Development of Portable Photo Spectrometer for Classification of Biomedical Fluids using Neural Network

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Copyright Statement

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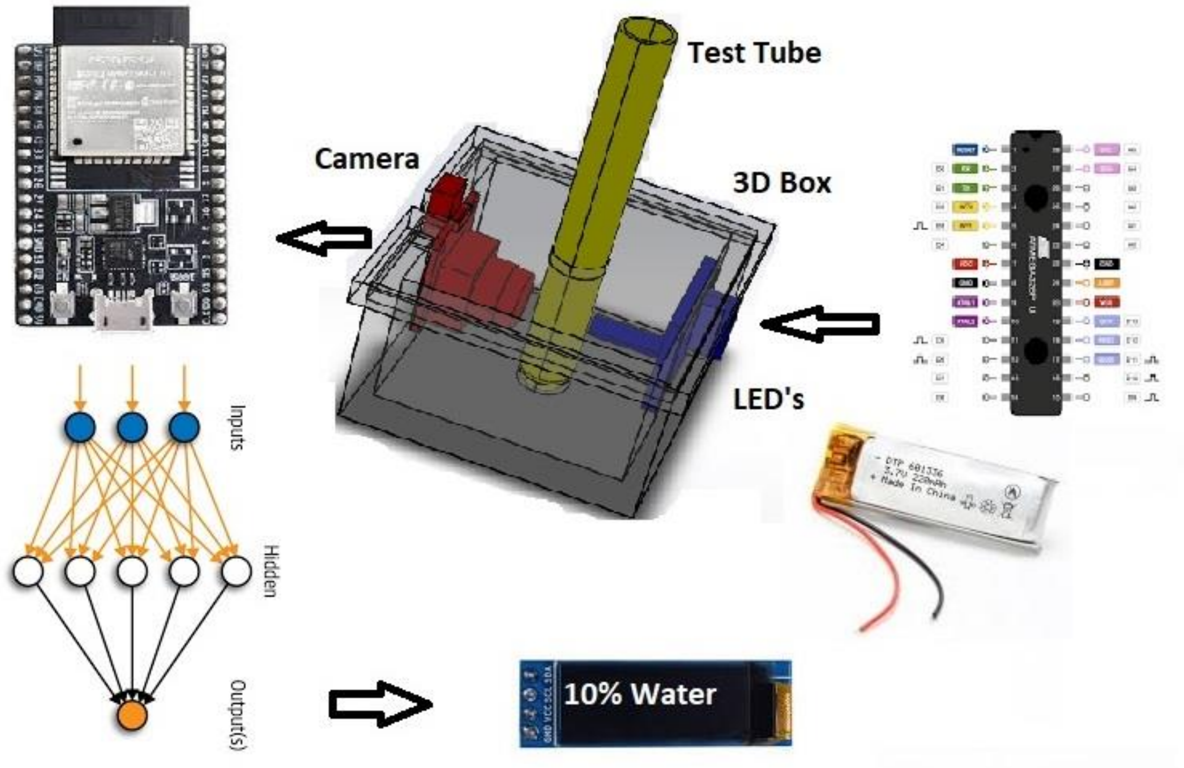
Abstract

Spectrometer is one of the powerful technologies in testing, discovering, and measuring spectral components of different fluids. It is commonly used is the field of Physics, Material science, Chemistry and Biochemistry. Different fluids such as blood, milk, petrol, and Human body fluids can be classified using the spectrometer on the base of the light absorbance of different wavelengths. Commercially various smart spectrometers are available for different fluids classification, but no one is classifying the fluids at real time having such a low price and high accuracy. In this study we have manufactured a light weight, portable, cost effective and standalone Artificial Intelligence based spectrometer device for the fluid classification. The device uses small quantity of the fluid as 3 milliliters in a test tube and predict the results by pressing the push button. The fluids such as milk and petrol were tested by the device and classified with 96% and 97% accuracy respectively. Initially data samples of different quality of fluids were taken using the light sources and camera, and the data was randomized and divided into testing and training data. After that Neural Network is trained to predict the results and microcontrollers are used for model deployment. The casing of the device was designed, and 3D printed having the size of 70 x 70 x 45 mm and weight of 200 grams. An OLED is used to see the results on the screen. The device can be used for the quality analysis for different fluids. It is easy to use, rechargeable, accurate and cost effective as compared to other spectrometers.

Keywords: Machine learning based spectrometer, Real time classification of fluid, Fluid Classification, Smart Spectrometer

Graphical Abstract



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Chapter 1: Introduction

Fluids are the substances which can flow and have no fixed shape. Fluids are everywhere from human body to car engines. Fluids are the part of human body such as blood, saliva, cerebrospinal fluid, urine, and many others. In our daily life we are using different liquids such as water, milk, petrol etc and different gases such as oxygen, nitrogen, carbon dioxide etc. And most of them are essential for the survival of mankind. There are different properties of fluids such as mass, volume, density, temperature and pressure which are used to study about the chemical and physical properties of fluids. [1] Any change in the chemical or physical properties of the fluids can change the behavior and effect of the fluid. We can know about the quality of the fluids through various tests and spectroscopy is one of the most usable method for liquid fluids testing. [2][3] Any change is the chemical and physical properties of fluid can be beneficial or can be dangerous depending on the type of fluid that is why the quality assurance is very important and can be done by spectrometer. Spectrophotometer is used for measuring the light absorbance through the containing sample. Light beam passes though the sample to measure the light absorbance. It is very commonly used in the field of Physics , Biology , Molecular sciences , Biomedical sciences , Biochemistry and Chemistry. [4][5][6] Some fluid testing devices are already available for fluid analysis and classification but these devices are not using multiple light sources as features and not able to classify the fluid at real time with good accuracy. One of them is spectrometer based device for testing of fruit ripeness which is portable, wireless, easy to use , rechargeable and having good accuracy but it is using a single light source. [7] And the other one is for fluid testing, which is also portable, light weight, rechargeable and easy to use but it is not able to classify the fluid at real time.[8] There are many similar devices available for fluid testing but most of them are laboratory based and not classifying the fluids in real time on the base of its spectral properties. Now by using the recent innovations and technologies such as Artificial Intelligence and machine learning it is possible to upgrade the functionality of spectrometers which can classify the fluids without human intervention or any further tests. [9] In this study we have designed a portable, lightweight, rechargeable, wireless, and easy to use fluid classification device which is useful for the testing and quality assurance of various fluids such as urine, blood, petrol, and milk etc. The device uses TSL1401 Camera module having 300 nm to 1000 nm light intensity range and combination of light sources. The size and weight of the device is 70 x 70 x 45 mm and 200 grams respectively. It is tested on milk and petrol and the classified the fluids with average accuracy of 94 %. The data was extracted by using the sample of different quality of fluids and label them as different classes and the data was divided into testing and training parts. The data was used to train the Neural Network Algorithm and making the model. Microcontrollers are used for the model deployment. [10] The results in real time can be seen on an OLED screen mounted on the device.

1.1. Background

Spectrometers are widely used in the industries and laboratories for various type of testing , diagnosis and treatments [11]. Spectrometer was invented in mid of nineteenth century to measure light absorbance and it is still useful for the industry and laboratories its basic principle is shown in Figure 1. [12] Miller and Huggin's spectroscope was one of the mostly used spectroscope in nineteenth century. The advancement in the field of science, computer and Engineering made it more smart and very small in size. With the invention of microprocessors and microcontrollers in 1970's the micro devices are manufactured and used by the whole world. [13] And with the passage of time and with new inventions in the field of physics, computer and chemistry very accurate spectrometers are available in different types on the base of working and light spectrum range such as Nuclear magnetic resonance spectroscopy, Mass spectrometer and Optical spectrometer are most common types.[14] With the advancement in technology and computer generations it is possible to make microchips and circuits using VLSI (Very Large Scale Integration). [15] CMOS (Complementary Metal Oxide Semiconductor) and TTL (Transistor-transistor logic) technologies have made the devices very compact ,small in size and cost effective.[16] With the invention of Light weight and rechargeable batteries such as Lithium Polymer batteries and Lithium ion batteries it is not possible for electronic devices to work for longer period with less weight. [17] Advancements in the field of materials sciences and mechanical engineering, it is possible to manufacture complex parts with custom material by some new techniques such as 3D printing and induction molding etc. [18] The designs manufactured by latest technologies are more accurate, cost effective and consuming less manufacturing time. Recently Artificial intelligence is one of the most famous and innovative field in the world having its major types of machine learning and deep learning. [19] In 2012 there were many efficient ways to train Neural Networks and optimizer to optimize the results to increase the accuracy were introduced which have upgraded a lot of innovative features in the old devices. [20] With the help of these technologies such as Spectrometers, Microprocessors, VLSI, Artificial Intelligence and 3D printing it is able to make devices which are more accurate, light weight, portable, predicting in real time, rechargeable and having fast response.

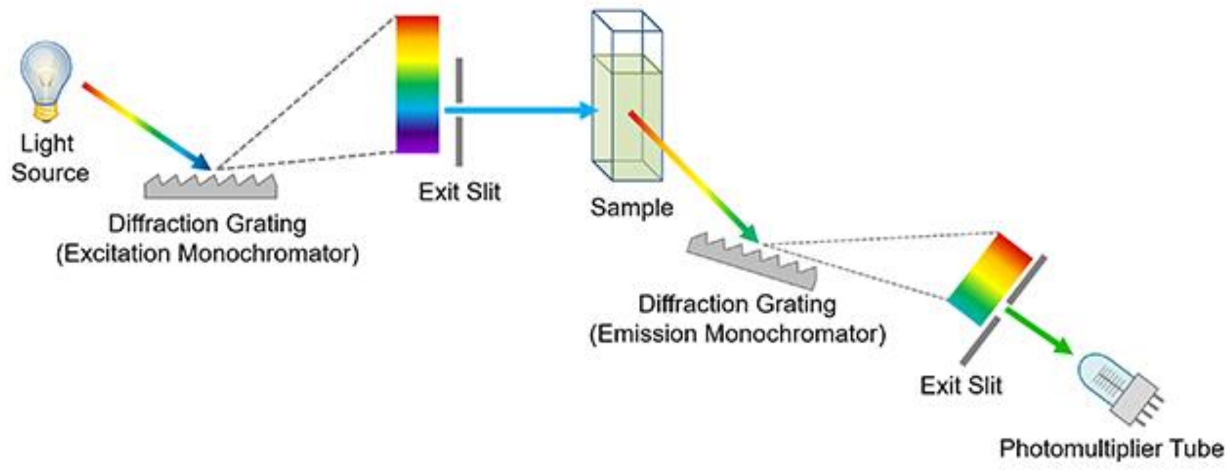

Figure 1 Basic Principle of Spectroscopy

1.2. Problem Statement

Spectrometer is a powerful tool which can provide information about the change in physical and chemical properties of the fluids. It is very important to know about the fluid properties because it can be good or bad for usage if the properties are changed. And sometimes it is required to know about the quality of the fluid in real time at any place, for example in case of petroleum or crude oil testing, milk testing or blood testing etc. So, for these scenarios there is a requirement for a portable, lightweight, cost effective and easy to use device which can classify the fluid at real time in different types of environments. The goal was to make a device which can classify the fluid into different classes of fluids according to change in properties of the fluid.

1.3. Core Objectives

The primary objectives of this study are:

- Design a portable and cost-effective fluid classification device.
- Device can used to train the data and predict the results for various fluids.
- Design should be compact, lightweight and take small quantities of fluid for testing.

1.4. Areas of application

- Research and Development
- Industries
- Laboratories
- Domestic Purposes

1.5. Thesis Overview

Chapter 1 contains the introduction along with the possible suggested solution and description of the problem statement. In Chapter 2 , the work that has been done in the related area is included. In Chapter 3 the detailed information about the experimental protocol and the techniques being used is provided. Chapter 4 contains the results obtained from this study. Chapter 5 contains the discussions of the results and conclusion of the whole work. In chapter 6 provides references for all the citations. Annexure is also provided.

Chapter 2: Literature Review

Classification of fluid is a process in which dispersed materials are separated on the base of physical and chemical properties. [21] Liquids are classified on the base of their crystalline properties by using different classification techniques such as machine learning algorithms, Support Vector Machine and K- Nearest neighbor etc. and Neural Network by using the data of the fluid properties[22] . But there was no real time testing device to predict the results. Near infrared Spectroscopy technology was used for quality analysis, classification, and authentication of liquid fluids. The fluids which were classified on the base of infrared spectroscopy are liquid food as fat, proteins, lactose , alcohols , phenolic compounds , milk , amino acids and typical minerals and the techniques used to classify these liquid fluids are partial least square (PLS) and Principle Component Analysis (PCA) and Least Discriminant Analysis (LDA). [23] Some similar devices have been developed for the classification of the fruits on the base of their ripeness which have used the spectroscope, microcontrollers, and mathematical modeling and for the classification of the fluids on the base of light absorbance but not able to predict the results in real time.

