be detected by conventional pulse oximetry. Using several light-emitting diodes and sensors, a pulse CO oximeter distinguishes the Hb compared to the oxygenated Hb. However, these studies do not give a direct and low-cost point of care solution. Also, the high price and unavailability of the sensors needed to perform this model is an obstacle to achieve the research goal.

There are many other methods proposed around the world. However, none of them fulfills all of our goals at once. In this research, we tried to unlock a way that may hold the answer to all the requirements. If a mobile camera is attached to the fingertip, while the mobile flashlight is turned on, the blood color can be seen on the mobile screen. This allowed us to capture videos that gave us the blood color we needed, that too non-invasively. Further data collection and analysis on these data, proved to be vital for coming to a conclusion. Details of the methods shall be discussed in the coming sections.

1.3 Research Objective

According to WHO reports, anemia is one of the leading health issues in the world.[35] In the developing countries, the prevalence of anemia ranges from 40% to 60%. Whereas, in the developed nations, the numbers fall between 20% to 30%.[22] Detecting Anemia accurately requires a full blood count testing which requires specialized equipment and lab facilities. These things are often unavailable in rural and low-resource settings, where Anemia is most prevalent. Hence, our aim is to provide a low cost, noninvasive and easy to use solution of detecting Anemia. The main objectives that we look to achieve from this study are:

1. To understand the characteristics of Anemia.
2. Find out the relation between Hb and blood color.
3. Understanding methods of image processing deeply.
4. To know about Anemia detection techniques in details.
5. Introduce more reliable image processing technique of detecting Anemia.
6. Develop a completely non-invasive and POC model.
7. Supervise the model for accuracy.
8. Suggest improvements that can be made to make the model better.

1.4 Research Methodology

This research aims to contribute in the development of a portable and POC device, which will detect anemia non-invasively. To justify the significance of the study, we needed to collect data. Now, data can be collected in two ways. Either an existing data or manually collecting data from patients. As there was no data available to analyze, we opted for manual data collection. As we know, anemia is a side effect of many other diseases. For this reason, we collected data from patients of Kustho Niyontron Institute and Hospital. Upon giving an ethical statement to the hospital authority, we promised to never share the personal data of patients and follow all the medical guidelines. Mainly we targeted the people coming in for a CBC test. In total, we collected data from 85 persons. We tried to maintain a 50-50 ratio of men and women. We also ensured that 50% of the data is of anemic patients. The patients ranged from 12 to 68 years old with Hb ranging from 6 to 15.

To conduct the research, we used the OnePlus 6t mobile device. Throughout the data collection, we used the same device to ensure data authenticity and credibility. While capturing video from a patient's fingertip, the resolution was set to 30 fps. A 10-second video was captured from each patient. While analyzing the data, we split the video into image files, which have us 300 images per person. We classified the anemic patients according to the WHO standard of Hb level, which was collected from a CBC report. According to the collected data, there were 39 female patients and 46 male patients. Also, 42 of them were non-anemic and 43 of them were anemic. Then, we preprocessed the data using OpenCV. For model designing, we used Keras sequential model of TensorFlow. The data was divided into two parts: testing data (20%) and training data (80%). Finally, we compared our results with existing research to convey an output.

1.5 Scope and Limitations

The target of this research is to detect the Hemoglobin (Hb) level of blood in a non-obtrusive way, which will be utilized to investigate and recognize if the individual is Iron Deficiency Anemia influenced or not. As it is medical research with the goal that the outcome must be extremely precise. The outcome was examined with a few Data Science and Machine Learning Algorithms, where we expected to gather various sorts of information with a decent amount. Since various kinds of information imply, we can contrast and various sorts of side effects of the infections. This dataset with a huge number of data helped the calculation to be increasingly exact.

Additionally, these data have been collected by ourselves and we have verified each data manually. There is no other data from external sources included in the dataset of this research. So, this data is very recent and hardly incorrect. So that these data will help to use in other medical objectives or research also.

In this research, we have tried to state that it is not impossible to detect the Hemoglobin level of blood in a non-invasive way. Every day, more than a hundred patients go to each hospital or clinic for the blood test. The result of a blood test result is called the "Hematology Report" or "Complete Blood Cell (CBC) Report".[29] It provides one's Hemoglobin, WBC count, RBC count, Platelet count, Neutrophils, Lymphocytes, Monocytes, Eosinophils, Basophils as well as HCT, MCV, MCH, MCHC, MPV, PCT, PP-LCR, PDW, RDW-CV and RDW-SD.[3] Furthermore, this report takes up to 4 hours to generate. So, if a patient needs to know only the hemoglobin amount, this research will help him/her to get hemoglobin amount in a non-invasive way in no time.

If the goal of this research is fully acquired, then it will create a huge impact on medical science. Especially for emergency patients. It will save time and human effort.

On the other hand, there are a few limitations in this research.

First of all, the dataset. The data collection was the most difficult part of this research. We were trying to collect a huge number of data from some external sources earlier, but we needed the motion image of their finger beside the other numerical data. This motion image was used in image processing and feature extraction to add another layer of data in our dataset. As a result, we had to collect data manually through field research. Due to the lack of finding perfect patients all the time and the lack of appropriate hardware, the size of the dataset decreased. Moreover, it unhealed to increase the accuracy of the result.

Secondly, the result. Hemoglobin level is a numeric value which ranges between 5 to 16, where the normal level of a competent male is approximately 13.5g/dL and a competent female is approximately 12.0g/dL.[19] In our research, one of our goals is to define this number without invasively taking the blood and we have failed to define the exact number accurately. But whereas, we are able to define a set of the range, if it is below 11 or above. Moreover, the primary symptom of iron deficiency anemia is the hemoglobin level goes below 11g/dL.[2] So, from our research, it is possible to accurately detect if the patient has the primary symptom of iron deficiency anemia or not. We believe, if this research continues with more appropriate data in a more advanced way, it will be possible to detect the exact numeric value of hemoglobin level.

1.6 Document Outline

Next parts of the paper are written and organized as follows:

Chapter 2 is compiled with the literature review and related work of this research. It contains an elaborated explanation of every tools and theory, those are used in this research. Literature Review contains 3 parts.

1. The first part is all about image processing. There is a big dataset of the processed image in this research. Those images are processed through some image processing algorithms and feature extraction from a set of 30 frames per second videos. Here the image processing methods and challenges are also discussed.

2. The second part is all about Machine Learning algorithms. The dataset of the processed images and reports used to train with a few machine learning algorithms. We have used a total of 4 machine learning algorithms and tested them with the test dataset. Each algorithm provided different accuracy of results. Then we have done the analysis, compare and contrast. As a result, came up with the most suitable algorithm for this research. In this part, all of the definitions and explanations of these algorithms will be discussed.

3. The last part of this sub-topic is about Related Work. It contains all the related works and projects of other researchers in a similar subject area. Intrusion

Detection Techniques and Intrusion Detection for Image Processing, Machine Learning, etc. will be discussed here also.

Chapter 3 restrains the methodology of this research. Methods that are used to train and test the datasets are discussed here. Additionally, it describes the procedures of data collection, verification, validation, and cleaning. Also, it describes how the datasets are prepared before fed in the algorithm model. Moreover, it talks about how we have collected the motion images and generated a set of image sequences from the 30 frames per second recorded video. Then how we did the feature extraction to use in the algorithms. Furthermore, it describes the ConV2D model of Keras algorithm and how they worked in this research. It gives nuances of the appraisal method that is used to evaluate the proposed model.

Chapter 4 is the part of implementation, execution and results. Here it discusses the implementation of the data model using Google COLAB using Python Language as well as how it does the feature extraction and image processing using Python Language. It shows how the rationale of the framework functions, and gives the outcomes found from testing the framework. All the hardware and software terms to get the result of this research will be discussed here.

Chapter 5 restrains the topic of Analysis, Evaluation and Discussion. Here it describes the comparison and analysis of the training model by testing them with the test dataset. After all, it will evaluate which one is performing better and highly acceptable in this research. All of the discussions about evaluation will be discussed here.

Chapter 6 is about the Future Work and the Conclusion. It contains reflection, the discussion of confinements and proposals. What can be done more about this research will be discussed here. Additionally, a summary of the outcome of this research will be discussed here.

Chapter 2

Literature Review and Related Work

2.1 Image Processing

The processing where the input is an image and the output can also be an image or some characteristic or attributes deracinate from the input image is image processing. It falls under the expeditiously increasing technology which deals with images, experiments it and tries to bring some valuable information. With its different experimentation, it is helping computer science disciplines in numerous ways. Image processing is basically the anatomization and manipulation of the raw input image, for enhancing the efficiency of output image using different mathematical functions and by using any type of processing where the input is an image, such as photographs or video footages or screenshots. The accomplishment from image processing can be either an image or it can be a set of distinctions or some important specifications related to the image. To complete the task of image processing, it is required to consider the input image as a 2-D signal or image and then some processing techniques need to be implemented to bring out the significant result.

2.1.1 Image Processing Definition

Image processing is a strategy to actualize some working over an image, to get an improved image or to separate some effective bearing from it. Image processing should be possible by importing the image by means of image acquisition tools, at that point the image should be analyzed down and controlled. Furthermore, finally, the Output where results can be modified image or report that depends on the experimentation of the image. For image processing, there are two sorts of strategies utilized, to be specific analog and computerized image handling.

Analog image handling can exploit printed versions like printouts and photos. Image investigators utilize variegated basics of understanding while at the same time utilizing these visual techniques. Computerized image handling procedures aid the control of computerized pictures by utilizing PCs. These customary stages that a wide range of information need to confront while utilizing digital facilities are pre-processing, enhancement, and data extraction.

There are fundamentally four stages in the image processing domain. They can be named as pre-preparing, division or segmentation, feature extraction and recognition or acknowledgment.[20] These means are tutelages and earth shattering in research, generally on account of software implementation and not many executed on equipment or hardware. The underlying pre-processing step is completed to glorify the nature of the original image by expelling commotion, lopsided brightness, light leak, and so forth as basic controlling components followed by segmentation where images are separated from the foundation into different elements with unique properties. Next in the stage of feature extraction, extraction is performed on each identified object to lessen its data to a rundown of substructures stored in memory. At last, in the acknowledgment stage, a lot of signals is effectuated utilizing this rundown which establishes the upper degree of processing by assigning a particular importance to each recognized object.

