INDUSTRIAL TRAINING REPORT

DETERMINATION OF VITAL PARAMETERS USING PHOTOPLETHYSMOGRAPHY

Submitted in partial fulfillment of the
Requirements for the award of

Degree of Bachelor of Technology in Computer Science & Engineering

Submitted By

Name: Harshita Chadha

University Roll Number: 35314802718

SUBMITTED TO:

Department of Computer Science &Engineering

MAHARAJA AGRASEN INSTITUTE OF TECHNOLOGY GGSIPU, DELHI

LIST OF TABLES AND FIGURES

FIGURES:

TABLES:

Table of contents

1. Introduction to the project

This section of the report serves to provide a high level introduction into the training tasks performed. The project undertaken during a period of nine weeks at the end of the sixth semester was entitled “Determination of vital parameters using photoplethysmography”. The project was developed as part of the 3 month long “Aspiring Computer Vision and Signal Processing Engineers Internship” as offered by MetFlux Research, a privately held, healthcare oriented startup at IIT Bombay.

The startup is the first Indian Company to create virtual organ models and the goal of the project was to develop signal processing systems that could be used to detect real time vital user parameters. These values could then be fed into the already existing, biochemical organ models to predict the present health conditions of the individual. Some other interesting results such as level of alcohol consumption, wakeness state etc could also be suitably predicted provided the vitals of an individual were available on the go.

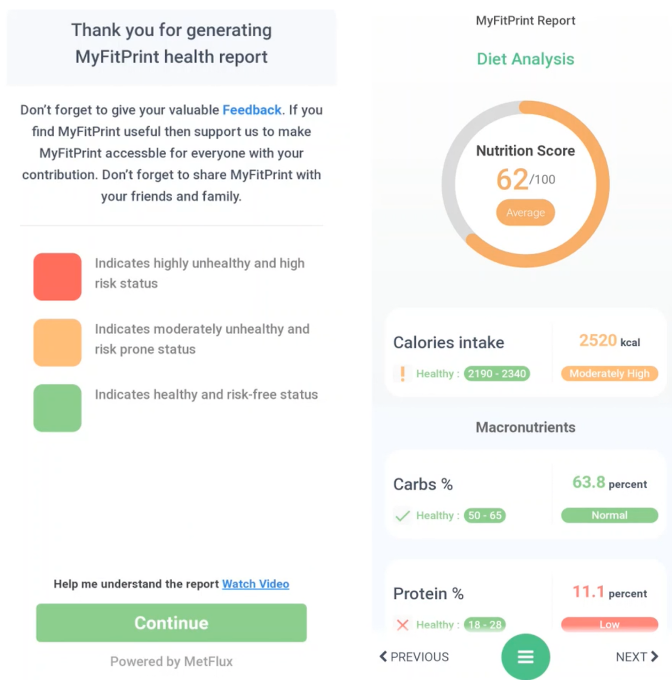

Figure 1: A snapshot of the “MyFitPrint” applications’s utilitarian services

One of the main goals of the project was to come up with techniques that could be used by everyday laymens to feed into the system their vital parameters. The company simply couldn't use complicated methods for parameter detection. Nor could they possibly ask the user to feed in these values on their own. This is because such approaches would take away the ease of use of the application they had already launched. The company has an application called “ MyFitPrint” which is a mobile app that helps one track their health and take care of their nutritional intakes and such. They wanted to develop an easy integration into their already existing framework that did the job. In such a case, the technique of photoplethysmography became the answer.

Photoplethysmography is a relatively recent technique derived from plethysmography. Plethysmography is used to measure changes in volume in different parts of the body. The test may be done to check for blood clots in the arms and legs. It is also done to measure how much air you can hold in your lungs. Most commonly, this test is performed to check blood flow in the arteries of the legs. This is done in people with conditions like hardening of the arteries (atherosclerosis). Atherosclerosis causes pain during exercise or poor healing of leg wounds. The technique is performed using a plethysmograph.