2.1 Selection of Sensor and light sources:

Multiple light sources are selected having different range of light intensities from 300 nm to 1000 nm. The light sources used are red light, blue light, Ultraviolet light, green light and Inferred light. By using just one light source we cannot get significant information about the fluid. For multiple light sources the selected senser should have to cover all light intensity ranges from 300 to 1000 nm. The TSL 1401-DB line scan camera sensor module is used to receive the light after passing through the fluid. [24] The camera module is consisting of TSL 1401 Linear sensor array of 128 sensors, imaging lens having focal length of 7.9 mm and control electronics. It is able to produce clocked Analogue data output having the voltage level according to the light intensity at each pixel. Analogue to Digital converter (ADC) can convert the image data from each pixel and transfer it to microcontroller for the detection of holes, liquid levels , edges , gaps and other visible features. [25] The light sources were used to blink in sequence for data recordings and then data was divided for different light sources. Light can be easily pass through the glass tube containing the fluid. The intensity range of the camera is from 300 nm to 1000 nm which can easily receive all lights mentioned above. With all these properties TSL1401 camera sensor is the best option to use because it is covering is required intensity ranges and have array to sensors which is better as compared to other pin diodes and sensors. The spectral response of the sensor is shown in Figure 2.

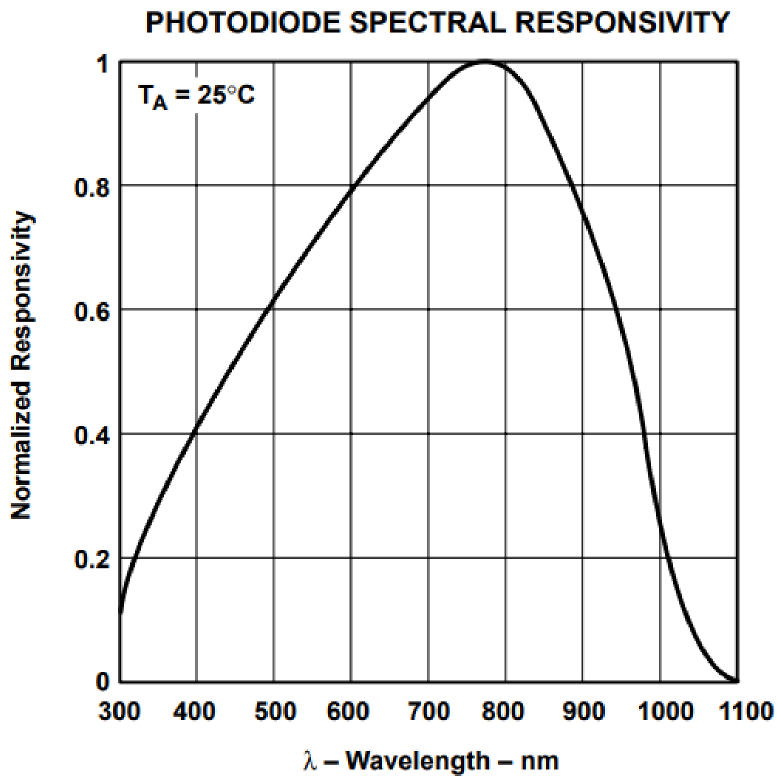

Figure 2 Spectral Response of Sensor

2.2 Material selection and Design constraints:

As in spectroscope the TSL camera sensor is receiving different light rays of different light sources. So, we cannot do this test in the existence of the external light because the existence of external light can affect the actual value of light absorbance. That is why the selected design should have proper covering for camera sensor and light sources. So, the design used should have proper covering and for covering the material used should not be a reflective material and it should not pass external light in the cover.

To make a custom and new design 3D printing is the best option so design is made which can be able to fulfill all requirements mentioned above. Polylactic acid (PLA) is used for the making the external mechanical design of the photo spectrometer. PLA is cheap, not a light reflector, providing good mechanical strength, lightweight and easily available. [26] PLA can be used in almost all 3D printers. In mechanical design a slot is available for inserting the glass tube containing the fluid for testing. Now if we talk about the electrical design then we must have TSL1401 camera sensor and light sources inside the 3d printed box. Furthermore, for real time classification we must have to show the results which means we need an LCD or any other way to show the results. Organic LEDs are very feasible to show the results because it has a lot of features and small size, rather than using an LCD, OLED is better option because it provides better controls over the GUI in the code, have heat sink for heat dissipation and have light as well to show the result at dark places. [27] A comparison between LCD and OLED is shown in figure 3.

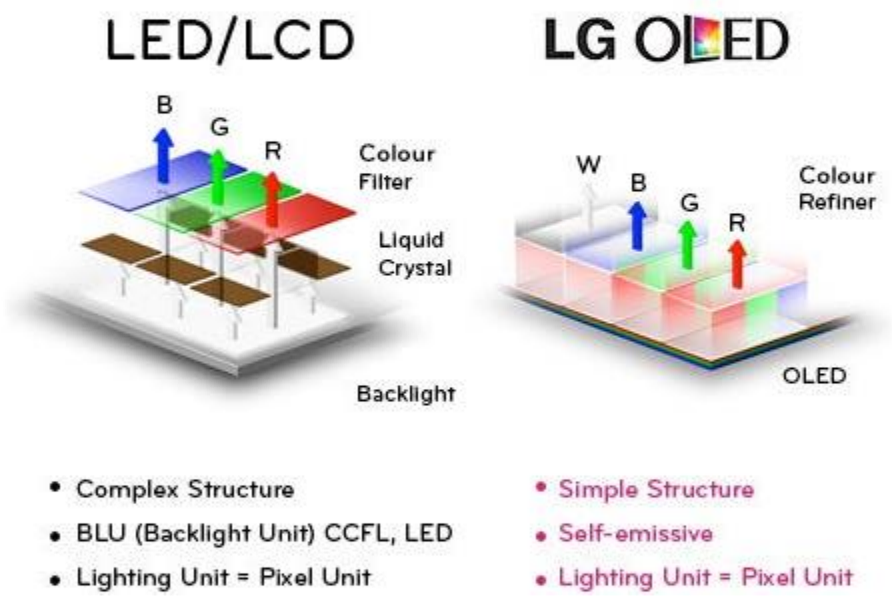

Figure 3 LCD vs OLED

For reading the analogue values from the TSL1401 camera sensor to process and to blink the light sources in a sequence for a specific time there is need of a microcontroller and analogue to digital converter (ADC). There are wide range of microcontrollers available having building ADC and crystal oscillators to generate clock. One of the most commonly available, easy to use and cheapest microcontroller is ATMEGA 328P which is according to the requirements. Most of the devices have used Arduino as a controller. But Arduino is costly and larger in size that is why rather than using Arduino, it is better to use ATMEGA 328P IC. As these the components discussed above are resistive and light emitting. So, it is not a good way to keep these components inside the 3D printed casing. Otherwise, the light can affect the actual light sources and heat can also affect the sensor and light sources. It is better to make 2 circuits one internal circuit which includes light sources and one external circuit which includes microcontrollers and OLED display.

2.3 Sensor calibration and data recording technique:

TSL1401 Camera sensor module has the linear response and there is not very much difference between the recorded values and actual required value. As sensor calibration is required for each fluid to be tested for calibration, the procedure is to record the data for each wavelength by passing multiple lights one at a time. The recorded output should be saved as raw ADC value for each light source. Then there are 2 ways to know about the value either it is true or not. One of them is comparing the results with the literature and knowing the difference between Actual ADC value and Expected ADC value and then we can easily adjust the outcome light absorbance by rotating the lens or adjusting the potentiometer. If the work is novel and not able to find in the previous research work, then the way is to use the standard spectroscopy machine to do the similar test for particular fluid and calculate the absorbance of the fluid using the Beer Lambert Law. [28] Take the fluid in the cuvette and place into the standard spectroscopy machine. The following equation of the Beer Lambert Law can be used to calculate the absorbance.

$$A = log_{10} \frac{I_o}{I}$$

Where

I_o is the Incident Intensity.

I is the transmitted intensity.

Or

$$A = \varepsilon c l$$

Where

ε is the molar absorption coefficient.

C is molar concentration.

l is the optical length path.

By comparing the values from the spectroscopy machine with the actual values recorded from the sensor the difference can be found. And the calibration can be done by adjusting the lens of the sTSL1401 Camera Sensor module. After calibration we can get the data in the form of raw ADC values furthermore, we can filter the values according to requirement. [29] For data acquisition of each fluid which we want to classify we must have to get the data for training the algorithm. To record that data of the fluid, it can be converted into different types by adding impurities and data can be recorded for each class of the fluid. While taking the data the quantity of the fluid there should be the proper measurements of the fluid quantity and mixing impurities. After that this data can be used to train the algorithm.

2.4 Artificial Intelligence based techniques to classify the data and model deployment method:

Machine learning is the branch of Artificial Intelligence in which we can train the algorithm to fit the model which can predict the results of the base of previously trained data. In this scenario data is labeled by each class. And each class label is based on the impurities added. There are different types of machine learning which are shown in Figure 4. When labels are available any supervise learning algorithm can be trained to predict the results. [30] Multiple Machine learning algorithm can be used to predict the results. And at the model having the best accuracy on training and testing data sets can be used for model deployment. But getting good accuracy is not very easy and straight forward. That is why some techniques can be used to get the better results such as Hyperparameter Tunning. During data training we can tune the algorithm by passing different values and types for all parameters and by cross validation we can increase the accuracy. Some methods which can be used for Hyperparameter tunning are Grid Search, Random Search and Bayesian optimization. [31] The other way to increase the accuracy is the use of optimizer which can automatically find the best parameter values to maximize the model accuracy such as Gradient Descent Optimizer, Adam Optimizer etc. [32][33]

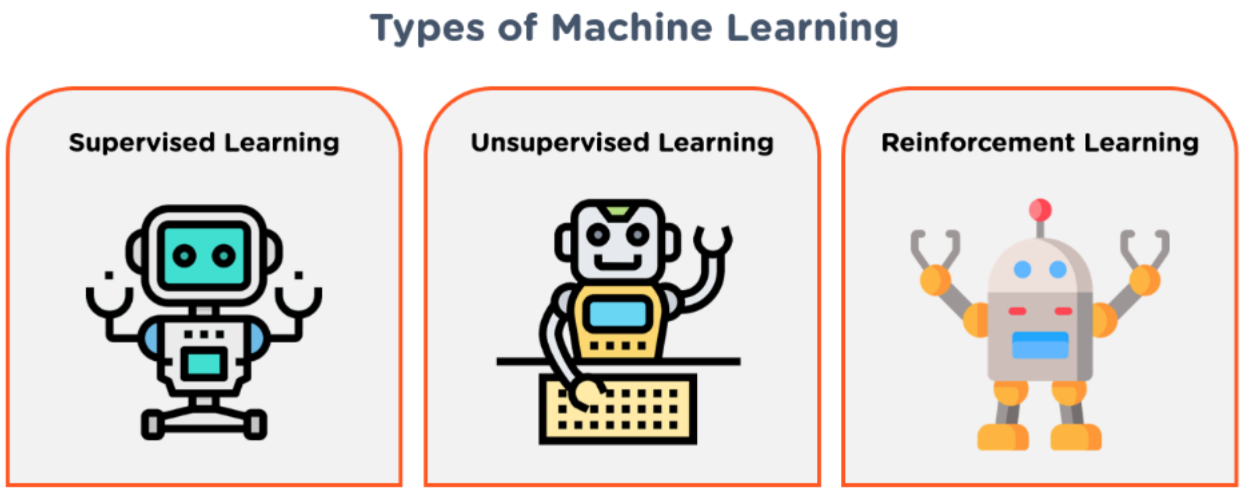

Figure 4 Types of Machine Learning

It is not possible for machine learning algorithms to predict the results having good accuracy for each fluid data. There are many studies which are describing the limitation of machine learning and data sets. [34] Some studies are showing that more data is required for the better accuracy. But some studies are showing some opposite results which mean more data or raw data can also lead to the decrease of model accuracy. [35] Another issue of less accuracy in training the algorithm can be the overfitting or underfitting of the data. If too much training data trained by the algorithm, then it can lead to overfitting of the algorithm (can be reduce by early stopping and network reduction method.) and if dataset is very small then there can be the underfitting. [36] [37] An example of overfitting and underfitting of the data is shown in the Figure 5. Whenever the data is more complex and having too much overlapping then Neural Networks can also be used to predict the results.