2.1.2 Image thresholding as a segmentation phase

The principal stage that we can consider in all phase of image processing and analysis is to make a image twofold (Image binarization, the image ought to contain any two-pixel esteems either 0 or 1 conversely with gray pictures which can contain 255-pixel esteems for a 8-bit picture) which acts like one of the major issues in pattern recognition, target tracking, and also in image segmentation where the grey level data is required to decrease to two level data or binary data. So as to distil helpful data from an image, it should be part into unmistakable constituents. Like forefront (where the pixel esteem is '1') and foundation (where the pixel esteem is '0') objects for additional partition where regularly the grey level pixels of frontal area segments are very unique from that of foundation.

Right now, extremely essential and articulate system accessible in literature known as thresholding which is the way toward apportioning pixels in the images into an object and foundation classes dependent on the interrelation between the grey level estimation of a pixel and the exceptional parameter threshold to recognize the article from the foundation, finding the right estimation of which to disparate a picture into judicious, forefront and foundation stays as a very crucial step in image processing domain.[18] In view of its organized exhibition and clarity, in theory, thresholding procedures have been concentrated widely and an enormous number of thresholding strategies have been distributed so far.[11] Finding an ideal threshold esteem guiding to a powerful binarized image requires expertise as the decision of the technique must be done prudently. After a simple pre-processing of the image, the thresholding has been placed in where the threshold esteem is dependent on the idea of the picture which turns into a predominant constituent toward the end.

After thresholding our raw image, we found this as an output pattern (Fig:2.1 and Fig2.2), and all the other images of the same patient have the same pattern as well.

2.1.3 Classification of Image Processing

There are various methodologies for Image processing explicitly feature extraction, feature determination, and characterization. The images are caught from the regarded theoretical arrangement and afterward features are extracted. The highlights are compulsory and acceptable data or information that are achieved from the input image. The way toward accomplishing the features is symbolized as Feature Extraction.[30] On the necessary training set, well felicitous features are chosen. The manner by which the subset of features is acquired from the huge set of features that are removed from the image is known as Feature Selection. It reduces the huge set of features by decimating the repetitive component, and the features are chosen which are generally pertinent. The subset of features contains just the acceptable features that are decreased by different properties. The features are then systematized into non-indistinguishable classes. The classes are included based on various parameters that are characterized by the end-users or the features might be combined into various classes naturally. The subset of features is indicated as contribution to various classifiers.[13]

There are differing characterization algorithms that are accessible for real-world applications, for example, Naive-Bayes, Decision Trees, K-means clustering algorithms, Machine Learning, k-Nearest Neighbor algorithms, Minimum Mean Distance (MMD), Support Vector Machine, Shadow algorithms, Neural Networks, Hidden Markov Model. These algorithms are best for distinctive applications and the determination of classifiers depends on the consummation of the algorithms in a particular sort of utilization domain.

Maximum Likelihood Classifier

In remote sensing, the most regularly utilized strategy for grouping or classification is this. It is a strategy for conjecturing the parameters by seeing the parameter estimations of a measurable model that amplify the probability of the apparent parameters[10]

K - Nearest Neighbor Algorithm (KNN)

KNN is one of the essential factual classification algorithms among differing machine learning algorithms. The objects are designated with the most comparative neighbors in the feature space.[21] The objects are designated to single the nearest neighbor if and just if k=1. The objects are grouped with the most number of votes given by the neighbors.[26] The KNN algorithm handles the neighboring element subsets for characterization and finds viable execution for automatic acknowledgment.[33] It works with K-means, K-medoids, and CLARANS to externalize the subset of tests from the training set. The k-nearest clusters are bunched to frame individual classes that can be separated into bigger and smaller groups.

Naive-Bayes Classifier

With strong inter-relationship among features and based on the Bayes hypothesis, the Naive-Bayes classifier is a sort of machine learning strategy.[44] The accomplishment of naive Bayes in the presence of featured conditions can be depicted as follows: optimality as far as zero-one loss (classification error) isn't definitely co-identified with the standard of the fit to a probability distribution (i.e., the reasonableness of the autonomy presumption). Ideally, an ideal classifier is achieved as long as both the current and accepted conveyances coordinate on the most-probable class.[6] Naive-Baye is one sort of classifier that models in-between appointed features of the issue. Each feature is independent of different features. It is coordinated by the quantity of characterization rules, for example, the maximum posterior to accept the Bayesian insights.[14] It is most ordinarily utilized classifier progressively issues like Facial recognition. One needs to initially choose the structure of the system that has the dependencies of factors and afterward the features are dispersed to discover the articulation. The issue with the Naive–Bayes approach is the autonomy of features. This is applied to facial appearances that can be excessively solid to exhibit the feelings or emotions of people. Especially, while arriving at its most exceedingly awful exhibition between these boundaries.Naive Bayes works best in two cases:

- totally independent features (true to form) and
- practically needy features (which is more subtle).[8]

Support Machine Vector (SVM)

The characterization and understanding of the informational indexes are generally performed by the SVM Classifier. It is additionally one of the supervised learning models that are non-probabilistic. It consists of focuses on the shown space and is part of a few districts mapped together. They are regularly utilized in image segmentation, message and transcribed original copies and classifying the images in the field of medication to discover different parametric features.[24] This includes accomplishing better translation and accuracy rates. It as a rule incorporates the following stages: Firstly, pre-processing of the images in the database then Separation of the database in training and test sets after that decision of the portrayal of the input information and decision of the method for training, which implies the strategy for multi-class training. Finally, training, test, and assessment of the performance.[34]

Genetic Algorithm

Genetic Algorithm (GA) is an advancement based technique that utilizes the populace for taking care of optimization problems.[17] It has been certainly applied in image segmentation and intensification of images. It basically assists with improving the nature of the images and gives a superior envisioned impression of the images to deliver better results. It is one of the trans-formative issues.[16] Genetic Algorithms work best on real-life issues. It has two parameters, for example, crossover and mutation that work better than regular image up-gradation methods. A run of the genetic algorithm favored a genetic portrayal of the solution domain and a fitness function to cross-check the solution space. Genetic Algorithm has a lot of profitability in securing the optimized solution. It is one of the most remarkable improvement systems on account of bigger space. The nature of image segmentation can be extemporized by the discoveries of the parameter in an optimized manner.

2.1.4 Image Processing Methods

Analyzing and manipulating a picture is defined as image processing. It is used in our day to day usages to better understand the mechanism and characteristics of our surrounding objects. Due to its nature of working principle, almost every sector of life is coming under its radar. From handling noise, recognizing characters to enhancing the details, image processing is done in many ways. The main methods are generally categorized into some parts: pre-processing, compressing image, detecting edge and segmentation.[45] Pre-processing of images consists of removal of background noise, intensifying decentralized data of an image, clearing unwanted data or detailing the image data before the analysis process.

The execution of compression which helps to encode the source image with scattered bits is image compression. To diminish the repetition of the image and to protect or transmit information in a productive structure is the adequate goal of image compression. To deal with the space complexity as much as possible is the main concern. But the most important thing which needed to be looked after is the decoded image displayed in the monitor should be similar to the original image as much as can be. The proposed system to maintain the quality of an image after the image compression process using the Wavelet Algorithm.[27] In their work, JPEG and PNG images were used and noted that for the JPEG image, the size is reduced almost half of the original image by using the Haar wavelet algorithm, because of the lossy compression type of JPEG image and it is found that the compressed image still maintains the quality and information of the original image. A solution proposed by Raju, et al.[23] enhances the quality of an image. From that point forward, the image was portioned utilizing a modified watershed algorithm that utilizes mean-shift clustering. This amplification approach used during segmentation was the conventional mean-shift algorithm, clustering-based k-means algorithm, and modified watershed algorithm. The modified watershed algorithm produced better segmentation results which are proved by various experiments when compared with the other two algorithms. The over-segmentation process is taken care of efficiently during the watershed algorithm. For medical usage, image compression utilizing integer multiwavelet transform for telemedicine applications Praveenkumar, et al.[25] have encouraged efficacious compression. The encoding interpretation is based on the Integer multiwavelet transform of medical application. In this case, this brought about better quality pictures where the work was centered around the satisfaction of loss-less image information. This had shown up much better coding productivity and less computational multifaceted nature than existing methodologies and it also got reduced bitstream and better scalability.

A set of mathematical methods for example edge detection helps in recognizing focuses in a digital image at which the image brightness transposes forcefully or, all the more outward appearance and has discontinuities. For division or segmentation algorithms there are two methodologies named as Canny edge detection and Otsu thresholding.[41] The intensity of the introduced algorithm was examined for clinical and non-clinical images. The two algorithms returned in great fragmented images. Canny segmentation is more reasonable than Otsu to the tested endoscopic pictures from the raw input that there is no specific distinction of the items from the input and grayscale images. All these methods are used for the digitization of an image so that we can analyze the image and find or get an idea from the image to solve any issue.

2.1.5 Define 'Image' in Image Processing

Taking care of digitized images by the medium of a computerized PC is widely known as Image Processing. Here, we also can hypothesize that, with the purpose of getting enhanced images either to coerce some utilitarian information by the use of computer algorithms.

What is an image?

Image is basically a two-dimensional capacity. It can be represented as F(x,y), where x and y are related or possessing facilitates, and the expansiveness of F at any pair of directions (x,y) is known as the intensity of that image by then is clarified as an image. We only can consider it as a digital image just when x,y, and sufficiency estimations of F are outlined.

In other words, an image can be outlined for a specific reason by a two-dimensional array systematized in lines and segments. A demarcated number of components, every one of which components have an individual viability at a specific area is establishment of Digital Image. These components are brought up as image components, picture components, and pixels. A Pixel is most widely used, to portray the components of a Digital Image.

Types of an image

Binary Image: Binary methods, 0 or 1. As its name gives the thought, this kind of image controls just two-pixel components i.e 0 and 1, where dark is meant as 0 and white is meant as 1. Monochrome is the generally utilized name of this sort of image.

Black and White Image: The sort of picture which subsists of the main color which is highly contrasting or coloring is essentially known as Black and white picture.