A plethysmograph is an instrument for measuring changes in volume within an organ or whole body (usually resulting from fluctuations in the amount of blood or air it contains). The word is derived from the Greek "plethysmos" (increasing, enlarging, becoming full), and "graphein" (to write). A photoplethysmogram (PPG) is an optically obtained plethysmogram that can be used to detect blood volume changes in the microvascular bed of tissue. A PPG is often obtained by using a pulse oximeter which illuminates the skin and measures changes in light absorption. A conventional pulse oximeter monitors the perfusion of blood to the dermis and subcutaneous tissue of the skin.

With each cardiac cycle the heart pumps blood to the periphery. Even though this pressure pulse is somewhat damped by the time it reaches the skin, it is enough to distend the arteries and arterioles in the subcutaneous tissue. If the pulse oximeter is attached without compressing the skin, a pressure pulse can also be seen from the venous plexus, as a small secondary peak.

Figure 2: A pulse oximeter using photoplethysmography for heart rate and SpO2 measurement

The change in volume caused by the pressure pulse is detected by illuminating the skin with the light from a light-emitting diode (LED) and then measuring the amount of light either transmitted or reflected to a photodiode. Each cardiac cycle appears as a peak, as seen in the figure. Because blood flow to the skin can be modulated by multiple other physiological systems, the PPG can also be used to monitor breathing, hypovolemia, and other circulatory conditions. Additionally, the shape of the PPG waveform differs from subject to subject, and varies with the location and manner in which the pulse oximeter is attached.

While photoplethysmography commonly requires some form of contact with the human skin (e.g., ear, finger), remote photoplethysmography allows to determine physiological processes such as blood flow without skin contact. This is achieved by using face video to analyze subtle momentary changes in the subject's skin color which are not detectable to the human eye. Such camera-based measurement of blood oxygen levels provides a contactless alternative to conventional photoplethysmography. For instance, it can be used to monitor the heart rate of newborn babies, or analyzed with deep neural networks to quantify stress levels. In the current project, both contact and non-contact photoplethysmography were used in order to obtain the required parameters.

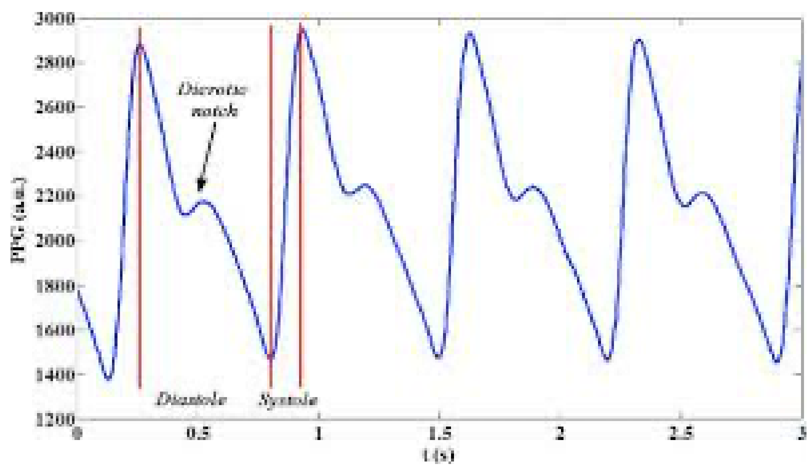

Figure 3: A typical waveform of a photoplethysmography signal

In the first week of the training, the goals were clearly specified. In a team of three interns, each individual was charged with the responsibility of finalising models for three parameters. The parameters assigned for the current project were thus, the heart rate, the blood pressure, and the SpO2 levels. During the course of project development, multiple research models proposed for detection of these parameters were programmed and then evaluated. At the end, about four final models were finalised and these produced less than 5% overall error margin in the penultimate trials.

In the upcoming sections of the present report, an overview of MetFlux as an organisation will be provided. This will be followed by discussing the goals of the training and enlisting the technology stacks used. The models used for parameter detection will then be described in detail. The report will be concluded by providing an estimate of the performance of the proposed models and discussions about future work.