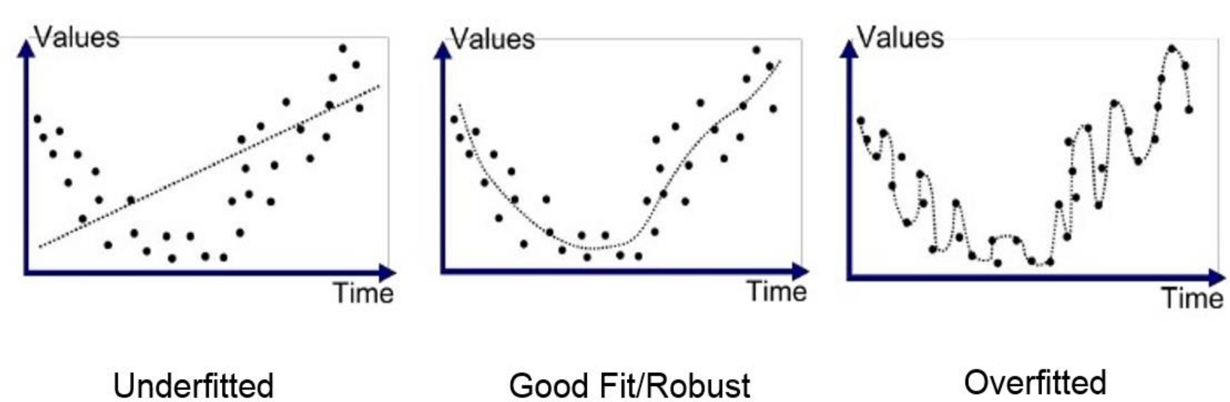

Figure 5 Overfitting and under fitting

Neural Networks can be used for better performance and when you have a lot of data. After using the algorithm to train data and make a model the next step is to deploy the model to a microcontroller or processor for real time results. [38][39] The model can be fit and deploy by using multiple software and programming languages such as MATLAB, Python etc. and Micro python, MATLAB, and C/C++ etc. Micro python is user friendly and easy but slower as compared to C/C++. C/C++ can be used for the fast response. [40] [41]

Chapter 3: Methodology

3.3 Design and Manufacturing

3.3.1 Electronic Design

TSL1401 camera sensor module has chosen to receive the light coming from the light sources. TSL1401 Camera module’s pin description and images are shown below in figure 6 and table 1.

Table 1 Sensor’s Pin Description

The operating voltages are 3 to 5 volts and operating current must be less than 5mA. The dimensions of the camera are 34.3 mm x 30.5 mm.

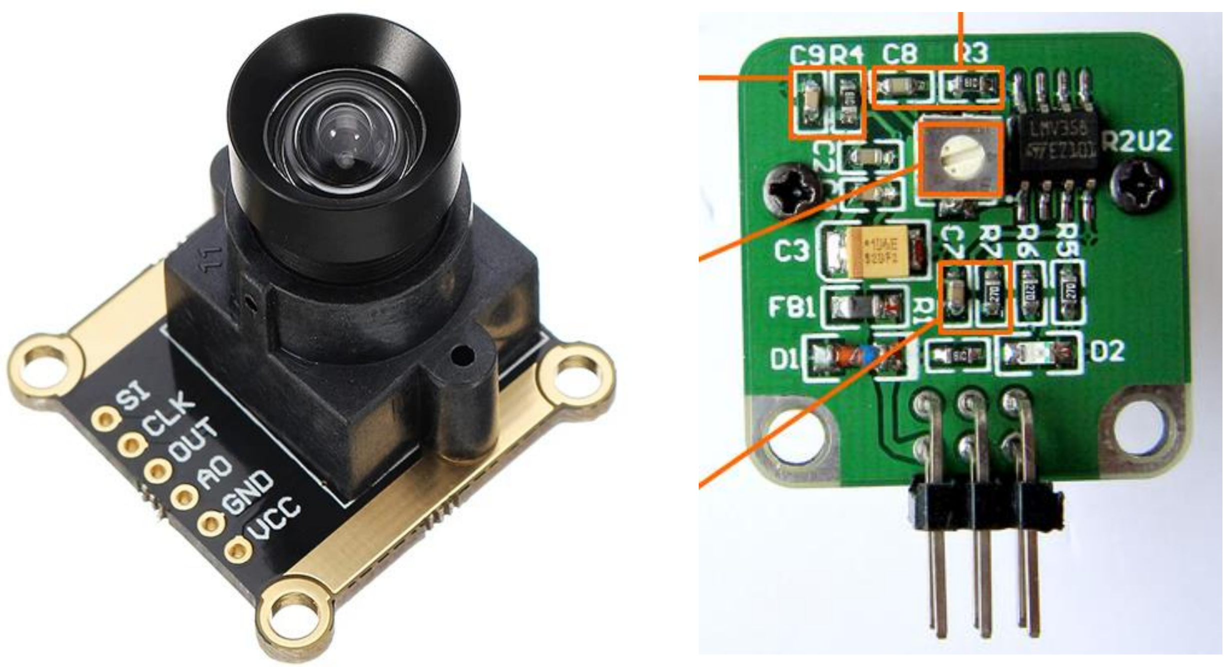

Figure 6 TSL1401 Camera Module

The operating voltages are 3 to 5 volts and operating current must be less than 5mA. The dimensions of the camera are 34.3 mm x 30.5 mm. The image of the camera is shown in figure 6. We have two circuits one of them is to be fixed inside the mechanical design and the other one is outside of the mechanical design. Total there are 4 lights and 4 resistors which are soldered on a small PCB. The PCB containing the light sources and resistors have designed and used inside the Mechanical Covering.

The first step was testing the circuit by connecting the light sources and camera sensor. Then in next step Printed Circuit Board (PCB) was designed on EAGLE CAD software. The Schematic and board view of PCB is shown in Figure 7 and Figure 8. It is a double layer PCB having LED’s and resistors on top side and female header at the back side for connecting the internal circuit with the external circuit through the slot available in mechanical design. There is Serial Peripheral Interface (SPI) communication between TSL1401 camera sensor and ATMEGA328P for data transferring. [42]

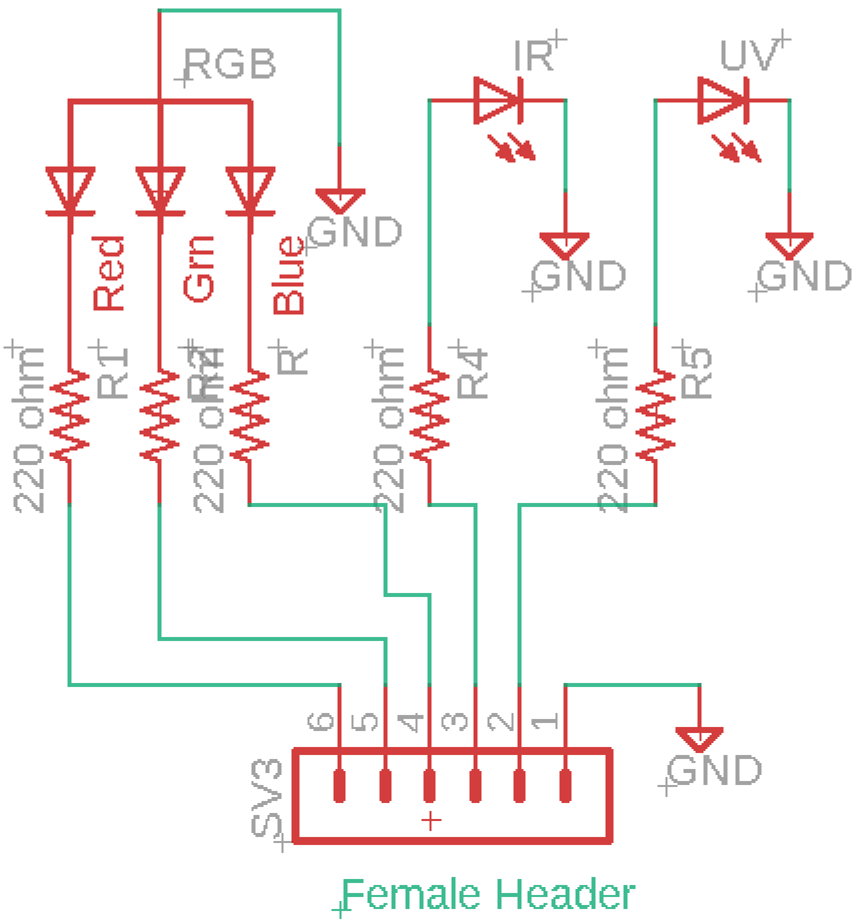

Figure 7 Schematic of Internal Circuit

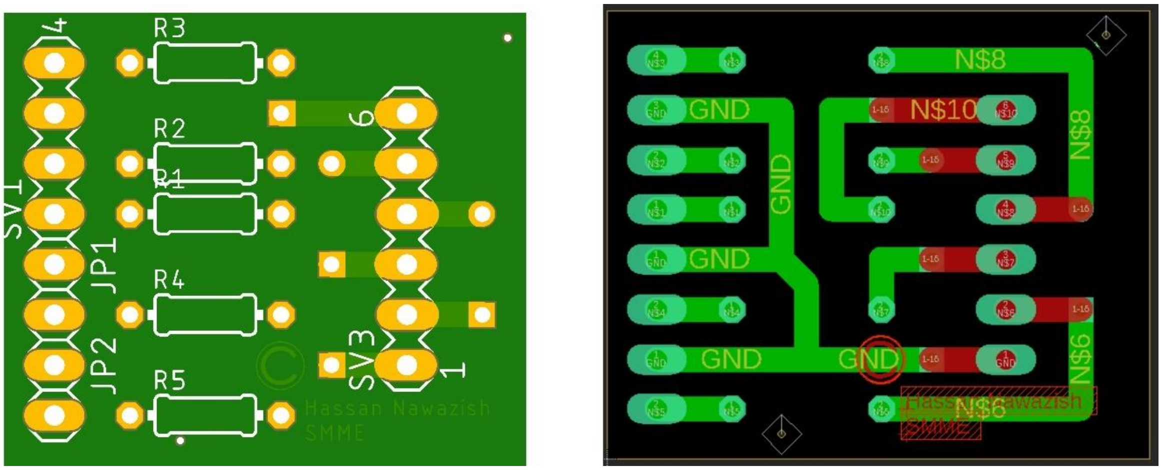

Figure 8   Board view of Internal circuit Board

The size of the copper track is 40 mil and via size is 20 mil. Both square and circular via configuration are used.

ATMEGA328P is used to blink the LEDs in sequence and record the data from the sensor. OLED is used to display the results and ESP32 is used for model deployment. These components are soldered on the external PCB. Furthermore, a reset button, battery connector and battery connecting switch are also used. Crystal oscillator is used to generate the clock signal. ATMEGA 328P is cheap easy to use and not have a complex circuitry. [43] The Pin description of ATMEGA 328P is given in the Figure 9.

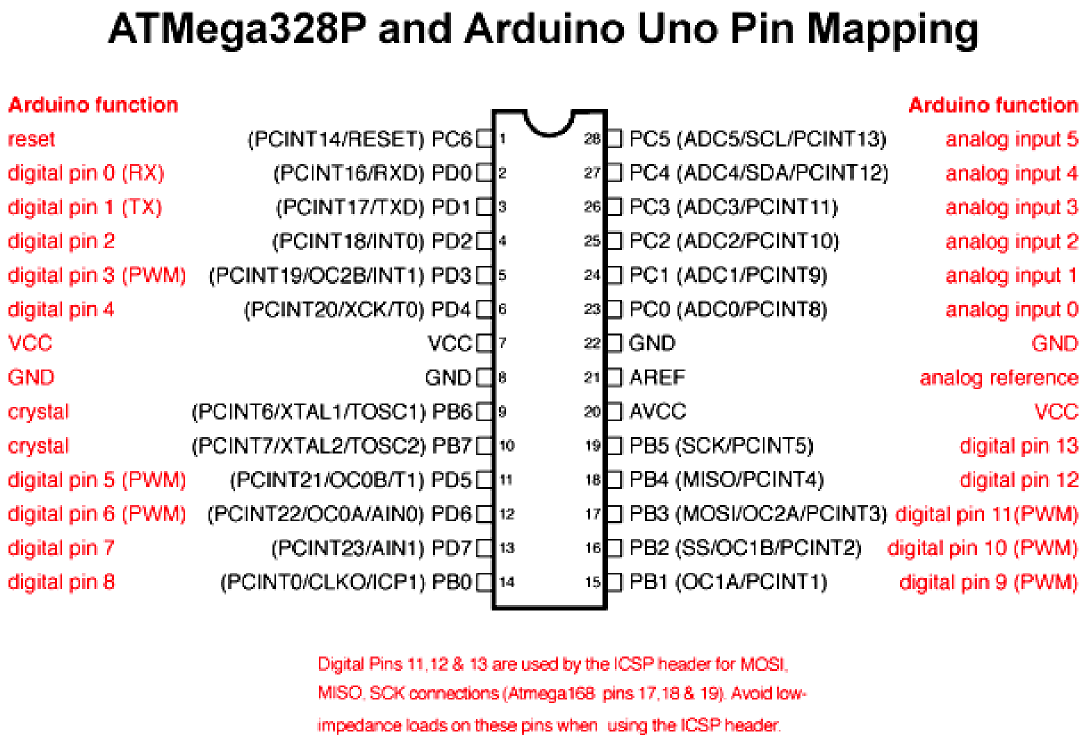

Figure 9 ATMEGA328P pin configuration

OLED of 128 x 32 size is used to display the result which provides good graphics and presentation. OLED of 128 x 32 size is shown in figure 10.