8-bit Color Group: Generally, the 8-bit shading design is the most distinctive image group which is utilized. 256 distinct shades of hues are the inborn element of this kind of image and they are generally known as Grayscale Image. Black signified as

In case of enhancement of the raw image, we must need to remember that it needs to be done very safely as that can make changes in the result which is very unfortunate for image processing. In that case, Image Restoration is a fundamental area that also takes care of ameliorating the appearance of an input image so that it could not distort the output. Enhancement is an individual and biased method, whereas restoration of image is unbiased and impartial technique. This totally depends on the human where he defines "good" and "bad".[15] This was the main challenge that we faced during image processing.

Nowadays as there are significant increases using different types of images in different sources so color image processing is building up influences. The idea of color model and basic processing of color are being analyzed and studied here in this particular area. For extracting the feature of interest image color can be used. We can also separate the image in different small groups of regions to compress the image data and there we can take the help of wavelets. Predominantly, autonomous segmentation, the process where segmentation of an image is done randomly that is the most difficult part. Similarly, on the other hand, weak or unpredictable segmentation algorithms almost always conclude the research with a failure. Generally, the more accurate the segmentation can be made then we are supposed to get more likely recognition to succeed. To achieve the desired output to get the processing done, at first, we need to find the perfect representation that helps us to get the suitable format as an approach for getting the solution. To highlight the feature of interest, a method or algorithm needs to be developed to describe the raw data to make something beneficial from that. To differentiate one class of object from another object by finding attributes which results in any information which is helpful is dealt by feature selection as a part of leveling. By assigning a label for example: "night", "defective", or "anemic" to an object based on the features defined by an algorithm is Recognition. To recognize an individual object from a raw image Recognition is the part which deals with it. That's why the most crucial part to deal with image processing is feature extraction as it plays a major role in the resulting output which will be used for further exploration.

2.2 Machine Learning for Anemic patient Detection

ML is important in any data related work. To train and analyze the system, ML is used all over the world. In this section, we focused on discussing ML briefly to learn its different types and applying procedures.

2.2.1 Machine Learning Definition

Machine learning (ML) in the field of computer science that uses scientific study and statistical models to perform a task without giving any explicit instructions.[42] Machine learning relies on finding patterns and inferences. The term ML or machine learning has been a buzz word in the recent era of computer science however this field of study has existed for quite a long time. The term was first coined by Arthur Samuel, an IBM engineer and American pioneer in artificial intelligence. Machine learning related to pattern recognition continued throughout the 1960s and 1970s, as described in the book of Duda and Hart in 1973.[43] A widely quoted, more formal definition was given by an American computer scientist and E. Fredkin University Professor, Tom Mitchell in 1997. That definition is something like this: A computer system learns from it's experience if its performance, improves with it's experience over time.[7]

Tom Mitchell's definition has three core components, which are: Task, Performance and Experience. Machine learning generally tries to mimic the biological learning pattern that is through experience. A computer system that performs a set of tasks is said to be learning if the performance improves based on experience. This indicates a linear relation between experience and performance. Therefore more experience would result in more accurate and better performance. A system capable of learning usually is capable of taking previous data as input that it uses as experience . The system makes use of different statistical analysis leveraging different ML algorithms to find patterns in the given data which in terms help the system to make better predictions in the future about unseen sets of new data.

2.2.2 Learning Style in Machine Learning

A core objective of the system that is learning is to generalize from its experience.[12] Depending upon the input, output and the task the system is intended to solve, the learning style varies. Selecting the right learning style is very important as the outcome of the trained system depends on it. The major learning approaches are:

Supervised learning

to be the gold standard in case of anemia detection so we labeled our data according to it. Patients having lower Hemoglobin (Hb) level than the threshold is labeled as anemic and the other group is labeled as non-anemic. Our system then builds a knowledge base based on the input labeled data leveraging the specified algorithm and trains itself. Later this knowledge is used by the system to predict the class label of the unseen data.

Unsupervised learning

In unsupervised data used as input is not labeled. Unlike supervised learning where the teacher of the system has full knowledge of the class labels of each item in which individual input data belongs to, in unsupervised learning, the trainer of the system does not possess full knowledge about the labels or classes of each individual item in input data. Instead, the trainer depends on the system itself to figure out the class label and underlying structure in the data, like grouping or clustering of data. Therefore unsupervised learning algorithms train on data that has not been labeled. The system tries to find commonalities in the data, creating grouping or clustering.

The new test data is measured based on these commonalities.

Semi-supervised learning

A semi-supervised learning algorithm works with data that has partial labeling. Typically a small quantity of data has labeling; a large sum of data does not. The learning accuracy can be improved considerably when unlabeled data, when used in conjunction with a minor proportion of labeled data. This learning algorithm is a mixture of supervised and unsupervised learning algorithms.

Reinforcement learning

Reinforcement learning is an approach in ML where the system learns based on reward or punishment. To form basic knowledge in reinforcement learning both labeled as well as unlabeled data can be used. The teacher of the system rewards it for each correct prediction and punishes the system for every incorrect prediction. This acts as a feedback for the system while making decisions about future predictions.

2.2.3 Algorithms of Machine Learning

Algorithms are basically a procedure that consists of a finite set of instructions that enables us to obtain an output given an input from a set of possible inputs through a systematic execution of the instructions.[31] ML algorithms can be split into the following groups (Brownlee, 2013):

Clustering Algorithms

Clustering is an algorithm in ML which involves grouping of similar data points. These algorithms try to identify patterns in input data so that they can be organized into groups. Each element within the group has maximum similarity to each other. The following are some of the most popular clustering algorithms:

- K-Medians
- K-Means
- Hierarchical clustering
- Expectation Maximization (EM)

Regression Algorithms

Regression analysis concerned with the statistical analysis of data that tries to find the relationship between a target known as dependent and a predictor known as the independent variable. Regression analysis is a vital tool for analyzing data. Regression Algorithms try to find a best-fitting curve/line among the data points. The most popular regression algorithms are:

- Linear regression
- Logistic regression
- Ordinary least squares regression (OLSR)
- Stepwise regression

Decision Tree Algorithms

Decision Tree Algorithms: Decision Tree algorithm is a supervised learning algorithm focused on creating a training model that is capable of predicting the class or value of the target variable. The model leverages learning decision rules which was inferred from training data. The system starts from the root of the decision tree and goes down comparing the values of each branch's attribute with the record's attribute. From this comparison, the system makes a decision on which branch to follow next and jumps to the next node of the tree. The algorithm searches down the tree structure until decisions are made. The following are the most popular decision tree algorithms:

- Classification and Regression Tree (CART) and
- Decision Stump

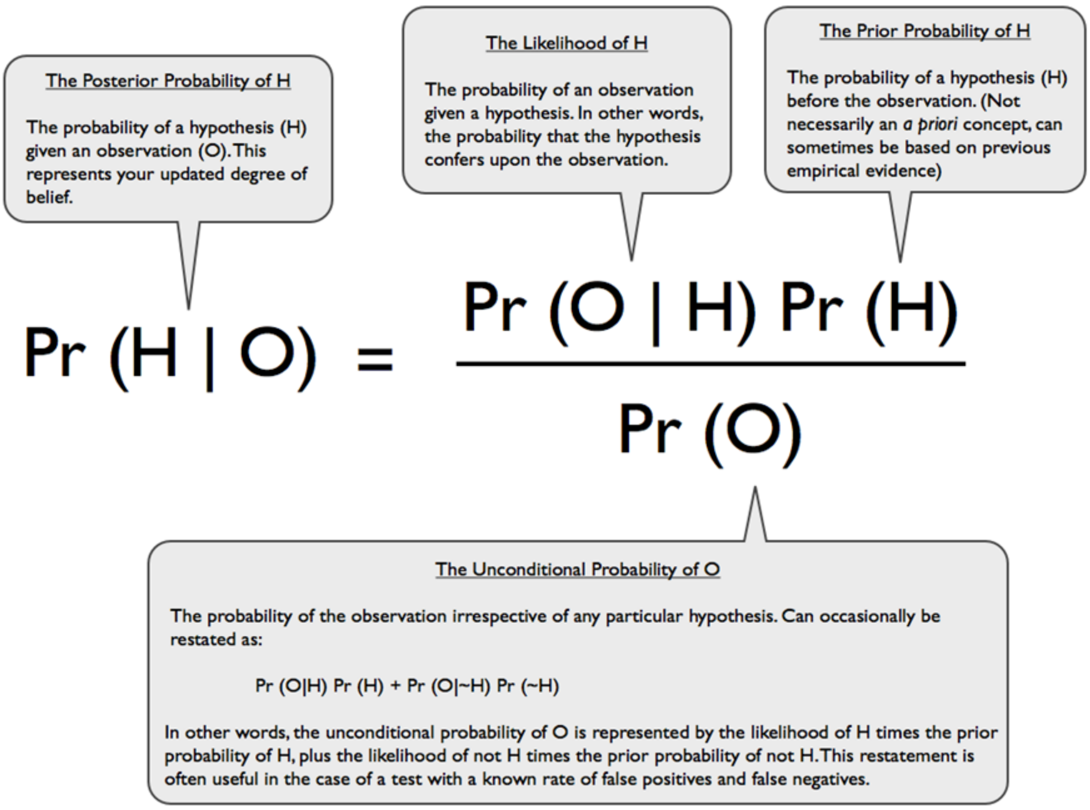


Figure 2.4: Equation of Naive Bayes Theorem
[40]

Bayesian Algorithms

Bayesian Algorithms: These ML algorithms are concerned with applying Bayes' theorem in classification and regression. Bayesian Algorithms assume that each feature it uses is conditionally independent of one another.

The following are the most well known Bayesian algorithms:

- Naïve Bayes
- Multinomial Naïve Bayes
- Gaussian Naïve Bayes
- Bayesian Network

Artificial Neural Network Algorithms

Neural networks in the biological brain process information by using non-computational principles. As opposed to digital computers, the biological brain operates in continuous time.[4] Such observation led to the study and development of artificial neurons and neural networks which tries to mimic the working mechanism of real neurons. Instead of executing instruction sequentially like normal computer programs, these algorithms were programmed to explore many competing hypotheses simultaneously. ANN uses massively parallel architecture composed of many simple computational elements with variable weights which are connected by links. The following are some examples of most prominent artificial neural network algorithms:

- Back-Propagation
- Perceptron
- Radial Basis Function Network
- Hopfield Network

There are many more ML algorithms such as deep learning, dimensionality reduction and features selection algorithms.