2. About the Company

MetFlux research is healthcare and wellness startup with its headquarters located at IIT Bombay in Mumbai Maharashtra. The company is presently a privately held organisation and was formed by Dr. KV Venkatesh in the year 2017. At MetFlux, the whole-body adult and child metabolic models are utilized in an app and web platform format for different applications – ranging from wellness, disease management and preventive healthcare to drug discovery and clinical data analysis – and to solve the unmet need for such an in-silico simulation platform.

MetFlux is a technology company providing intelligence to health data for all sectors using a proprietary physiology based platform. They provide solutions through meaningful interpretation of health data using systemic models of physiology and disease for all biological systems. Their range of services include R&D help, Wellness products, and working alongside strategic partners for achievement of specific healthcare goals. MetFlux provides individualized health reports presenting the current, predicting future and proposing a better future in terms of lifestyle indicators, health risks and scores for individuals. This is beneficial as you conduct health checks for corporates, schools, colleges and other institutions.

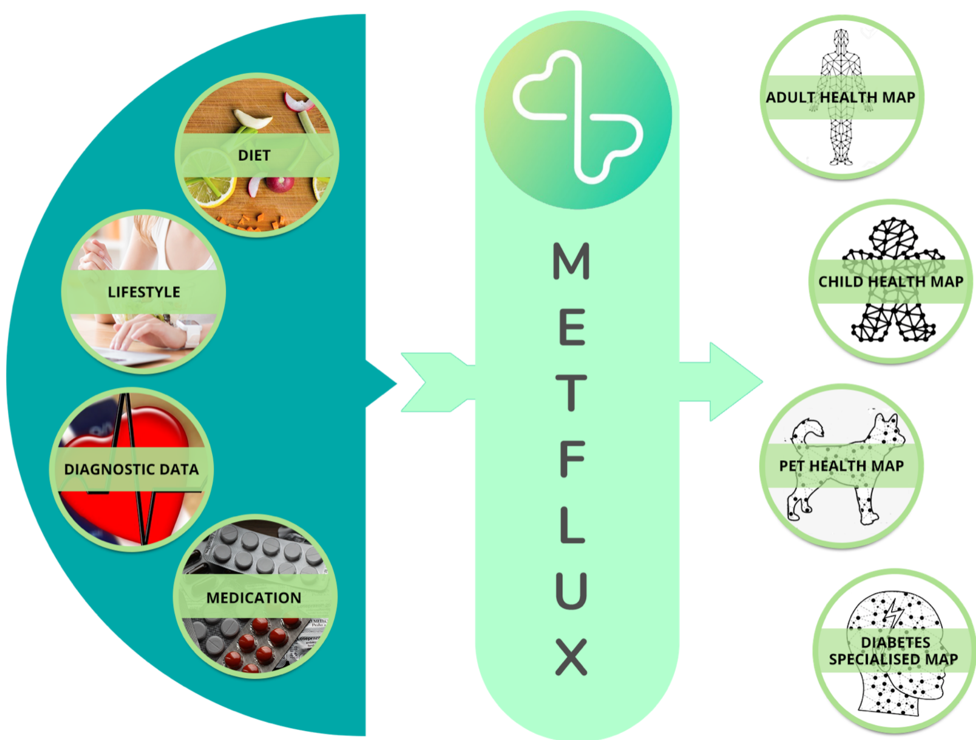

Figure 4: MetFlux model functionality

MetFlux models have a three fold approach, they Present a current health map of the said individual, Predict a future health map based on current lifestyle and Propose a diet lifestyle based solution to arrive at a new target health map. The models present the current health map of biological systems in terms of primary metrics such as BMI, z-score, complete calorie balance, nutrient break up and advanced overall scores and risks to present health of body organs.