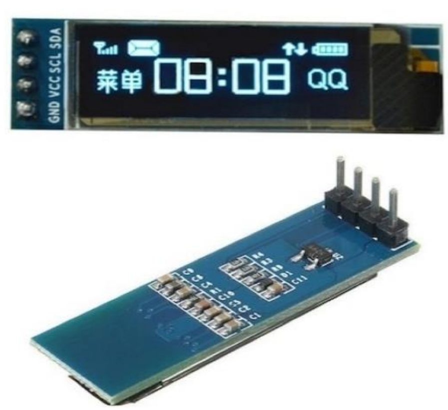

Figure 10 OLED 128 x 32

ESP32 is used to deploy the Neural Network model. ESP32 is available for UART, I2C and SPI communication. There is I2C communication between ESP32 and OLED to transfer the data.[44]

And there is Serial communication between ESP32 and ATMEGA328P to transfer the data. [45] Pin Configuration of ESP32 is shown in figure 11.

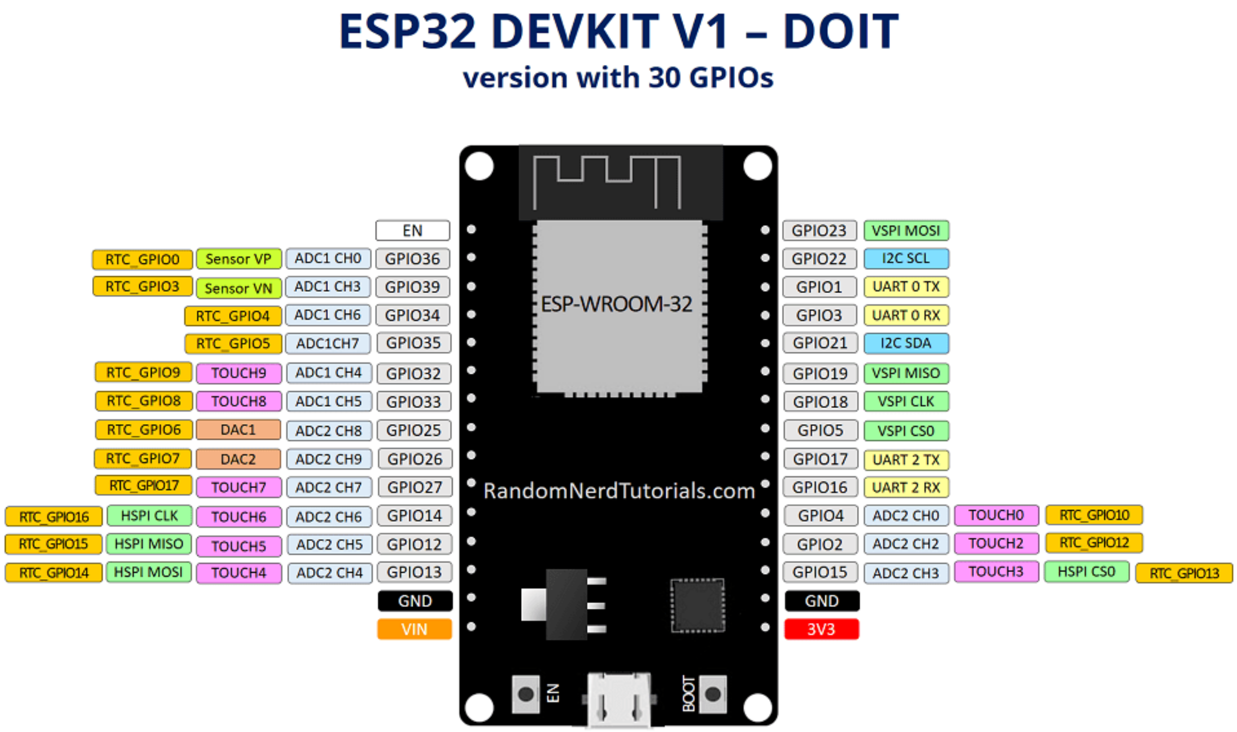

Figure 11 ESP Pin Configuration

The external circuit design was made on Eagle CAD and electronically simulated on proteus before circuit designing. [46] The circuit schematic and board are shown in figure 12 and figure 13. And figure 14 is showing the mechanical design of the circuit.