2.3 Related Work

There has been various research on non-invasive techniques to detect anemia in the past. However, very few of them were globally accepted. Many of them were proved only in theory, but none of them contained all the essential requirements to fulfill our research goal. In this section, we will shortly discuss some of those studies to better understand this field.

2.3.1 Anemia using Image processing

This research helps us to find one of the most effective procedures to get a successful result. In this research, they processed each video in a total of 5 steps. As a matter of first importance, they separated each picture outline from every fingertip video which was recorded by a cell phone. Also, the isolated every red, green, and blue pixel power for each casing of video. Thirdly, they subdivided a picture outline into a 10x10 square grid where each rectangular-formed territory of this picture is characterized as a square.[38] Fourth of all, normal red, green and blue pixel forces of each square where each edge gives us 100 normal (mean) values for red pixels, 100 arrived at the midpoint of qualities for green pixels, and 100 found the middle value of qualities for blue pixels. Lastly, they produced time arrangement information as information included and made gathering numerous squares together to distinguish ROI regions.
For every fingertip video, they have determined five info include vectors (perceptions) called TRA, BRA, LCA, RCA, and CIA dependent on five gatherings of squares. For the AGB 75 dataset, they have made five subsets of information highlight frameworks for that dataset. They saw that each of TRA, BRA, LCA, and RCA included 30 time-arrangement signals and the CIA had 16 signs. To create a solitary perception, they found the middle value of 30 signs into a solitary time-arrangement signal for the TRA, BRA, LCA, and RCA and arrived at the midpoint of 16 time-arrangement signals for the CIA. At that point, they applied the PLSR on each found the middle value of the subset where the component of the TRA, BRA, LCA, RCA, and CIA was 75x100. A while later, we determined the MAPE and R esteems for five subsets (TRA, BRA, LCA, RCA, and CIA). Afterward, they thought about which subset gave relatively better execution dependent on MAPE and R esteems. They introduced the ROI region name with R esteems (in enclosures) of five subsets of information including frameworks for each dataset.

2.3.2 Optimum Wavelengths on Hemoglobin Concentration Measurement

This research focused on using different LEDs to generate light and calculate the ratio of those. They tested with different combinations of LEDs to find the perfect combination. Initially, they used 425, 455, 515, 615, 660, 695, 850, and 950 nm. They used two sets at a time. Two photodiodes were placed on the fingertip. Transmitted light was observed by a multispectral sensor. The changes in light transmission was calculated by Beer-Lambert's Law.

$$A = logIo/It = c \times \in (\lambda) \times l$$

Where A is the sample absorbance, l is the transitive length, c is Hb concentration and $\in (\lambda)$ is the coefficient of molar extinction or the ability of certain absorbents to absorb at certain wavelengths.
This method is also known as PPG. To measure Hb, values needed to be obtained from the AC and DC components of the PPG signal. The values are calculated with these equations,

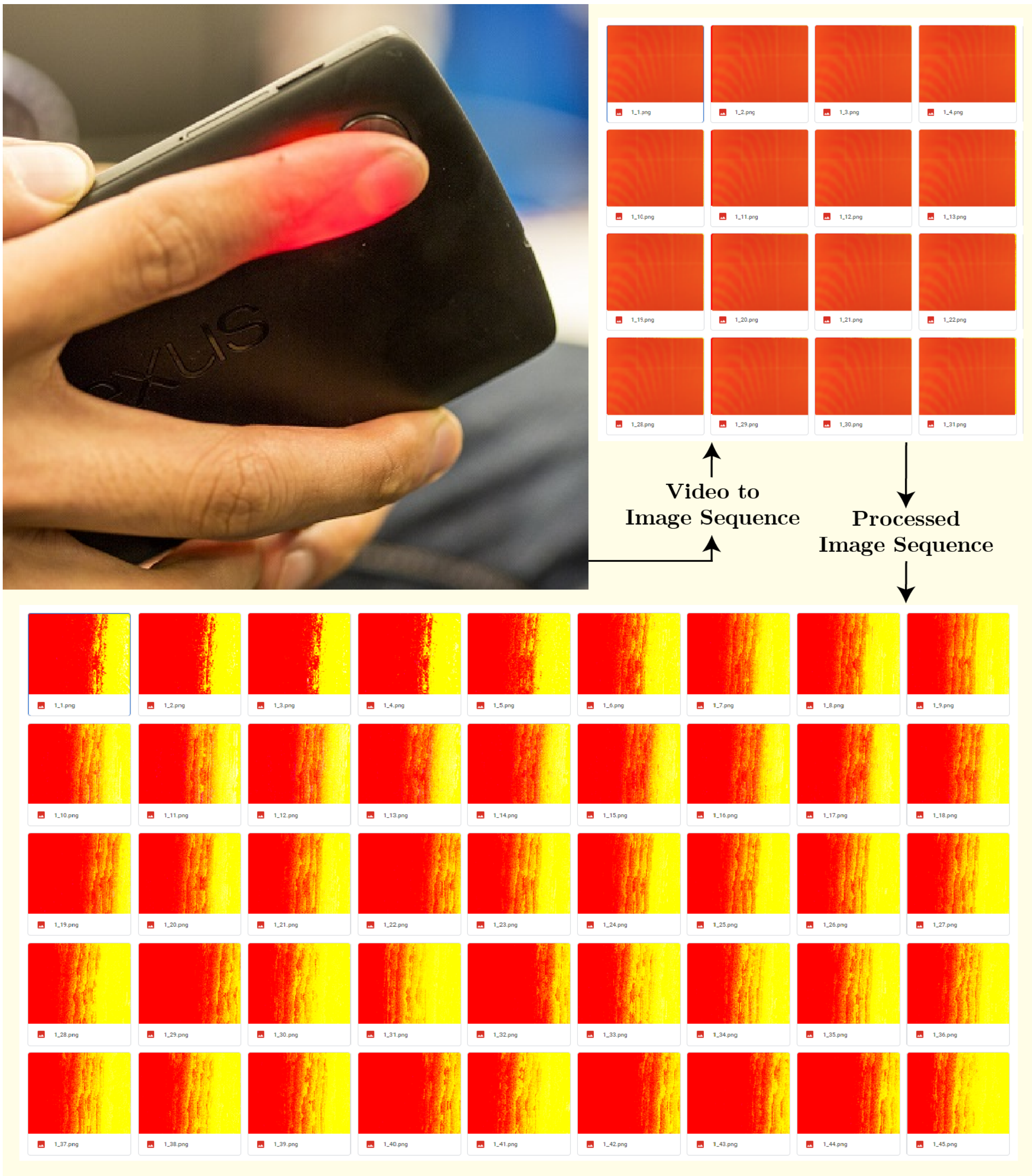


Figure 2.5: Anemia detection process using color analysis

$$It = 1/2(2DC + AC)$$

$$Io = 1/2(DC - AC)$$

Therefore, a ratio is measured with another equation,

$$Ratio = A\lambda 1/A\lambda 2 = \{(AC/DC)\lambda 1\}/\{(AC/DC)\lambda 1\}$$

Finally, analyzing the correlation, the best two combinations of LEDs were chosen. According to this paper, 615 and 455 nm combination gives the best correlation to detect Hb concentration.[37] However, these LEDs of different nm are not often available. Also, this mechanism is quite expensive. That is why this method is not suitable for rural areas.

2.3.3 HemaApp

This study was closest to our research. To execute this design, they also relied on a smartphone camera. They took a 15-second video and converted it into RGB files. Next, they extracted the RGB files using image processing. Finally, they trained their systems using SVM.

This study is supposed to show a sensitivity of 85.7% and a precision of 76.5%.[32] However, there are some key differences between this research and ours. They analyzed the data using color analysis with Beer-Lambert's law. They used ML only for training the data. Whereas, we used a sequential ConV2D model of Keras to analyze the images and find a correlation. Also, the development of HemaApp was made possible by analyzing the data only. The mass usability of it in the rural area was never confirmed. Nevertheless, this study gave us the necessary insights to work with smartphone cameras and scopes of improvement.

2.4 Summary

In this chapter, we discussed the mechanism of image processing and ML. Both are vast fields of learning. So, it was important to learn in detail of these sectors to decide which particular method suits our research.

First, we discussed about images and their nature. We also learned how image processing is done and what are the tools needed to work with. Then, ML was discussed in brief. These discussions gave us the knowledge to combine these two sectors and apply them in designing the desired model. Finally, some previous studies were discussed to understand the existing methods and possibilities of improvement.

Chapter 3

Methodology

It incorporates the depiction of the dataset we have utilized in creating and testing the model, as well as the portrayal of Keras Convolutional 2D algorithms. Here the procedure of data collection, processing, clustering and classifying talks about too. The scientific equation and computation in the exploration will likewise incorporate here also.

3.1 Model Design

The reason for identifying the Hemoglobin level of human blood in a non-invasive way is as of now clarified in the past part. Here we talk about the philosophy of research. All together thus, the model requires structuring a procedure that takes information from a dataset that might be gathered either from a dataset or physically. At that point the data process through a few stages. Besides, the algorithms handle that information and make a data model. Therefore, this data model is used to identify the human Hemoglobin level. This worth isn't in an exact numeric worth. It gives the yield in a range as beneath 11 or above. From this range, we get the yield if this is an iron-deficient patient or not. Figure 0 gives a significant level perspective on the model design.