MetFlux models can predict the effect of diet and lifestyle on physiology. This is important as our modern day lifestyle is significantly different from the evolutionary active one and this has led to a large number of lifestyle diseases that plague the current population. The company specializes in customizing the models to capture an individual's response rate and thus provide person specific solution.This comes handy for medical professionals to provide person specific rather than generalized medicine. With specialized and yet simple diagnostic data on individuals, an individualized MetFlux model helps in developing a personal medicine approach for medical professionals as they treat their patients.

In addition, MetFlux has developed specific models to assist medical professionals in treating lifestyle ailments in patients holistically. It presents the interaction effects between diet, activity and drugs for sustainable solutions. Moreover, a specific class of product titled the PET models also help assess the current health map of various pets and follows the same PPP approach to make lifestyle suggestions for improved pet health.

MetFlux's wellness products are designed to address the particular goals:

- Converting corporate health data into actionable reports.
- Insights into the impact of diet and lifestyle choices on an organization/clients health.
- Rationalizing health app recommendations through physiological health models.
- Treating patients for lifestyle ailments with a holistic lifestyle approach.
- Monitor your pets' health scientifically.

In terms of research and development, MetFlux provides support in the drug discovery pipeline – from conception to market launch. Systems Biology and Bioinformatics tools at MetFlux provide meaningful insights from lead identification and optimization to pre-clinical & clinical trials. Population wise and individualized analysis services to generate Personalized reports for population studies are also offered. MetFlux platforms can be used for data analysis not only from individuals but also from a population and clinical studies. Moreover, PK/PD modelling services are also offered for the analysis of PK-PD data from pre-clinical and clinical studies. MetFlux conducts studies to characterize and analyze PK/PD data for disease specific and off target effects. The other offered research and development services are also enlisted below:

- Effect of Diet and Lifestyle - Diet and Lifestyle effects on physiology

We specialize in quantifying macro and micro nutrients along with exercise effects on physiology through hormonal regulation on individuals and in a population. This helps quantify the effect of lifestyle on the efficacy of an active ingredient on physiology.

- Omics data analysis - Rationalizing Genome-proteome-metabolic-intractome data
  MetFlux capabilities can be used in large omics data rationalization using pathway and systems biology theoretical analysis, which is particularly useful for commercial and academic research organizations and hospitals.
- Toxicology - Predicting off target effects on protein and physiology
  MetFlux predicts off-target effects for an active ingredient or chemical using bioinformatic tools. Further using pathway and system biology models we can assist in predicting physiological short term and long term effects.
- Clinical Research Studies - Statistical and modelling approach to analyse clinical data
  MetFlux supports analysing and rationalizing clinical research data to characterize variability in a clinical data for an active ingredient and in conducting individualized and population level analysis of cohorts in a clinical research study.
- Bioinformatics Analysis - Tools for pathway/network analysis, structural bioinformatics and genome wide analysis
  MetFlux In house tools can be used for network analysis, genomic platform, flux balance analysis, sequence analysis, structural assessment and anti-target analysis. Tools also include Bio-chemoinformatics, DeNovo design of drugs and poly-pharmacological studies.
- Customized Models - Client specific model development
  MetFlux has in its repertoire several proprietary system biology models including signalling, immune and metabolic networks. Based on this expertise, MetFlux can develop customized models for specific phenotypic responses to our clients.
- Pathway Analysis - Development and analysis of networks for a specific phenotypic response
  MetFlux can develop systems level networks and databases for our clients. Network analysis capabilities such as Boolean and graph theoretic analysis can be delivered.

MetFlux provides its services to a number of different industries including pharmaceuticals, nutraceuticals, food, clinical research organisations, research institutions, wellness centers, hospitals, clinics, etc. The supporting Technology Services by Metflux include:

- Patent Search & Analysis, & Technology Landscaping
- Behavioural Health Assessment & Development Plan
- High End Diagnostic Measurements
- Functional foods developed using a mix of technology and tradition to remove disease

The MetFlux project that was worked upon during the course of the present training was their wellness mobile application "MyFitPrint". The app is a scientifically developed platform to assess your overall wellness. It is powered by deep physiology intelligence built over years of scientific research. MyFitPrint helps to analyze your health and risks with your minimum efforts and resources from your side. During your health assessment, the app asks you questions about your basic anthropometry, diet, activity, lifestyle, and diagnostics and generates a comprehensive health map of you. MyFitPrint also sets your fitness goals and provides personalized diet, activity, and lifestyle advice to achieve your fitness goals. With MyFitPrint, our mission is to empower you to assess your fitness in a scientific way before you act and transform your health.