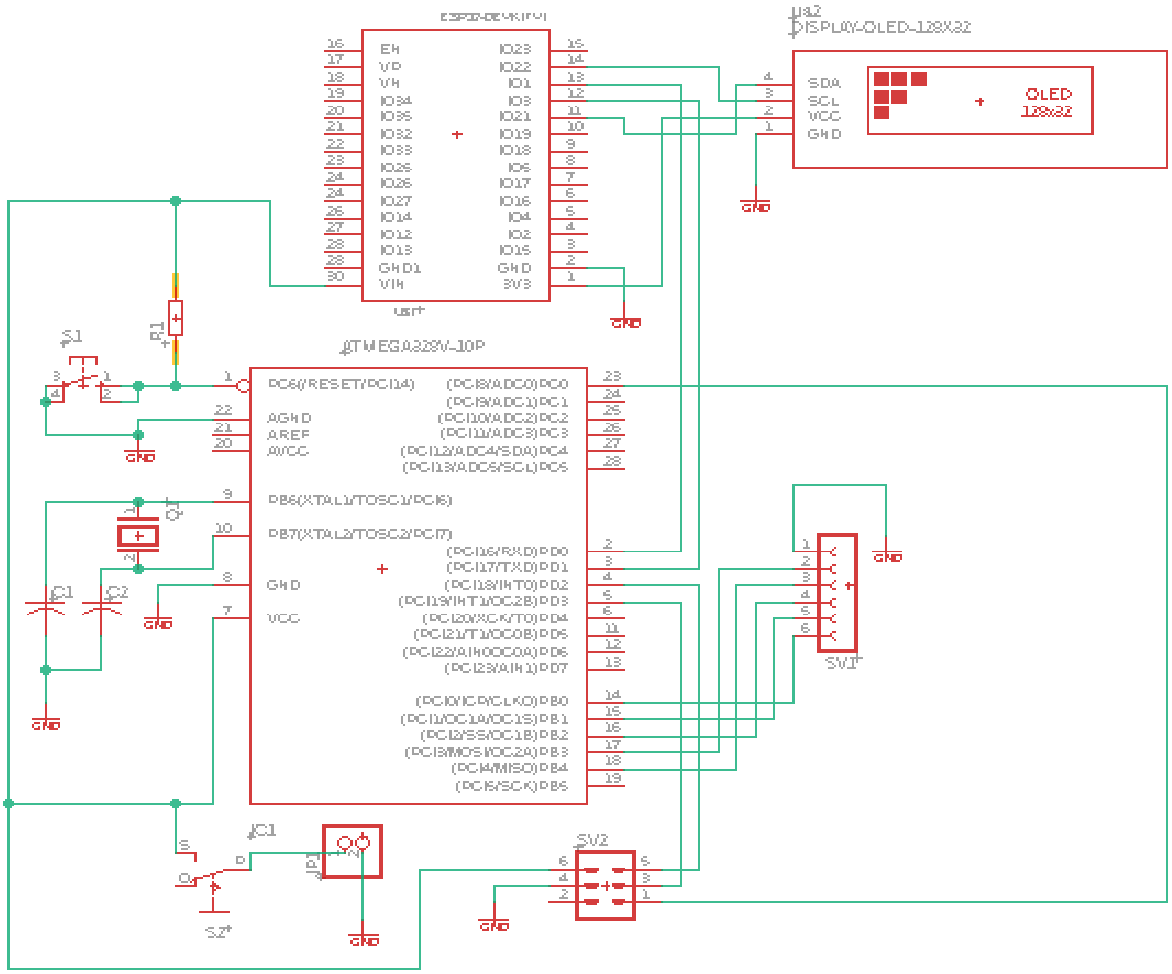

Figure 12 External Circuit Diagram

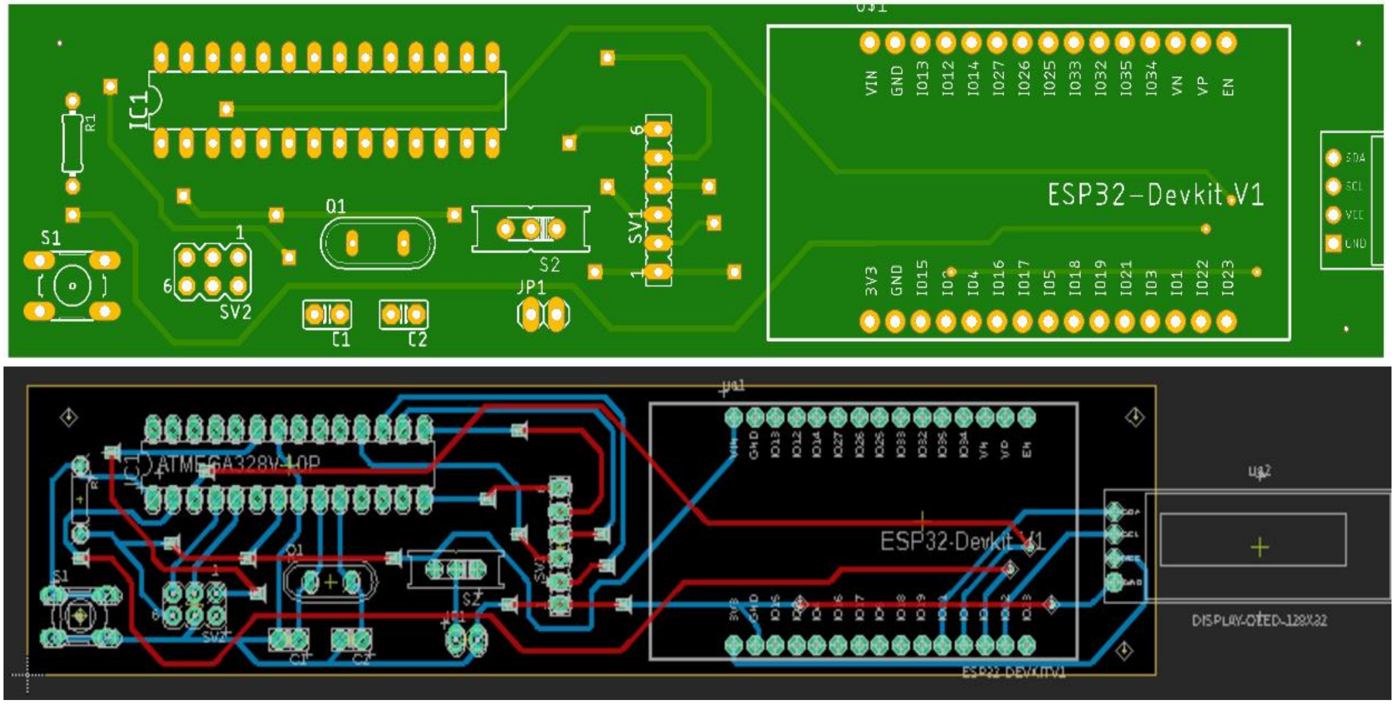

Figure 13 External Circuit Board View

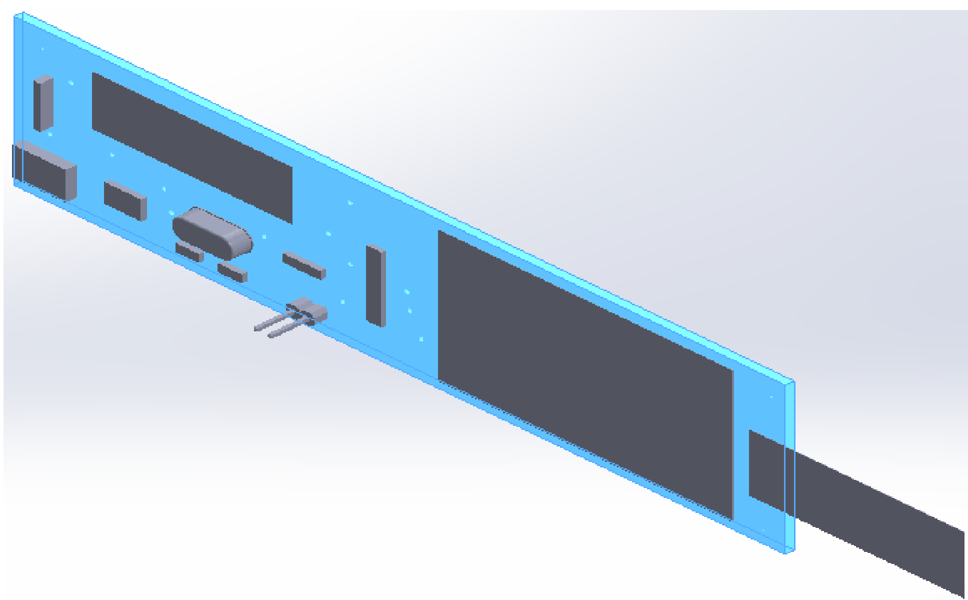

Figure 14 External Circuit Mechanical Design

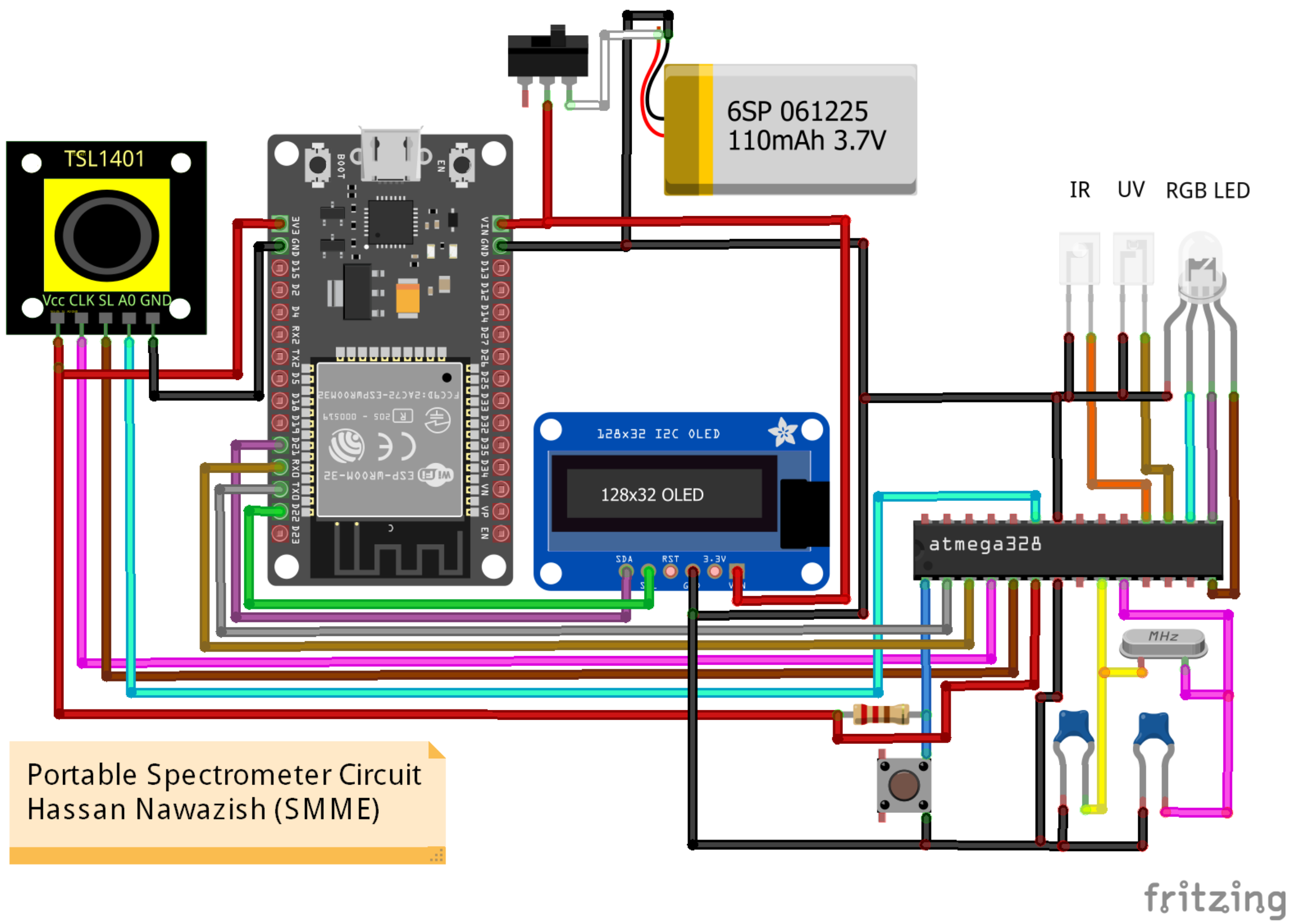

Figure 15 Circuit Diagram using Fritzing Software

In the external circuit board, the track width is 16 mil and squared via's are used having size or 24 mil. The overall Circuit Diagram including Internal and external circuit is shown in figure 15. The diagram was made on Fritzing software which is very good tool to make circuit schematics and Circuit Diagrams for understanding. [47]

The circuit was made in the laboratory in the first step circuit was printed on the sticker paper and circuit was pasted on to the Copper PCB board with the help of iron. Both layers of the PCB were synchronized by using the holes by drilling. In the next step circuit was inserted into the mixture of hot water and Ferric chloride for the chemical reaction (etching) . [48] After 30 minutes circuit was taken off and washed with water. In the next step drill machine was used to make the holes and vias for component installation and connections. And then components were soldered by using the hot solder. After that circuit was tested by using the Multimeter and then battery was connected, and circuit was working fine. At the end PCB paint of yellow color was also used to secure the connections for a long time. Circuit after each process is shown in the figure 16 and figure 17.

Figure 16		Circuit reaction with Ferric Chloride

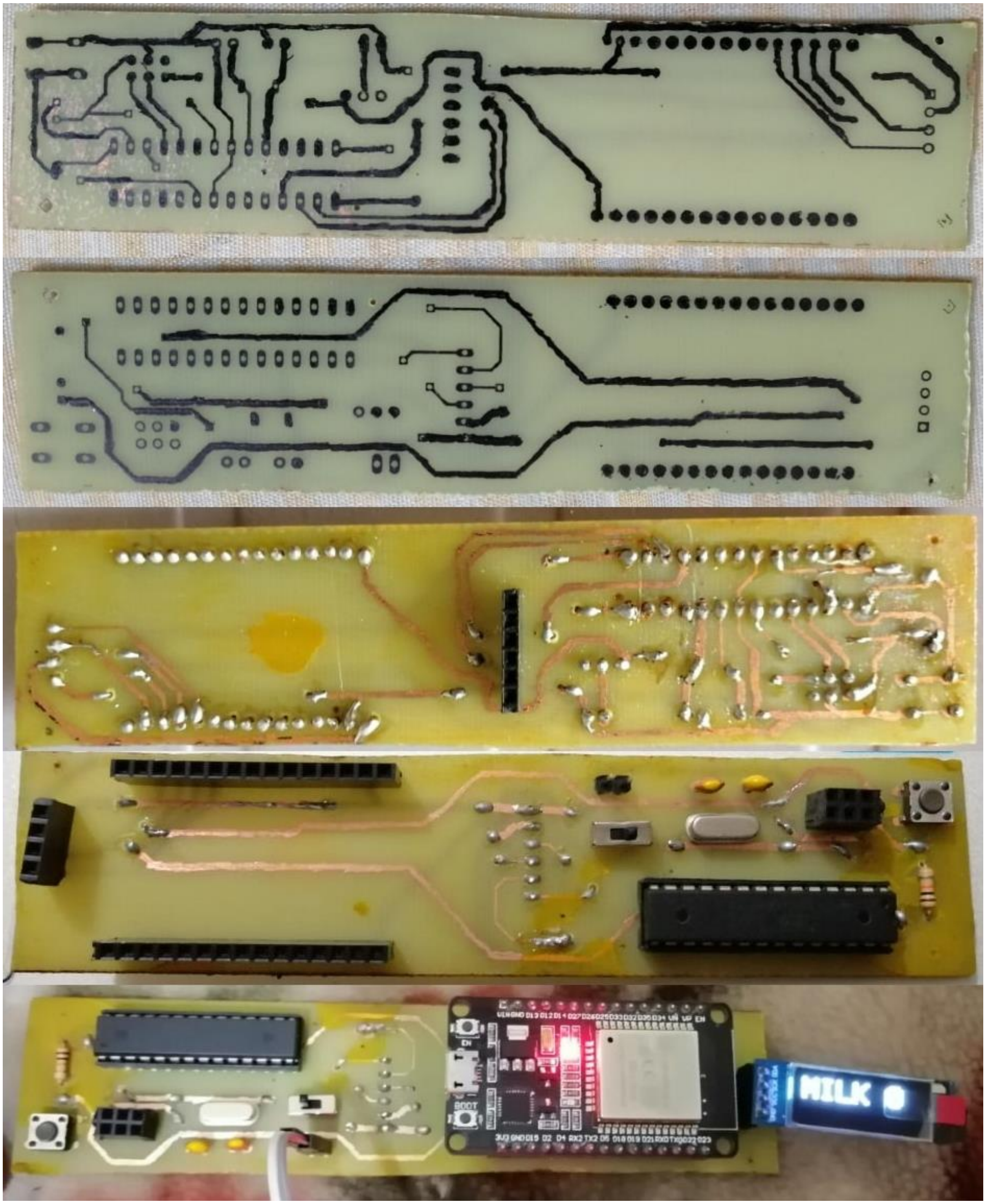

Figure 17 Circuit Manufacturing

3.1.2 Mechanical Design:

Solid works software is used for making the CAD design. The dimensions of the design are 70 x 70 x 45 mm. Total there are two parts one is the main casing part which have the slot of camera and external Circuit board connection. The other part is the top cover of the main part which have the slot for inserting the test tube. The mechanical design is shown in the figure. The design was 3D printer by the ANET printer and PLA material was used to manufacture the parts. The design is shown in Figure 18.

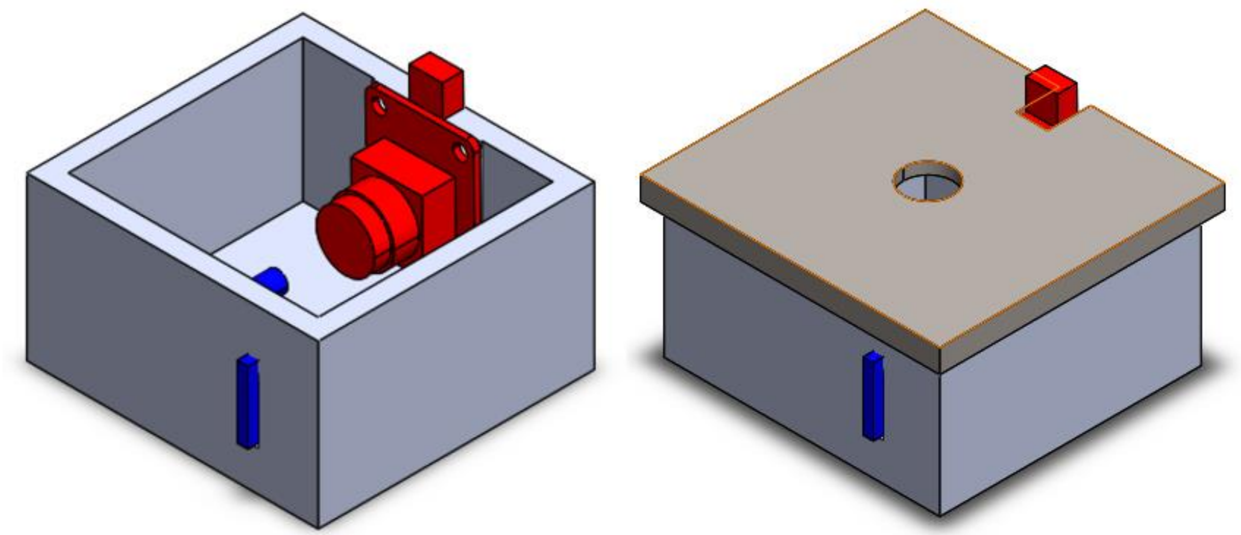

Figure 18 Mechanical Design using Solid Works

3.2 Data Acquisition

The device was tested on the Milk (Fluid). In the first step milk was taken from three random dairy forms. After that, impurities as water were added into the milk. The scale was used to add the controlled amount of water into the milk as shown in figure 19. Different percentage of water such as 10 %, 20 %, 30% and 50% were added into the milk and milk was poured into the glass test tube of 15 mm radius. The glass tube containing the milk was inserted into the water and the push button was pressed and it have recorded the data. Initially LEDs were blinked, and camera have received the light passing through the glass tube containing the fluid and received by camera. The data was taken in room with and without light as well. The data was stored into the MATLAB using serial communication in the form of CSV files. Due to the reflection and diffraction the receiving data was noisy. There is total 128 sensors in TSL1401 after the filtering the data from sensor number 28 to sensor number 77 was extracted. As there are total 5 light sources so there were five arrays overall and 5 columns in the CSV file. The raw data and filtered data is shown in Figure 20 and Figure 21.