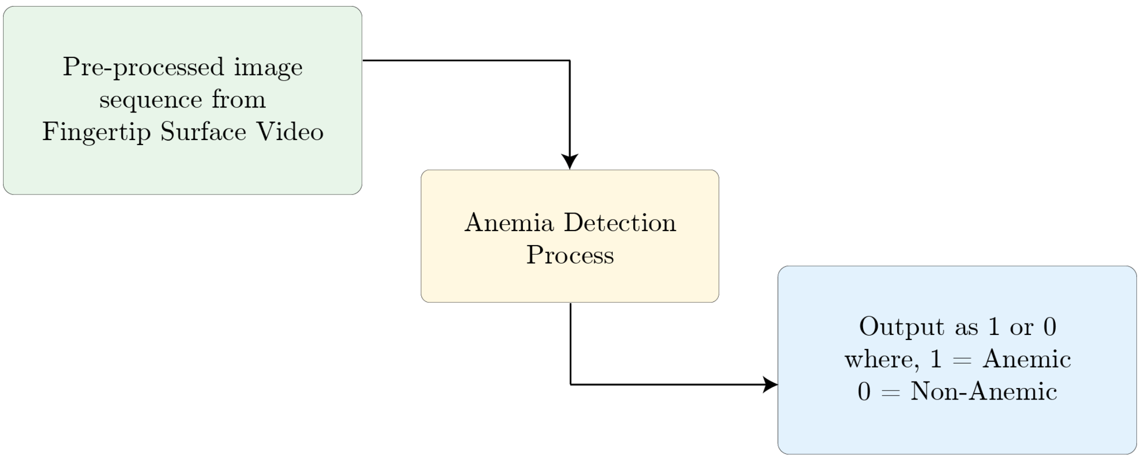


Figure 3.1: Anemia Detection Process - high level view

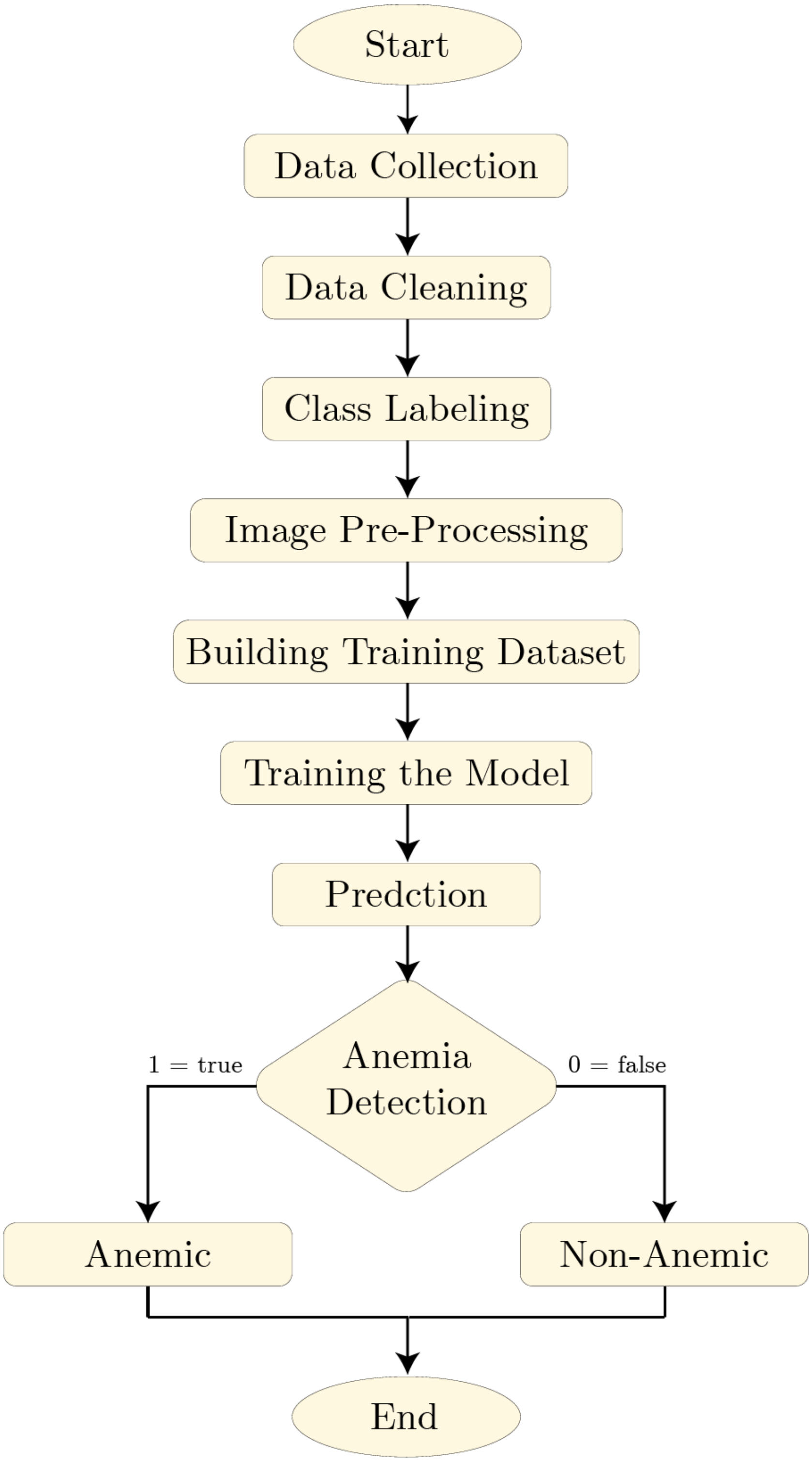


Figure 3.2: The flow chart of the proposed non-invasive anemia detection model

3.2 Data Collection/Input Data

The data collection process is one of the most troublesome pieces of this examination. In the previous time, we have attempted to locate an instant dataset from on the web, yet we have neglected to locate an appropriate one. It was difficult to locate an ideal readymade dataset, as we have a prerequisite of numerous fields of information for every patient.

Subsequently, we choose to gather information truly from various medical clinics. After various methods, we got consent to gather information from the Hematology Department of "National Cancer Institute, Mohakhali, Dhaka" medical clinic. Consistently several patients go to the Hematology Department of that emergency clinic to test their blood. They get a Complete Blood Cell (CBC) report as the consequence of blood tests. Nearly, the limit of them is influenced by various cancer diseases. So that there is a chance of getting a greater range variety levels of Hemoglobin in their blood.

Our goal was to gather the video of their finger surface with a video recording device, where the camera and finger surface will be joined and the flashlight remains on. We have utilized the "Oneplus 6T" Android cell phone gadget as the video recording gadget. The motivation to pick Oneplus 6T is it creates close to the real-world color in every pixel of the digital photograph, which is near like what we can see from our eyes.

The software of this camera may change the actual color to more vibrance and eye-comfortable color with a built-in AI technology. And the Auto HDR technology may change the sharpness and contrast from actual rate to a different value to make the output video more eye-pleasing. The PDAF technology of this camera software continuously tries to detect faces in the video, which may change the focus level of videography. That is why, we have turned off the AI and autofocus, as a result, while recording all kinds of instant processes of the camera disabled. But the OIS and Auto-Gyro EIS were turned on which doesn't affect the image color and quality. Because of that, we got the real-color video, which comes directly from the actual processed images of the camera sensor without any kind of post-process.

The name of the camera sensor of this device is Sony Exmor IMX519, which is a Complementary MOS (CMOS) APS specially built for capturing high-quality smartphone photography. The video was recorded in Full HD (1920w*1080h) resolution with 30 frames per second. From the metadata of the video, it is also known that the ISO is 500, shutter speed is 1/18 second, the focus point value is f4.0 and the white balance is in daylight mode which is 5500 Kalvin. We recorded every video with exact 10 seconds duration Moreover, we gather the CBC report of the patients likewise, where we can get all the information of blood including Hemoglobin level. While recording the finger surface recordings, we gathered their blood test token sequential. In the CBC report, the token sequential is referenced. That is the way we can coordinate the video with the CBC report.

The gathered dataset has a practically equivalent measure of male and female information. So, it is unbiased as far as sexual orientation. Moreover, we recognized that the most extreme number of the patient has underneath 11 hemoglobin. So, it makes the dataset biased as far as the hemoglobin level. Accordingly, we intended to gather more information from the individuals who have a hemoglobin level over 11 to make the dataset fair. A people group of BRAC University helped us to gather the remainder of the information. We have utilized a similar chronicle gadget in a similar configuration with the goal that it doesn't bungle the dataset. That is how the data assortment process finished effectively. The following errand with this data is data cleaning.

3.3 Data Cleaning

The measure of data is not large right now the entirety of the information gathered truly with the goal that we as of now have a reasonable thought regarding every datum. Thus, the information cleaning process is exceptionally straightforward right now. Indeed, even we don't have to utilize any data science algorithm to clean the data.

We have gathered in an aggregate of more than 120 patient's finger surface videos. Be that as it may, because of various specialized and human-made issues, we were unable to gather some patient's CBC report and a portion of their serials didn't coordinate the CBC sequentially. With the goal that we decreased those disarray data to guarantee the most extreme exactness of the gathered data. Also, a portion of the video data appears to be incredibly different from others, which resembles wrong. We needed to evacuate those abnormal data moreover. Be that as it may, we have concocted a sum of 85 rows of unadulterated data at long last.

3.4 Data Pre-Processing

In this research, we have 2 kinds of datasets. Firstly, the sequential image files and secondly the hemoglobin value database. From the previous section, we already acknowledge that we have 85 rows of data in total. We transferred the entirety of the raw natural video records with appropriate names in cloud storage (Google Drive). Additionally, we made a CSV record where we orchestrated every one of the 85 rows of information with their hemoglobin level, video file path, patient number, Anemic class, and so on. The filename is "HemoglobinDataset.csv" which is compatible with Microsoft Excel (any version) or Google Sheets. And all of the images can be found in the "Finger Surface Videos" folder. Inside the folder, we can see 85 subfolders. Each of them contains 300 frames of images. Each folder refers to each patient. And the folder was renamed according to the serial column of the dataset.

In Figure 3.3, There are 54.1% Male and 45.9% Female in our dataset. Which is 46 and 39 respectively in number.

In Figure 3.4, Here we can see that how many patients there are for each Hb level.

3.6.1 Confusion Matrix

Disarray Matrix is a presentation estimation for Machine Learning Classification issues, where yield can be in any event two classes. It is a table with 4 particular mixes of envisioned and genuine characteristics.