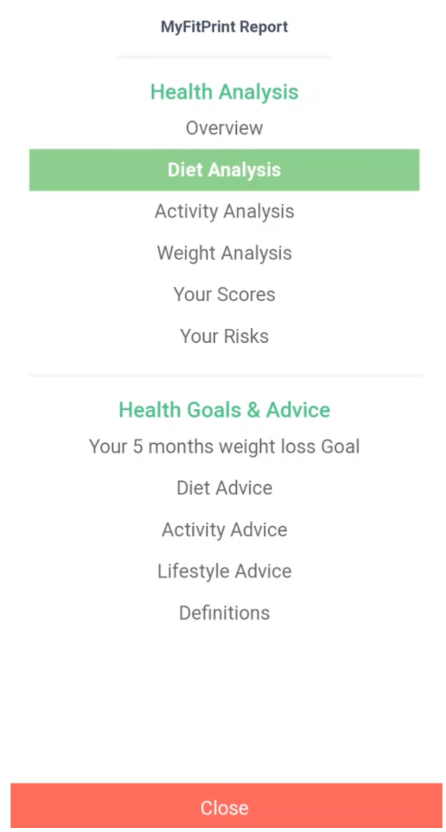

Figure 5: MyFitPrint application Graphical User Interface

The app asks you a set of questions related to basic anthropometry, work & leisure activity, diet, and provides you scientific analysis based on your answers. The output is divided into different sections and quickly provides you related analysis for free after answering a few related questions. You can receive a downloadable MyFitPrint Premium report after answering a complete set of questions. MyFitPrint Premium report includes body fitness, diet, activity, disease risks and lifestyle scores analysis. MyFitPrint also sets your health goals and gives scientifically curated diet, activity, and lifestyle advice to achieve your fitness goals. MyFitPrint can be used for the following individuals:

- Business - MyFitPrint App can help businesses to assess and make decisions to improve different aspects of their employees' health. MyFitPrint organization report provides critical insights regarding the health of their employees to design effective programs, thus contributing to workplace productivity.
- Individuals - MyFitPrint helps you to benchmark different aspects of your health and provide science-driven analysis. This is as easy as answering a few questions about your body, diet, and lifestyle. MyFitPrint provides individuals personalized advice to act on yourself to transform your health.
- Parents - MyFitPrint helps parents to assess their children's health in a scientifically informed way. Parents can benchmark their children's health in terms of nutrition, physical activity, growth with simple answering few questions and follow MyFitPrint advice to achieve optimal growth for their children.
- Fitness Professionals - MyFitPrint MyFitPrint empowers fitness professionals with scientifically analyzing the health of their clients in a holistic way before starting a fitness program. MyFitPrint can also help you to access the effectiveness of the fitness regimen at the end of the program.

3. Training Goals

The goals of the training may be defined as being two fold. On the student level, the goal was to expand on theoretical skills and gain an industry oriented view of the biomedical signal analysis field. Not only did the training help expand one's skill set in the field, the most meaningful experience of working in a corporate environment was also achieved. Thus in terms of skills, the training helped in not only the enhancement of technical skills pertaining to python programming, convolutional neural networks, and real-time signal processing, it also helped inculcate values of team work and collaborative development.