Figure 19 Milk Samples

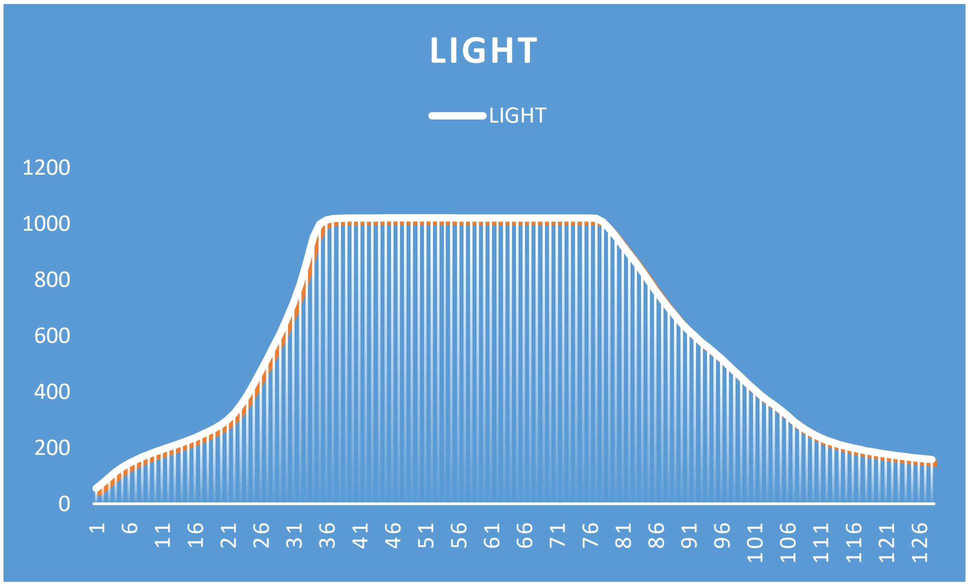

Figure 20 Raw Data

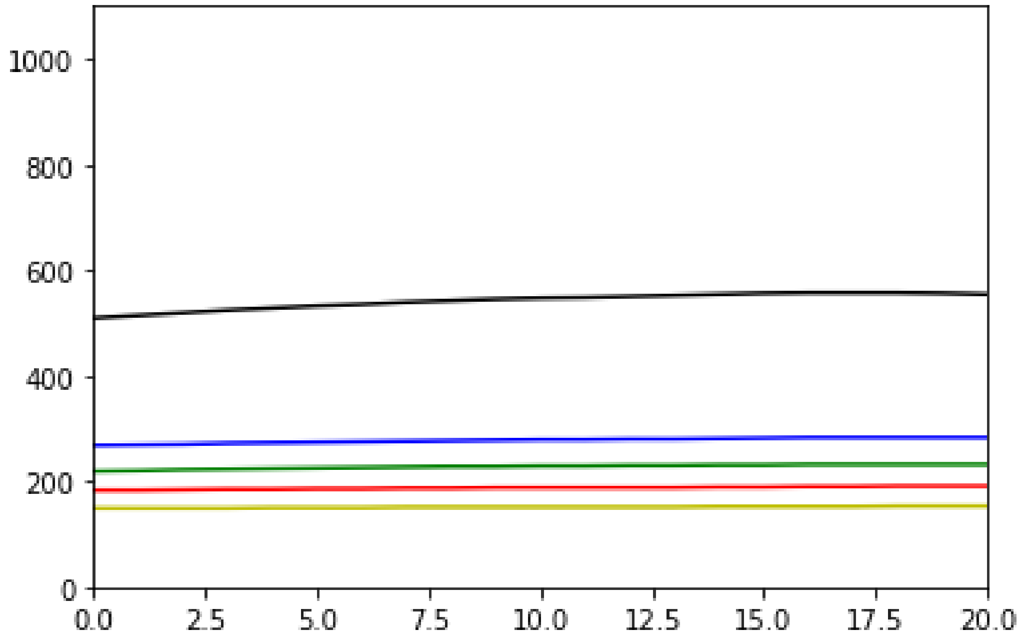

Figure 21 Filtered Data

This data was received by the 8-bit ADC of ATMEGA328P. As absorbance of each light is different in different classes of the milk. So, milk was classified into different classes on the base of these light features. The absorbance of the fluid is calculated by Beer Lambert Law.

$$A = log_{10} \frac{I_o}{I}$$

3.3 Machine Learning Algorithms

The data was arranged into the CSV file and initially machine learning algorithms were used for predicting the results. The data was arranged according to classes and label of each class was provided in CSV file as shown in Table 2..

	Red	Green	Blue	InfreRed	UltraVoilet	Class Label	Class
0	149	171	221	337	131	1	MILKSHOP
1	149	172	221	339	131	1	MILKSHOP
2	150	174	222	340	132	1	MILKSHOP
3	151	175	222	342	132	1	MILKSHOP
4	151	176	223	343	132	1	MILKSHOP

Table 2 Data Format

Python's Seaborn library was used for the data visualization and the data is shown in the figure 22.

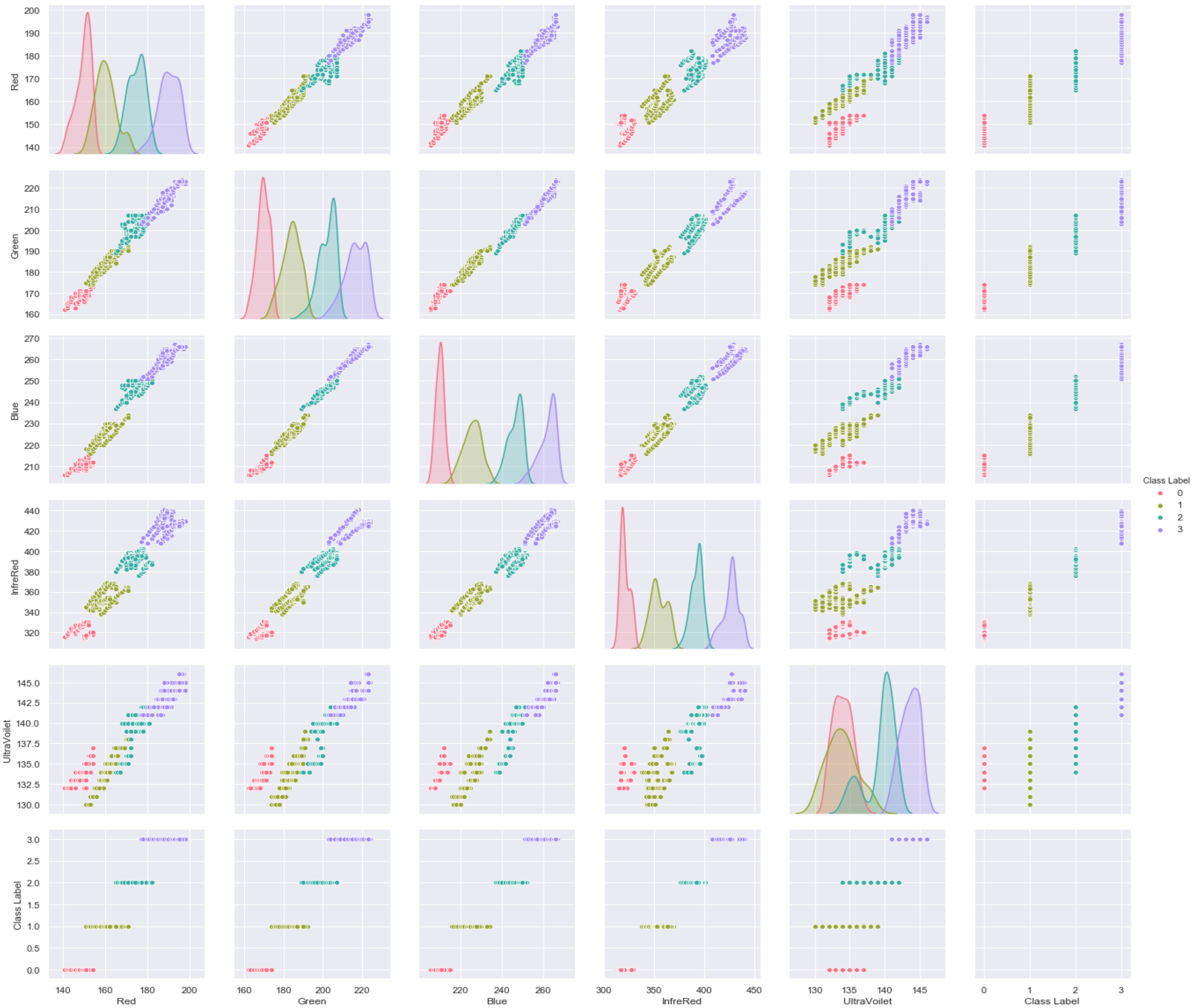

Figure 22 Data Visualization

The box plots of the data are also shown in the figure 23.

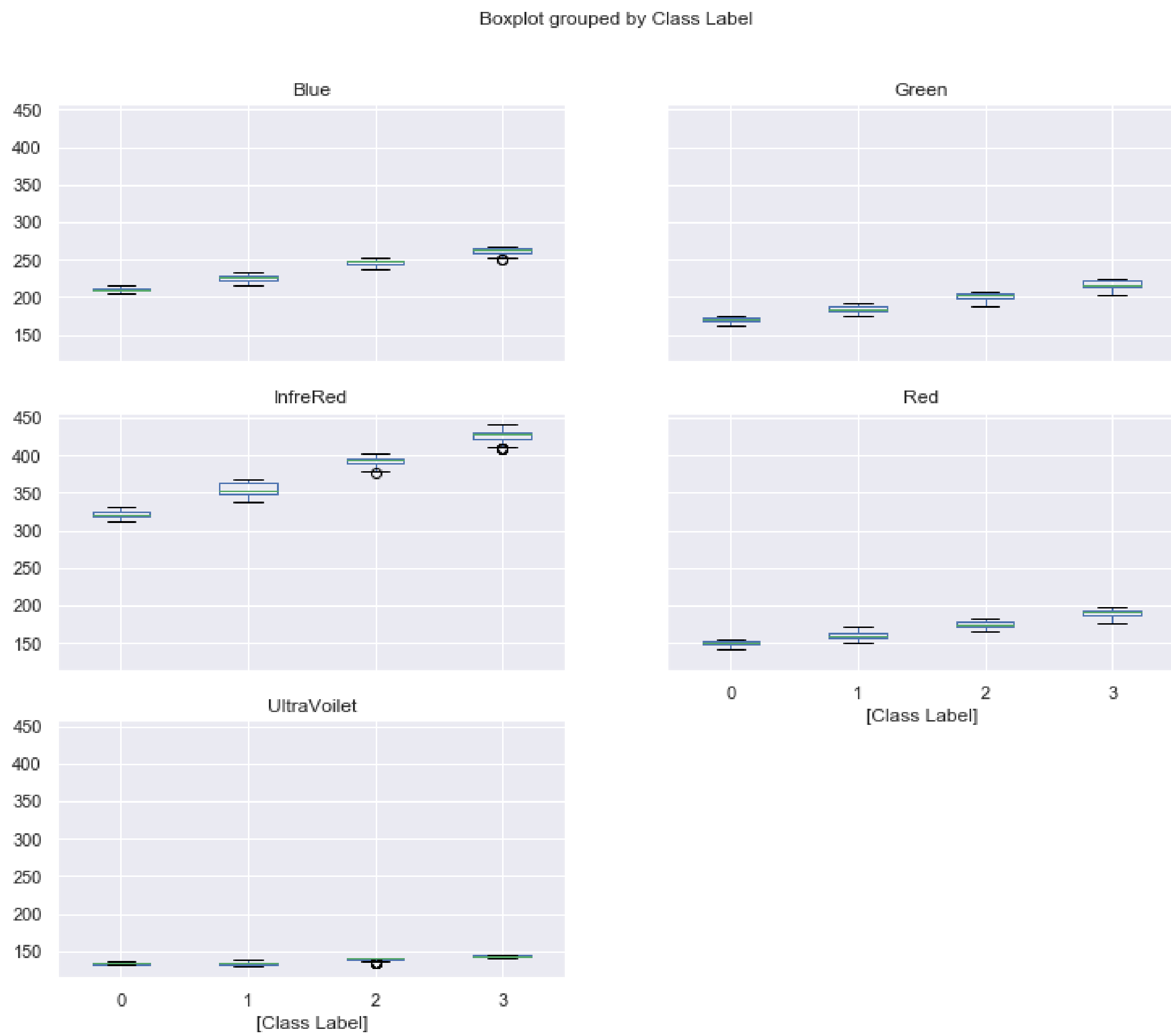

Figure 23 Data Boxplots

The overall data was divided into 25% testing and 75% training data sets. And after that data was randomized by using the randomization script in python. The Jupyter notebook was used for programming. Initially Support Vector Machine (SVM) was used to train and predict the results. The results by training the algorithm provided 56 % accuracy on the testing data which is very low. After the hyperparameter tunning the accuracy was increased to 92 % on testing data set which is significant. The results for SVM are shown in the figure 24.