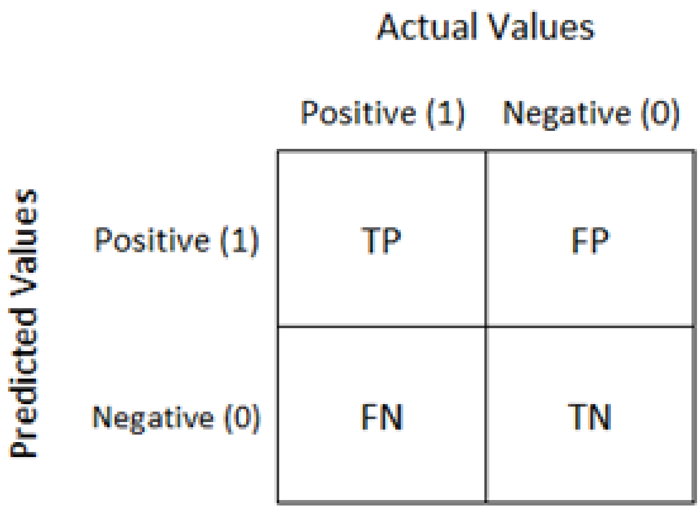


Figure 3.8: Structure of a confusion matrix

Here,
Class 1 is Positive (P)
Class 2 is Negative (N)

Definition:

- Positive (P) : Positive observation (e.g. Apple).
- Negative (N) : Non-positive observation (e.g. Not Apple).
- True Positive (TP) : Positive observation, also predicted to be positive.
- False Negative (FN) : Positive observation, but predicted to be non-positive.
- True Negative (TN) : Negative observation, also predicted to be negative.
- False Positive (FP) : Negative observation, but predicted to be positive.

It is extraordinarily significant for assessing Recall, Precision, Specificity, Accuracy and specifically AUC-ROC Curve.

We can not rely upon a lone estimation of exactness in game plan when the classes are imbalanced. For example, we have a dataset of 85 patients in which 5 have diabetes and 95 are strong. In any case, if our model just predicts the prevailing part class, for instance, every one of the 85 people is sound in spite of the way that we have a plan exactness of 95%. Right now, need a disarray network.

Classification Accuracy: Classification Accuracy is given by the association:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

Recall or Sensitivity: The Recall is described as the extent of the all dwarf of adequately orchestrated positive classes isolated by indisputably the quantity of positive classes. Or of course, out of all the positive classes, the sum we have foreseen precisely. The review should be high.

$$Recall = \frac{TP}{TP + FN} \; or \; \frac{TruePositive}{ActualResults}$$

Precision: Precision is characterized as the proportion of the all out number of accurately grouped positive classes isolated by the complete number of anticipated positive classes. Or on the other hand, out of all the prescient positive classes, the amount we anticipated accurately. Accuracy ought to be high.

$$Precision = \frac{TP}{TP + FP} \; or \; \frac{TruePositive}{PredictiveResults}$$

3.6.2 F-score or F1-score

It is difficult to differentiate the two models and unmistakable Precision and Recall. So to make them for all intents and purposes indistinguishable, we use F-Score. It is the Harmonic Mean of Precision and Recall. When appeared differently in relation to Arithmetic Mean, Harmonic Mean rebukes the over the top characteristics more. F-score should be high.

$$F - score = \frac{2 \times Recall \times Precision}{Recall + Precision}$$

Specificity: Specificity defines the extent of actual negatives that are accurately distinguished.

$$Specificity = \frac{TN}{TN + FP}$$

F1 is a general proportion of a model's exactness that joins accuracy and review, in that unusual way that expansion and duplication simply blend two fixings to make a different dish out and out. That is, an acceptable F1 score implies that you have low bogus positives and low bogus negatives, so you're effectively recognizing genuine dangers and you are not upset by bogus cautions. A F1 score is viewed as immaculate when it's 1, while the model is an absolute disappointment when it's 0.

Chapter 4

Implementation and Results

4.1 Implementation

This chapter describes the implementation of the proposed model for anemia detection. The model was implemented and tested using OpenCV and Tensorflow Keras models. The implementation phase of the model includes three stages; input data pre-processing, training the model, implementation and testing. The stage of input data pre-processing consists of collecting medical data manually from over 500 patients. Those data are then processed and cleaned. Another part of pre-processing is labeling the data accurately based on the CBC report of patients specifically based on the HB level of them. After pre-processing the model was created using the TensorFlow Keras Convolutional Neural Network model or CNNs for short. The model is trained on classified data of anemic and non-anemic patients. The trained model is later used for classifying data into anemic and non-anemic. This part likewise gives the results of running the implementation of the proposed model for anemia identification. The Keras model is preferred here to run the test using part of unclassified input data for achieving the result.

4.1.1 Input Data Pre-Processing

Before utilizing this video information in the picture preparing calculation, it is essential to process the video documents in a usable picture group. For that, we have utilized a python library OpenCV to execute the program to make a picture grouping from every video document. We have utilized the Google COLAB Web IDE to run the preprocessing of the video data. Video data set and the CSV dataset are as of now in Google Drive. For every video, it needs to run the code to make a picture arrangement from the video.

Open CV can capture the video file frame by frame with *VideoCapture* function.

$$vidcap = cv2.VideoCapture(videoPath)$$

Here the *VideoCapture* function takes each frame in a temporary variable *vidcap*.

As we already know, captured mp4 files are taken as 30 frames per second setting and each video is approximately 10 seconds long, so theoretically we are supposed to get **30 x 10 = 300** pictures approximately.

$$ret, th = cv2.threshold(image, 5, 255, cv2.THRESH\_BINARY)$$

The threshold function takes each frame and re-generate the image by applying a binary thresholding. The first argument is the image we get from the video frame by frame. Second argument is used as the value to be used for threshold to classify the values of the pixel of the image. The third argument is used as the value which is given to a pixel is its value is more than the value set as threshold. Different styles of thresholding is provided by OpenCV and it is given as the fourth parameter of the function which in our case is *cv2.THRESH_BINARY* indicating a binary thresholding.

$$cv2.imwrite(file + "/" + file + "_{\%}".png"; \%\ count, th)$$

Finally, the *imwrite* function takes the new generated image file and saves it as a PNG image file. The capturing of image frames from the video is collected in a loop until the end of each video and applied to the thresholding function on by one. After this process each frame is saved as a *png* file for later processing in a secure storage. After running this process for 85 video files of all the patients, we got **29129** image files in PNG format. In the implementation section, we will see how we trained these images to make the data model and how the data model will be used to determine a patient if he/she is Anemic or Non-Anemic.

We also collected the CBC report of the patients and created an excel spreadsheet documenting their patient id, sex and hemoglobin level along with corresponding video file path.

Serial	Hb	sex	Video Path
518	11.2	f	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/518/
543	10.7	m	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/543/
544	10.6	f	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/544/
545	10.8	f	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/545/
546	11.6	f	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/546/
547	10.8	f	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/547/
548	9.9	f	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/548/
549	10.5	f	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/549/

Figure 4.1: Snapshot of data before class labeling

Later we added class labels to each patient depending upon their gender and Hb level. According to worldwide standards a male patient having Hb level lower than 13 is said to be anemic while for female patients this threshold Hb level is 12. So, we class labeled each patient according to their gender and corresponding threshold Hb value to two groups, 'anemic' and 'non-anemic'.
This class label is later used along with the image sequence of the corresponding videos to create the training data to effectively train the model.

4.1.2 Algorithm Implementation

The model is created using **TensorFlow Keras API**. TensorFlow Keras or *tf.keras* is *TensorFlow*'s high-level API for building and training deep learning models. We

A	B	C	D	E
Serial	Hb	sex	Anemic	Video Path
518	11.2	f	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/518/
543	10.7	m	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/543/
544	10.6	f	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/544/
545	10.8	f	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/545/
546	11.6	f	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/546/
547	10.8	f	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/547/
548	9.9	f	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/548/
549	10.5	f	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/549/
552	13	f	0	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/552/
554	9.7	m	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/554/
555	10.2	m	1	/content/gdrive/My Drive/Thesis Access/Defense/Image Sequence Processing Footage/Finger Surface Videos/555/

Figure 4.2: Snapshot of data after class labeling

used Convolutional Neural Networks, or *CNN*s for short, from the Keras API. The processed data from the previous chapters are used here to build a training dataset from which we will create our model to train and test in the later stages.

Training data

Previously saved and processed data is used to create the training data set. The anemic conditions of each patient were determined by their gender and Hb level and given a class label of anemic or non-anemic in the *"HemoglobinDataset.csv"* file. An array was created named *'class_label'* and anemic conditions of each patient were added to this array in binary format, where 1 represents anemic and 0 represents non anemic condition. Using *Opencv 'imread'* function threshold applied image sequences from the video of patients were loaded into memory. These images were loaded in grayscale mode.

$$img\_array = cv2.imread(os.path.join(path, img), cv2.IMREAD\_GRAYSCALE)$$

The images were then resized using the opencv *'resize'* function to a **64 X 64** array.

$$new\_array = cv2.resize(img\_array, (IMG\_SIZE, IMG\_SIZE))$$

After resize operation each image array along with the corresponding binary class label of the patient was appended to an array named 'training_data' which is our final dataset on which the model will train on. Each image from each video was processed like this and added to the training data with their corresponding binary anemia label. So, we ended up with a total of 29129 rows of data as our training data. This training data was saved to storage for further processing.

Model Building

The training data was loaded and randomized using the shuffle function from the python's random package. The image data was loaded into an array 'X' and the class label of the corresponding image was loaded into an array 'Y'. The image data was normalized by dividing it by 255. This X array is the image data that we will feed to the CNN model and Y array works as the true value of the anemic condition of the patients which we will use later to evaluate our model on performance.