The clear goals assigned to me along with the end results produced are listed in the table below:

Vital Parameter Considered	Desired Methodology	Desired error rates and time constraints	Finally developed models	Actual error rates	Time interval taken in trials
Heart Rate	Machine learning free, signal processing based using contact photoplethysmography.	Less than 10%; 30 seconds	Event related moving average with dynamic thresholding using PPG signals.	6.8%	30 seconds and 15 second samples used with minor changes in error rates.
SpO2 or Oxygen Saturation	Contact and contact free signal processing using photoplethysmography.	Less than 10%; 30 seconds	Using AC and DC PPG components along with calibration constants.	Contact : 1.27% Contact -less: 1.01%	Minimum signal length 16 seconds required.
Blood Pressure	Accurate model free of ECG dependency; preferably developed	Less than 10%; 30 seconds	Deep learning based	1.6 and 1.5 for diastoli	30 second PPG signals.

	using PPG signals.		approach using a combination of an approximation and refinement network.	c and systolic blood pressure respectively.	

Table 1: Training Goals

From the perspective of the organisation, their expectations of the interns were specified during the first week of the internship. The goal of the team was to develop multiple models that would use photoplethysmography to measure vital parameters. The utility was so designed so that it could be added into their existing application: MyFitPrint. The main goal was to detect parameters using the camera. The constraints of the exercise included noise filtering, working in illumination robust spaces, and providing results in a time limited manner.

4. Training Environment and Technology Stack Used

The training was undertaken from 1st June 2021 to 31 August 202, a duration of about 3 months. The company that provided the training, MetFlux Research has its headquarters in Mumbai, India on the IIT (Indian Institute of technology), Bombay Campus. Unfortunately, due to the ongoing global pandemic, the option of travelling was not available. Thus, the internship was completed remotely. During the training period, daily virtual meetings were scheduled for the intern group where progress and problems were discussed. Bi-Monthly presentations were also kept, wherein the interns had to report their progress to the founding director. Moreover, once a month, company wide meetings were kept for team building exercises.

Each week, the performance of each intern was evaluated, and new tasks/ improvements on ongoing approaches were suggested by the project manager. Each interb was also granted monetary compensation for workstation set-up in remote working environments. In addition, any licensed software that became a requirement for development was approved via internal requests and company sanctioned.

The internship was entitled "Aspiring Computer Vision and Signal Processing Engineers Internship" and dealt primarily with biomedical signal processing using machine techniques. Various platforms and programming languages such as python, MATLAB, etc were used in order to achieve the desired conclusions. A brief overview of the technological stack used is presented below:

- <u>Python:</u>
  Python is an interpreted high-level general-purpose programming language. Its design philosophy emphasizes code readability with its use of significant indentation. Its language constructs as well as its object-oriented approach aim to help programmers write clear, logical code for small and large-scale projects.

  Python is dynamically-typed and garbage-collected. It supports multiple programming paradigms, including structured (particularly, procedural), object-oriented and functional programming. It is often described as a "batteries included" language due to its comprehensive standard library. Guido van Rossum began working on Python in the late 1980s, as a successor to the ABC programming language, and first released it in 1991 as Python 0.9.0.

  Python 2.0 was released in 2000 and introduced new features, such as list comprehensions and a garbage collection system using reference counting. Python 3.0 was released in 2008 and was a major revision of the language that is not completely backward-compatible. Python 2 was discontinued with version 2.7.18 in 2020.Python consistently ranks as one of the most popular programming languages.

Python comes equipped with multiple libraries that can be used to perform specific useful taks. For the development of the present project the following libraries were most extensively used:

- NumPy - NumPy is the fundamental package for scientific computing in Python. It is a Python library that provides a multidimensional array object, various derived objects (such as masked arrays and matrices), and an assortment of routines for fast operations on arrays, including mathematical, logical, shape manipulation, sorting, selecting, I/O, discrete Fourier transforms, basic linear algebra, basic statistical operations, random simulation and much more. At the core of the NumPy package, is the ndarray object. This encapsulates n-dimensional arrays of homogeneous data types, with many operations being performed in compiled code for performance. Vectorization describes the absence of any explicit looping, indexing, etc., in the code - these things are taking place, of course, just “behind the scenes” in optimized, pre-compiled C code. Vectorized code has many advantages, among which are:

    - ➔ vectorized code is more concise and easier to read
    - ➔ fewer lines of code generally means fewer bugs
    - ➔ the code more closely resembles standard mathematical notation (making it easier, typically, to correctly code mathematical constructs)
    - ➔ vectorization results in more “Pythonic” code. Without vectorization, our code would be littered with inefficient and difficult to read for loops.