Some other Supervised Machine learning algorithms were also used for getting the best results such as K- Nearest Neighbor Classifier, Decision tree classifier, Gradient Boosting Classifier

Logistic Regression and Random Forest classifier. The test score and train score of all classifiers are given in result section in table.

3.4 Neural Network and Model Deployment:

3.4.1 Training Neural Network:

Initially Machine Learning Algorithms were used to train the data and predict the results. But there was an issue while using the machine learning Algorithms that whenever the data was randomized the accuracy becomes change with the difference of 10, which means our results are not valid whenever we will change the data. So, the next approach to get the best results by using the Neural Networks. A 4-layer Artificial Neural Network was trained, and ADAM optimizer was used to get the possible results. Different activation functions were tried for the Neural Network layers as shown in Figure 25 and selected the activation functions providing the best results. The Rectified Linear Unit (ReLU) and Softmax activation functions are used with 200 epochs and batch size of 5. [49] [50]

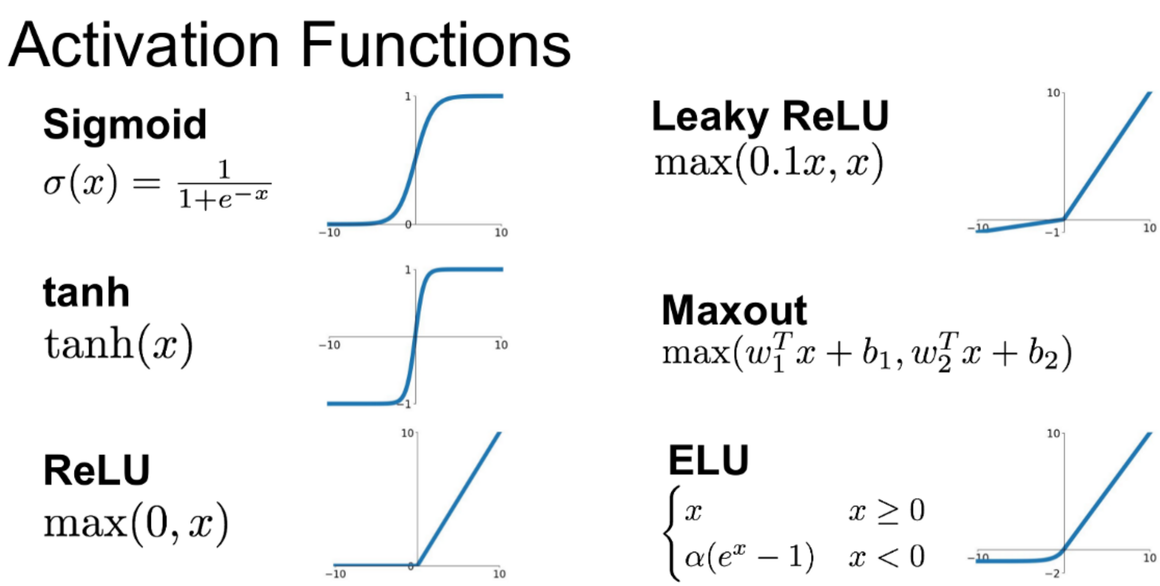

Figure 25 Activation Functions

The formula and example of Softmax function is given in figure 26. The results of training and validation loss and training and validation accuracy are given in figure 27 and 28 in result section. [51]

$$\sigma(\vec{z})_i = \frac{e^{z_i}}{\sum_{j=1}^{K} e^{z_j}}$$

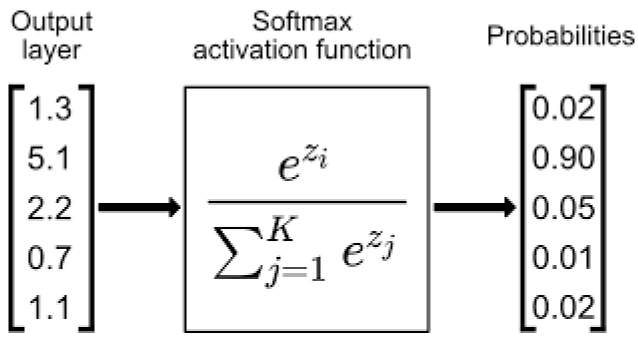

Figure 26   Softmax Activation Function

3.4.2 Model Deployment and Programming:

ESP32 microcontroller is used for model deployment which have all the properties of latest microcontroller with Bluetooth and Wi-Fi capabilities. [52] The Neural Network was training, and model was made. The code was converted from python to C++ for model deployment via ESP32. [53] The code was uploaded, and the controller was implemented on Printed Circuit Board.

Chapter 4: Results

The results for Machine Learning algorithms and Support Vector Machine Classification are given below.

Classifier	Train score	Test score	Train time
Decision Tree	0.9968	0.6826	0.002
Gradient Boosting Classifier	0.9872	0.6057	0.458
Nearest Neighbors	0.8370	0.6057	0.001
Random Forest	0.9808	0.5673	0.084
Logistic Regression	0.8146	0.4711	0.009
Neural Network	0.954	0.943	

Table 3 Machine Learning Results

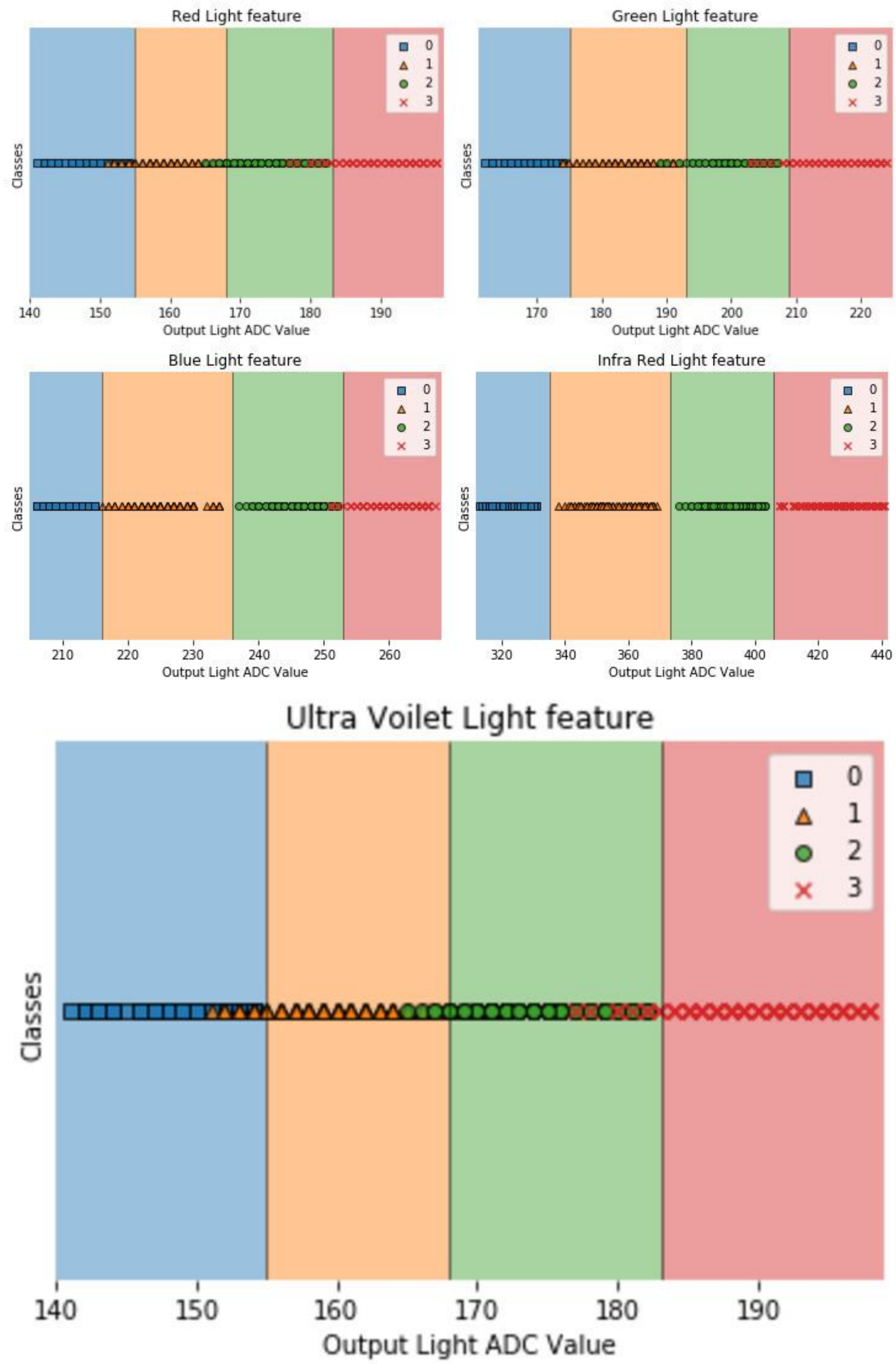

Figure 24 SVM results

The results after training the Neural Network are given below in figure.

```
model.fit(X,dummy_y,epochs=200, batch_size=5, verbose=1)

83/83 [==============================] - 0s 1ms/step - loss: 0.1491 - accuracy: 0.9517
Epoch 38/200
83/83 [==============================] - 0s 916us/step - loss: 0.1335 - accuracy: 0.9541
Epoch 39/200
83/83 [==============================] - 0s 850us/step - loss: 0.1087 - accuracy: 0.9614
Epoch 40/200
83/83 [==============================] - 0s 849us/step - loss: 0.0990 - accuracy: 0.9614
Epoch 41/200
83/83 [==============================] - 0s 929us/step - loss: 0.1029 - accuracy: 0.9686
Epoch 42/200
83/83 [==============================] - 0s 862us/step - loss: 0.1092 - accuracy: 0.9734
Epoch 43/200
83/83 [==============================] - 0s 851us/step - loss: 0.1206 - accuracy: 0.9517
Epoch 44/200
83/83 [==============================] - 0s 872us/step - loss: 0.1944 - accuracy: 0.9251
Epoch 45/200
83/83 [==============================] - 0s 833us/step - loss: 0.1444 - accuracy: 0.9565
Epoch 46/200
83/83 [==============================] - 0s 840us/step - loss: 0.1035 - accuracy: 0.9614
Epoch 47/200
83/83 [==============================] - 0s 843us/step - loss: 0.1019 - accuracy: 0.9686
Epoch 48/200
83/83 [==============================] - 0s 889us/step - loss: 0.0964 - accuracy: 0.9686
Epoch 49/200
83/83 [==============================] - 0s 977us/step - loss: 0.0946 - accuracy: 0.9734
```