After importing all the necessary packages and modules from *tensorflow* we start to build our *tensorflow* sequential model.

$$model = Sequential()$$

Then we add a 2D convolution layer to the model specifying it's kernel size and input shape.

$$model.add(Conv2D(64, (3, 3), input\_shape = X.shape[1 :]))$$

We add *'relu'* as an activation function and add a max pooling operation using a pool size of **2*2**.

$$model.add(Activation('relu'))$$

$$model.add(MaxPooling2D(pool\_size = (2, 2)))$$

We added another 2D convolution layer which uses the output of the first 2D convolution layer as it's input. The second 2D convolution layer uses the similar activation function and max pooling of 2X2. After this a Flatten layer was added. Flattening a tensor means to remove all of the dimensions except for one. This is exactly what the Flatten layer does.

$$model.add(Flatten())$$

After flattening we added a dense layer with 64 units which dimensionality of the output space.

$$model.add(Dense(64))$$

We added another dense layer with one unit and added a *sigmoid* activation function. This last dense layer is our final output layer.

$$model.add(Dense(1))$$

$$model.add(Activation('sigmoid'))$$

As an optimizer we choose Adam optimizer with a learning rate of **0.0001**. We compiled the model specifying the loss function as *binary_crossentropy* and training metrics as accuracy using our *adam* optimizer.

$$model.compile(loss =' binary\_crossentropy', optimizer = adam, metrics = ['accuracy'])$$

Finally we called the model.fit function to start the training of our data providing the parameters as X array containing the image data, Y array which contains the actual class labels, batch size of 64, epoch count of 1000 and validation split as 0.2 indicating to use 20% of the whole dataset to use for testing the accuracy.