Figure 27 Neural Network Results

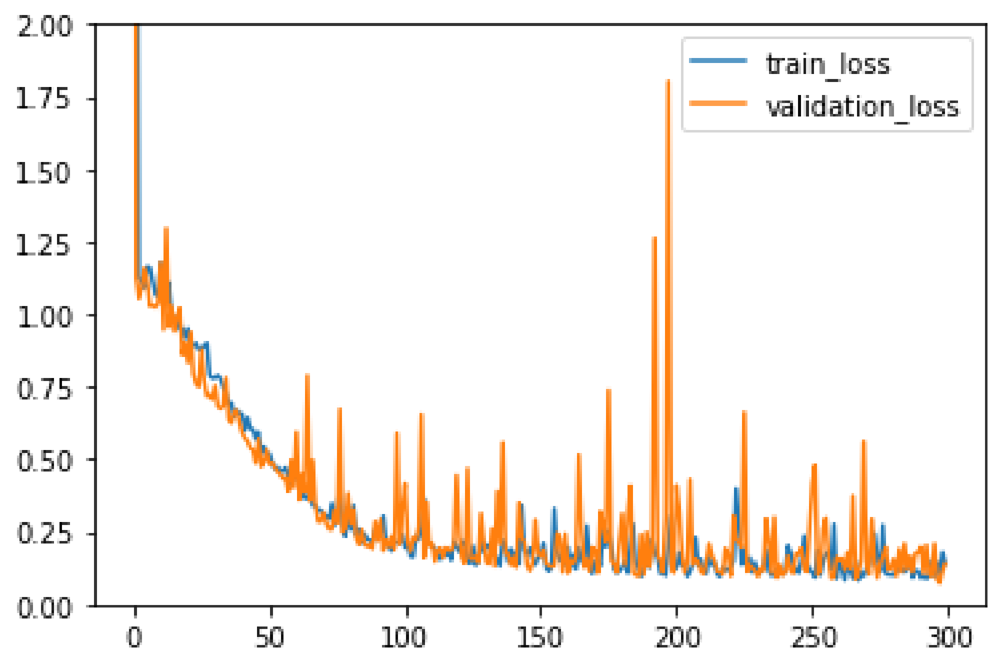

Figure 28 Train and Validation loss

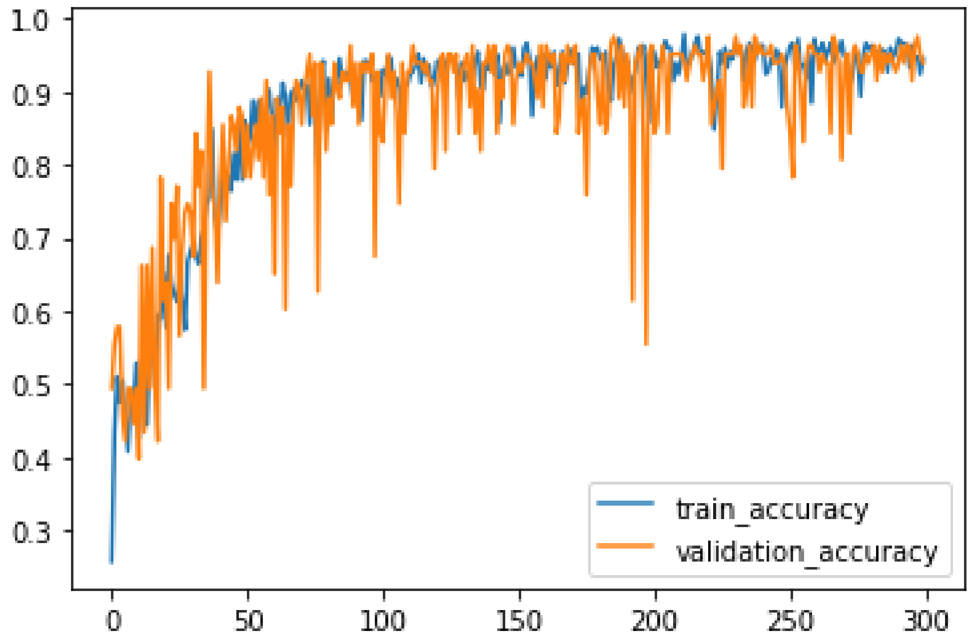

Figure 29 Train and Validation Accuracy

Chapter 5: Discussions

The aim of this study was to develop a device which can be able to classify the milk for decrease in the cases of milk adulteration. After this study we were able to classify the milk with 95.5 % accuracy. And the device is extracting the features from the milk using multiple light sources. Initially we have used the machine learning techniques such as Support Vector Machine (SVM) , K nearest neighbor (KNN) Decision tree classifier, Gradient Boosting Classifier, Nearest Neighbor Classifier, Random Forest classifier and Logistic Regression the accuracies 68.2±8% and the accuracy was changing whenever the data was randomized. Then we used the Neural Network to classify the data which performed better as compared to other machine learning techniques and provided the accuracy of 95.5 %, having ±0.8% change after data randomization. The algorithm was trained and converted to C++ script to use in microcontrollers. OLED, Multiple light sources, TSL-1401 Camera sensor, ESP32 and ATMEGA 328P were used for training, predicting, and visualizing the results.

5.1. Conclusion

Fluid classification can be done by using this device. Any fluid data can be used to train the algorithm. Different classes of the fluid can be made by adding impurities and then by using the measured amount of the fluid data can be extracted. Different fluids can have different model accuracies depending on the contents of fluid and light absorbance. Once the data is trained you can use the device for real time classification of the fluid. Device is easy to use and you can see the results on the OLED screen by just clicking one button. The device was tested on some fluids such as milk and petrol and given significant results. The average accuracy was around 96 % which can be increased or decreased for other fluids.

Appendix l

```
close all;
clear;
clc;
clk='D2';
si='D3';
r='D4';
g='D5';
bl='D6';
uv='D7';
b=arduino();
writeDigitalPin(b,clk,0);
writeDigitalPin(b,si,1);
writeDigitalPin(b,clk,1);
writeDigitalPin(b,si,0);
writeDigitalPin(b,clk,0);
for j=1:128
  writeDigitalPin(b,clk,1);
  writeDigitalPin(b,clk,0);
end
writeDigitalPin(b,si,1);
writeDigitalPin(b,clk,1);
writeDigitalPin(b,si,0);
writeDigitalPin(b,clk,0);
writeDigitalPin(b,r,1);
v=zeros(128,1);
for j=1:128
    v(j)=1023-(readVoltage(b,'A0')*1023/5);
     writeDigitalPin(b,clk,1);
     writeDigitalPin(b,clk,0);
```

```
end
writeDigitalPin(b,r,0);
writeDigitalPin(b,g,1);
w=zeros(128,1);
for j=1:128
    w(j)=1023-(readVoltage(b,'A0')*1023/5);
%     w(j)=5-w(j);
     writeDigitalPin(b,clk,1);
   writeDigitalPin(b,clk,0);
end
writeDigitalPin(b,g,0);
writeDigitalPin(b,bl,1);
x=zeros(128,1);
for j=1:128
    x(j)=1023-(readVoltage(b,'A0')*1023/5);
%   x(j)=5-x(j);
    writeDigitalPin(b,clk,1);
    writeDigitalPin(b,clk,0);
end
writeDigitalPin(b,bl,0);
writeDigitalPin(b,uv,1);
y=zeros(128,1);
for j=1:128
    y(j)=1023-(readVoltage(b,'A0')*1023/5);
%     y(j)=5-y(j);
     writeDigitalPin(b,clk,1);
     writeDigitalPin(b,clk,0);
end
writeDigitalPin(b,uv,0);
plot(v);
axis([0 128 0 1050]);
```

```
xlabel('Number of Detectors');
ylabel('Voltage(Light) Recieved after absorbance');
title('RGB & UV Absorbance');
hold on
plot(w,'r-');
hold on
plot(x,'g-');
hold on
plot(y,'y-');
axis([0 128 0 1050]);
hold on
```

Appendix ll

```
#define clockPin     2
#define siPin        3
#define VOUT         A0
#define INTVAL       A1
int exposure;
int utime;
int Value[128];
int rawValue[128];
int rValue[128];
int gValue[128];
int bValue[128];
int uvValue[128];
int irValue[128];
float rMean, gMean, bMean, uvMean, irMean;
int r = 8;
int g = 9;
int b = 10;
int uv = 11;
int ir = 12;
void setup()
{
  pinMode(siPin, OUTPUT);
  pinMode(clockPin, OUTPUT);
  Serial.begin(115200);
  pinMode(r, OUTPUT);
  pinMode(g, OUTPUT);
  pinMode(b, OUTPUT);
  pinMode(uv, OUTPUT);
  pinMode(ir, OUTPUT);
```

```
getCamera();
 for (int j = 0; j < 128; j++)
{
  rawValue[j] = Value[j];
}
digitalWrite(r, 255);
getCamera();
for (int j = 0; j < 128; j++)
{
  rValue[j] = Value[j];
}
digitalWrite(r, LOW);
digitalWrite(g, 255);
getCamera();
for (int j = 0; j < 128; j++)
{
  gValue[j] = Value[j];
}
digitalWrite(g, LOW);
digitalWrite(b, 255);
getCamera();
for (int j = 0; j < 128; j++)
{
  bValue[j] = Value[j];
}
digitalWrite(b, LOW);
digitalWrite(uv, 255);
getCamera();
for (int j = 0; j < 128; j++)
{
  uvValue[j] = Value[j];
```

```
    }
    digitalWrite(uv, LOW);
    digitalWrite(ir, HIGH);
    getCamera();
    for (int j = 0; j < 128; j++)
    {
      irValue[j] = Value[j];
    }
    digitalWrite(ir, LOW);

    rMean = mean(rValue);
    gMean = mean(gValue);
    bMean = mean(bValue);
    uvMean = mean(uvValue);
    irMean = mean(irValue);
    //String DATA = String(rMean) + String(',') + String(gMean) + String(',') + String(bMean)
+ String(',') + String(irMean) + String(',') + String(uvMean);
    Serial.print(rMean);
    Serial.print(',');
    Serial.print(gMean);
    Serial.print(',');
    Serial.print(bMean);
    Serial.print(',');
    Serial.print(irMean);
    Serial.print(',');
    Serial.println(uvMean);

  }

  void loop() {
```

```
}
void getCamera()
{
  digitalWrite(clockPin, LOW);
  digitalWrite(siPin, HIGH);
  digitalWrite(clockPin, HIGH);
  digitalWrite(siPin, LOW);

  //utime = micros();

  digitalWrite(clockPin, LOW);

  for (int j = 0; j < 128; j++)
  {
    digitalWrite(clockPin, HIGH);
    digitalWrite(clockPin, LOW);
  }

  //delayMicroseconds(exposure);

  digitalWrite(siPin, HIGH);
  digitalWrite(clockPin, HIGH);
  digitalWrite(siPin, LOW);

  //utime = micros() - utime;

  digitalWrite(clockPin, LOW);

  for (int j = 0; j < 128; j++)
  {
    //  delayMicroseconds(20);
```

```
    Value[j] = analogRead(VOUT);

    digitalWrite(clockPin, HIGH);
    digitalWrite(clockPin, LOW);
  }

  //delayMicroseconds(20);
}

float mean(int In[128])
{
  int sum = 0;
  float meanValue;
  for (int z = 55; z < 78; z++)
  {
    sum = sum + In[z];
  }
  meanValue = sum / 23;
  return meanValue;
}
```

Appendix lll

```
%tensorflow_version 2.0.0
pip install tensorflow==2.0.0
import tensorflow as tf
tf.__version__

# import the necessary libraries
from numpy import loadtxt
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
from sklearn.preprocessing import LabelEncoder

#GET X and GET Y
from tensorflow.keras.utils import to_categorical
dummy_y = to_categorical(encoded_Y)

model = Sequential()
model.add(Dense(12, input_dim=5, activation='relu'))
model.add(Dense(12, activation='relu'))
model.add(Dense(12, activation='relu'))
model.add(Dense(4, activation='softmax'))
model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])

model.fit(X,dummy_y,epochs=300, batch_size=5, verbose=1)

# making some prediction
# model.predict([[Red, Green, Blue, IR, UV]])
pred=model.predict([[141,162,206,316,132]])
# print all the predictions
print(pred)
```

```
# the values shown here are the probability values of all the classes
# we choose the class with highest probability value

#surety about the prediction
percentage = "{:.0%}".format(pred[0,pred.argmax(axis=1)[0]])
print(percentage)

# predicted class label
print(pred.argmax(axis=1)[0])
model.save('mo.h5')
model.summary()

Model: "sequential_1"
_________________________________________________________________
Layer (type)             Output Shape           Param #
=================================================================
dense_4 (Dense)          (None, 12)             72
_________________________________________________________________
dense_5 (Dense)          (None, 12)             156
_________________________________________________________________
dense_6 (Dense)          (None, 12)             156
_________________________________________________________________
dense_7 (Dense)          (None, 4)              52
=================================================================
Total params: 436
Trainable params: 436
Non-trainable params: 0

para_meters = model.get_layer('dense_4')
para_meters.get_weights()
```

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