$$model.fit(X, Y, batch\_size = 64, epochs = 1000, validation\_split = 0.2)$$

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d (Conv2D)              (None, 62, 62, 64)        640
_________________________________________________________________
activation (Activation)      (None, 62, 62, 64)        0
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 31, 31, 64)        0
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 29, 29, 64)        36928
_________________________________________________________________
activation_1 (Activation)    (None, 29, 29, 64)        0
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 14, 14, 64)        0
_________________________________________________________________
flatten (Flatten)            (None, 12544)             0
_________________________________________________________________
dense (Dense)                (None, 64)                802880
_________________________________________________________________
dense_1 (Dense)              (None, 1)                 65
_________________________________________________________________
activation_2 (Activation)    (None, 1)                 0
=================================================================
Total params: 840,513
Trainable params: 840,513
Non-trainable params: 0
_________________________________________________________________
```

Figure 4.3: The summary of the model

4.2 Results

After running for 1000 epochs out model training was completed and we ended up with 94.55% train accuracy and 91.5% test accuracy. Training the model on more epochs would result in overfitting of the model in which case the train accuracy will increase but test accuracy will decrease.

We predicted all the data of the X array with our newly trained model and compared the result with the actual class label stored in the Y array. After running the model on all test data which consists of 29129 rows, The evaluation parameters of the confusion matrix was generated from the model. Table 4.2 shows the results of the proposed anemia detection model on a confusion matrix.

Total data = 29129	Predicted Anemic	Predicted Non-Anemic
Actual Anemic	**TP** = 10958	**FN** = 1690
Actual Non-Anemic	**FP** = 143	**TN** = 16338

Chapter 5

Evaluation

This chapter provides insight about the evaluation metrics of the proposed model of anemia detection. It contains the performance metrics of the proposed model as indicated by the outcomes given in the past section. These performance metrics can be assessed using the proportion of correct and incorrect forecasts made by the proposed model, and include sensitivity, specificity, precision, misclassification rate and overall accuracy.

5.1 Analysis

The proposed model of anemia detection using CNN from Keras of TensorFlow was used in testing unlabeled dataset consisting of 11651 records (20% of input dataset). Every individual record in the testing dataset constitutes images from the patients of anemic and non-anemic. The class label of the test data was generated from the CBC report of the patients. The anemic patients' images had class labels of 1, meaning true value for probable anemia. On the other hand non-anemic patients were labeled 0 indicating their non-anemic condition. This 0 or 1 value to indicate anemic status was generated from the Hb level of the corresponding patients.

The CNN model was trained using the same but labeled training dataset consisting of 46606 records (i.e. 80% of the input dataset). Then it was run against a testing dataset, which is the rest 20% data but without the class label. The dataset was randomized so that the model does not get varied data to train on and to prevent overfitting. When the model was used for prediction on the total data, it produced predictions in a form of "1" or "0". The prediction result made by the model were compared with the actual class label of the data, and the results show:

- The total number of predicted anemic conditions which was actually anemic was 10958. Therefore, the true positive (TP) value of the model is: TP = 10958.

- The total number of predicted anemic conditions that were actually non anemic was 1690. Therefore, the true negative (TN) value of the model is: TN = 1690.

- The total number of predicted non anemic conditions that were actually anemic was 143. Therefore, the false positive (FP) value of the model is: FP = 143.
- The total number of the predicted non anemic conditions that were actually anemic was 16338. Therefore, the false negative (FN) value of the model is: FN = 16338.

Accuracy

The accuracy rate of the model can be calculated from its confusion matrix. The equation of measuring accuracy rate is:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

= 0.9370730200144186

Sensitivity

Sensitivity also called true positive rate refers to the test's ability to correctly identify sick patient.[5] Sensitivity measures the proportion of actual positives that are correctly identified as such, in our case our model's successful prediction of anemic patients. The equation of measuring sensitivity from the confusion matrix is:

$$Recall = \frac{TP}{TP + FN} \text{ or } \frac{TruePositive}{ActualResults}$$

= 0.9288526893579293

Specificity

Specificity indicates the model's ability to correctly detect healthy patients without a condition. Specificity of a model is the proportion of healthy patients who will test negative in prediction meaning the number of actual non anemic patients detected correctly as non-anemic by our model. The mathematical equation to measure specificity is:

$$Specificity = \frac{TP}{TP + FP} \text{ or } \frac{TruePositive}{PredictiveResults}$$

= 0.9913233420302167

Precision

Precision indicates a patient labeled by our model as anemic is indeed anemic. In order to get the value of precision the number of correctly classified positive data or true positive is divided by the total number of predicted positive data.

$$Precision = \frac{TP}{TP + FP}$$

= 0.9466876056456994

F1-Score

The F1 score (also F-score or F-measure) is a measurement of a model's accuracy in Binary classification. It considers both the precision score and the recall score of the model to compute the score..

$$F - measure = \frac{2 \times Recall \times Precision}{Recall + Precision}$$

0.9348506122854656

Matthews Correlation Coefficient (MCC)

Matthews Correlation Coefficient is actually one kind of Correlation coefficient to get and define the quality of multiclass classifications which is basically used in machine learning, It works with genuine and false positives and negatives and is ordinally treated as a well impartial estimation that can be utilized through the classes are of totally different sizes. The MCC is in nature a correlation coefficient where the worth is between - 1 and +1 where a coefficient of +1 speaks to an ideal forecast, 0 a normal arbitrary expectation and - 1 an opposite expectation. Phi coefficient is another generally utilized name as Matthews connection coefficient.

$$MCC = \frac{TP \times TN - FP \times FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}}$$

=0.8200798453//

ROC Curve

A receiver operating characteristic curve, or ROC curve, is a graphical plot to visualize the diagnostic ability of a binary classifier system like our model. A ROC space is generated by plotting values of False Positive Rate (1 specificity) and True Positive Rate (sensitivity) in x and y axes respectively. The upper left corner or coordinate which is (0,1) of the ROC space represents 100% or perfect sensitivity and 100% or perfect specificity of the model and represents a perfect classification. The model is performing better if the ROC curve gets as close to the perfect classification point as possible. From our proposed model the generated ROC curve gives a AUC value of 0.98

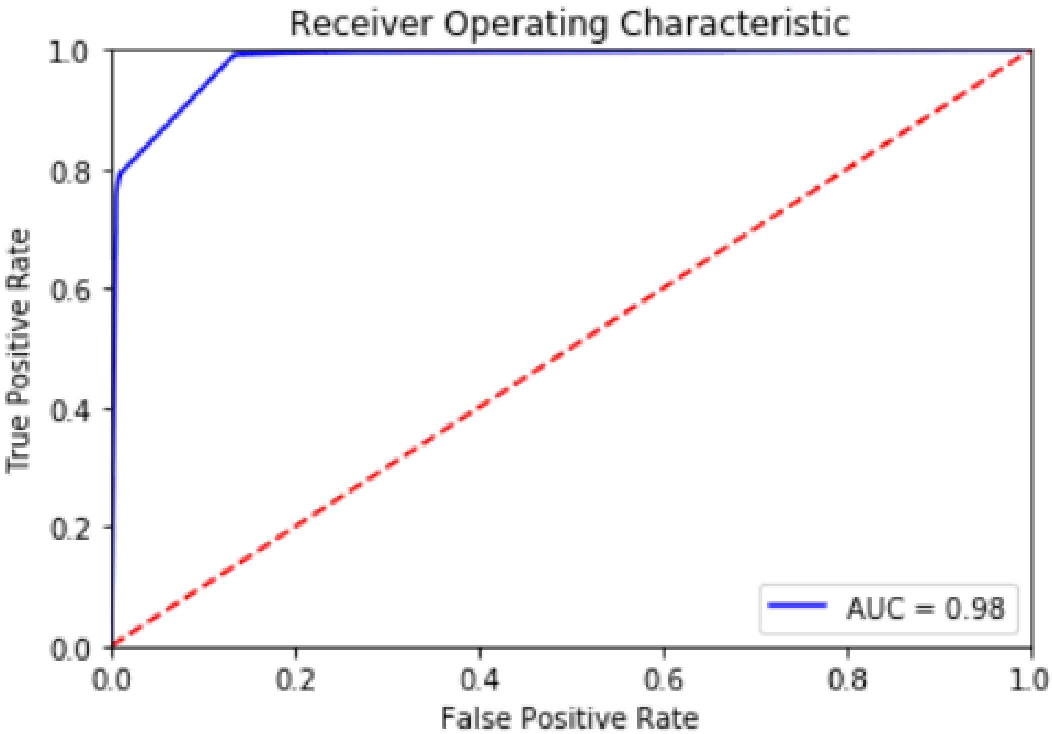


Figure 5.1: Receiver operating characteristic curve

Chapter 6

Conclusion

6.1 Research Overview

Image Processing and Machine Learning is becoming blistering technologies in present years. Recently, in today's healthcare system, throughout the entire clinical process from diagnostics and medicament arrangement to surgical strategies and even for further research studies, imaging plays a vital role which cannot be ignored. For the reason that most of the imaging models or procedures have gone directly digital and the resolution of images are multiplying constantly, treatment through breaking down pictures needs to confront a considerable amount of impediments that are ascending from enormous information volumes. In this research, we try to find out an anemic patient with a low-cost environment as a big portion of people suffering from anemia is from rural areas. Moreover, we tried and succeeded to make a non-invasive way to detect anemia using a 10 seconds short fingertip video. Later, through analysis, we found out the result showing an accuracy of 94.55% which is a big improvement of previous works. While such techniques are coping with challenges, we tried to solve the issue and as medical image processing remains a vital field of research more improvement can be done.

6.2 Contribution and Impact

The proposed model aims to detect anemia, where medical infrastructure is unavailable or costly. The main contribution of this study is, this solution is reliable and non-invasive. Also, it costs less than other proposed solutions. In this era, almost everybody has a smartphone. Even if they don't, it is easy to find one in the locality. To perform this model, only a smartphone is enough. By performing image processing and Machine Learning together, anemia can be detected within seconds.

From the very first, we were clear about our ultimate goal, which is to help the people of the rural region of developing countries. The proposed model will help detect anemia on a continuous basis, that may help millions of lives. For example, during the maternal period, iron consumption is very essential. Otherwise, the risk of anemia may damage their babies. Anemia may fluctuate over time by the eating habit of a woman. That is why continuous measurement is necessary to ensure maternal health. For now, this model can only detect anemia on a primary level.

However, deeper studies may find more correlation with Hb, which may enable the path for the detection of other diseases in a non-invasive way as well.

We believe non-invasive methods are the future of medical science. We have already seen laser technology applied in physical bisections. Hence, non-invasive ways will prevent infections and the complexity of an operation. Even if this study may not prove to be enough, these are important for future development. Also, this research may help some other researchers to develop a more convenient model.

6.3 Recommendation and Future Work

Although we got above 90% correlation, there is a lot to improve and study. This sector is still not well established in the medical sector. So, to prove the credibility of this method, more research needs to be done.

We collected data in a medical center, where lighting conditions were not suitable. That is why, the data might be disrupted due to specular reflection or unwanted light source. Therefore, a more dedicated space and device needs to be constructed. Again, study can be done on other body parts like conjunctiva or tongue. There should be detailed study on pregnant women, as they are at high risk due to anemia.

We would recommend more study on how to improve the analysis model. We took only two parameters into consideration: Hb level and blood image from mobile device. Also, we classified the data as anemic or non-anemic only. However, more parameters may help determine Hemoglobin in a convenient way. Also, with appropriate sensors, more study should be conducted on pulse CO oximeters.

Bibliography

[1] F. Rodkey, T. Hill, L. L. Pitts, and R. Robertson, "Spectrophotometric measurement of carboxyhemoglobin and methemoglobin in blood.", *Clinical Chemistry*, vol. 25, no. 8, pp. 1388–1393, 1979.

[2] B. Lozoff, G. M. Brittenham, A. W. Wolf, D. K. McClish, P. M. Kuhnert, E. Jimenez, R. Jimenez, L. A. Mora, I. Gomez, and D. Krauskoph, "Iron deficiency anemia and iron therapy effects on infant developmental test performance", *Pediatrics*, vol. 79, no. 6, pp. 981–995, 1987.

[3] T. O. Scholl, M. L. Hediger, R. L. Fischer, and J. W. Shearer, "Anemia vs iron deficiency: Increased risk of preterm delivery in a prospective study", *The American journal of clinical nutrition*, vol. 55, no. 5, pp. 985–988, 1992.

[4] N. Karayiannis and A. Venetsanopoulos, "Anns: Learning algorithms", *Performance Evaluation and Applications. Kluwer Academic Publishers, Boston*, 1993.

[5] D. G. Altman and J. M. Bland, "Statistics notes: Diagnostic tests 2: Predictive values", *Bmj*, vol. 309, no. 6947, p. 102, 1994.

[6] P. Domingos and M. Pazzani, "On the optimality of the simple bayesian classifier under zero-one loss", *Machine learning*, vol. 29, no. 2-3, pp. 103–130, 1997.

[7] T. M. Mitchell *et al.*, *Machine learning*, 1997.

[8] I. Rish *et al.*, "An empirical study of the naive bayes classifier", in *IJCAI 2001 workshop on empirical methods in artificial intelligence*, vol. 3, 2001, pp. 41–46.

[9] U. Unicef and U. WHO, "Who: Iron deficiency anaemia: Assessment, prevention, and control", *A guide for programme managers*, 2001.

[10] J. Xie and H.-T. Tsui, "Image segmentation based on maximum-likelihood estimation and optimum entropy-distribution (mle–oed)", *Pattern Recognition Letters*, vol. 25, no. 10, pp. 1133–1141, 2004.

[11] N. Nacereddine, L. Hamami, M. Tridi, and N. Oucief, "Non-parametric histogram-based thresholding methods for weld defect detection in radiography", in *Transactions on Enformatika, Systems Sciences and Engineering*, Citeseer, 2005.

[12] C. M. Bishop, *Pattern recognition and machine learning*. springer, 2006.

[13] D. Lu and Q. Weng, "A survey of image classification methods and techniques for improving classification performance", *International journal of Remote sensing*, vol. 28, no. 5, pp. 823–870, 2007.

[14] B. Demir and S. Ertürk, "Improving svm classification accuracy using a hierarchical approach for hyperspectral images", in *2009 16th IEEE International Conference on Image Processing (ICIP)*, IEEE, 2009, pp. 2849–2852.

[15] R. S. Hegadi, "Image processing: Research opportunities and challenges", *NSRC Dec*, 2010.

[16] G. Yiqiang, W. Yanbin, J. Zhengshan, W. Jun, and Z. Luyan, "Remote sensing image classification by the chaos genetic algorithm in monitoring land use changes", *Mathematical and Computer Modelling*, vol. 51, no. 11-12, pp. 1408–1416, 2010.

[17] R. K. Mohanta and B. Sethi, "A review of genetic algorithm application for image segmentation", *Int. J. Comput. Technol. Appl*, vol. 3, no. 2, pp. 720–723, 2011.

[18] A. Sultana and M. Meenakshi, "Design and development of fpga based adaptive thresholder for image processing applications", in *2011 IEEE Recent Advances in Intelligent Computational Systems*, IEEE, 2011, pp. 633–637.

[19] O. Zhernovaya, O. Sydoruk, V. Tuchin, and A. Douplik, "The refractive index of human hemoglobin in the visible range", *Physics in Medicine & Biology*, vol. 56, no. 13, p. 4013, 2011.

[20] B. O. Alijla and K. Kwaik, "Oiahcr: Online isolated arabic handwritten character recognition using neural network.", *Oiahcr: online isolated arabic handwritten character recognition using neural network.*, vol. 9, no. 4, 2012.

[21] R. O. Duda, P. E. Hart, and D. G. Stork, *Pattern classification*. John Wiley & Sons, 2012.

[22] N. Nik Rosmawati, S. Mohd Nazri, and I. Mohd Ismail, "The rate and risk factors for anemia among pregnant mothers in jerteh terengganu, malaysia", *J Community Med Health Educ*, vol. 2, no. 150, pp. 2161–0711, 2012.

[23] K. S. Raju and D. V. Karthikeyani, "Improved satellite image preprocessing and segmentation using wavelets and enhanced watershed algorithms", *International Journal of Scientific & Engineering Research*, vol. 3, no. 10, 2012.

[24] L. Thai, T. Hai, and N. T. Thuy, "Image classification using support vector machine and artificial neural network", *International Journal of Information Technology and Computer Science (IJITCS)*, vol. 4, no. 5, pp. 32–38, 2012.

[25] E. PraveenKumar and M. Sumithra, "Medical image compression using integer multi wavelets transform for telemedicine applications", *International Journal Of Engineering And Computer Science*, vol. 2, pp. 1663–1669, 2013.

[26] U. R. Babu, Y. Venkateswarlu, and A. K. Chintha, "Handwritten digit recognition using k-nearest neighbour classifier", in *2014 World Congress on Computing and Communication Technologies*, IEEE, 2014, pp. 60–65.

[27] M. Samad and A. Al Suman, "A reconstruction of original image from destroyed image through haar wavelet transform", 2014.

[28] C. Camaschella, "Iron-deficiency anemia", *New England journal of medicine*, vol. 372, no. 19, pp. 1832–1843, 2015.

[29] ——, "Iron-deficiency anemia", *New England journal of medicine*, vol. 372, no. 19, pp. 1832–1843, 2015.

[30] P. Thamilselvana and J. Sathiaseelan, "A comparative study of data mining algorithms for image classification", *Int. J. Educ. Manage. Eng*, vol. 5, pp. 1–9, 2015.

[31] M. H. Alsuwaiyel, *Algorithms: design techniques and analysis*. World Scientific, 2016.

[32] E. J. Wang, W. Li, D. Hawkins, T. Gernsheimer, C. Norby-Slycord, and S. N. Patel, "Hemaapp: Noninvasive blood screening of hemoglobin using smartphone cameras", in *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, 2016, pp. 593–604.

[33] M. Kamalahasan, K. Vijayarekha, and P. Vimaladevi, "Review on classification algorithms in image processing", vol. 2, pp. 1–6, Nov. 2017.

[34] K. Manjula, K. Vijayarekha, and P. Vimaladevi, "Review on classification algorithms in image processing", *International Journal of Innovative Trends in Engineering & Research*, vol. 2, no. 11, 2017.

[35] W. H. Organization *et al.*, *The global prevalence of anaemia in 2011. geneva: World health organization; 2015*, 2017.

[36] H. Butler, W. MacNevin, E. Naseri, J. Torrealba, N. Bressan, G. Jiwani, and A. Ahmadi, "Development of a non-invasive point-of-care hematocrit sensor for anemia detection", *CMBES Proceedings*, vol. 41, 2018.

[37] H. Zakaria and R. A. Rochmanto, "Optimum wavelengths on haemoglobin concentration measurement", in *2018 International Symposium on Electronics and Smart Devices (ISESD)*, IEEE, 2018, pp. 1–3.

[38] M. K. Hasan, "Best (biomarker estimation): Health biomarker estimation non-invasively and ubiquitously", 2019.

[39] Q. Li, F. Liang, L. Weilan, W. Shi, and Y. Han, "Prevalence of anemia and its associated risk factors among 6-month-old infants in beijing", *Frontiers in pediatrics*, vol. 7, p. 286, 2019.

[40] S. Shaier, *Ml algorithms: One sd ()- bayesian algorithms*, Feb. 2019. [Online]. Available: https://towardsdatascience.com/ml-algorithms-one-sd-%CF%83-bayesian-algorithms-b59785da792a.

[41] A. Sonianu, "A literature review of various image processing techniques", *Journal of Research Contribution and Education*, vol. 1, no. 1, pp. 17–20, 2019.

[42] *Machine learning*, Apr. 2020. [Online]. Available: https://en.wikipedia.org/wiki/Machine_learning.

[43] s. Bozinovski, *Teaching space: A representation concept for adaptive pattern classification.*

[44] M. Imran, M. B. Rao, and C. Kavitha, "An improved naive bayes classification to enhance image registration",

[45] R. Ravikumar and V. Arulmozhi, "Digital image processing-a quick review",