  Broadcasting is the term used to describe the implicit element-by-element behavior of operations; generally speaking, in NumPy all operations, not just arithmetic operations, but logical, bit-wise, functional, etc., behave in this implicit element-by-element fashion, i.e., they broadcast. Moreover, in the example above, a and b could be multidimensional arrays of the same shape, or a scalar and an array, or even two arrays of with different shapes, provided that the smaller array is “expandable” to the shape of the larger in such a way that the resulting broadcast is unambiguous. NumPy fully supports an object-oriented approach, starting, once again, with ndarray. For example, ndarray is a class, possessing numerous methods and attributes. Many of its methods are mirrored by functions in the outermost NumPy namespace, allowing the programmer to code in whichever paradigm they prefer. This flexibility has allowed the NumPy array dialect and NumPy ndarray class to become the de-facto language of multi-dimensional data interchange used in Python.

- SciPy - This is a free and open-source Python library used for scientific computing and technical computing.SciPy contains modules for optimization, linear algebra, integration, interpolation, special functions, FFT, signal and image processing, ODEsolvers and other tasks common in science and engineering. SciPy is also a family of conferences for users and developers of these tools: SciPy (in the United States), EuroSciPy (in Europe) and SciPy.in (in India). Enthought originated the SciPy conference in the United States and continues to sponsor many of the international conferences as well as host the SciPy website. The SciPy library is currently distributed under the BSD license, and its development is sponsored and supported by an open community of developers. It is also supported by NumFOCUS, a community foundation for supporting reproducible and accessible science.

- Matplotlib - Matplotlib is a plotting library for the Python programming language and its numerical mathematics extension NumPy. It provides an object-oriented API for embedding plots into applications using general-purpose GUI toolkits like Tkinter, wxPython, Qt, or GTK. There is also a procedural "pylab" interface based on a state machine (like OpenGL), designed to closely resemble that of MATLAB, though its use is discouraged. SciPy makes use of Matplotlib.Matplotlib was originally written by John D. Hunter. Since then it has an active development community and is distributed under a BSD-style license. Michael Droettboom was nominated as matplotlib's lead developer shortly before John Hunter's death in August 2012 and was further joined by Thomas Caswell. Matplotlib is a NumFOCUS fiscally sponsored project. Matplotlib 2.0.x supports Python versions 2.7 through 3.10. Python 3 support started with Matplotlib 1.2. Matplotlib 1.4 is the last version to support Python 2.6. Matplotlib has pledged not to support Python 2 past 2020 by signing the Python 3 Statement.

- Dlib - Dlib is a modern C++ toolkit containing machine learning algorithms and tools for creating complex software in C++ to solve real world problems. It is used in both industry and academia in a wide range of domains including robotics, embedded devices, mobile phones, and large high performance computing environments. Dlib's open source licensing allows you to use it in any application, free of charge. It is also available to use as a python library using bindings.

- OpenCV - OpenCV (Open Source Computer Vision Library) is a library of programming functions mainly aimed at real-time computer vision. Originally developed by Intel, it was later supported by Willow Garage then Itseez (which was later acquired by Intel). The library is cross-platform and free for use under the open-source Apache 2 License. Starting in 2011, OpenCV features GPU acceleration for real-time operations. Officially launched in 1999 the OpenCV project was initially an Intel Research initiative to advance CPU-intensive applications, part of a series of projects including real-time ray tracing and 3D display walls.The main contributors to the project included a number of optimization experts in Intel Russia, as well as Intel's Performance Library Team. In the early days of OpenCV, the goals of the project were described as:

- ➔ Advance vision research by providing not only open but also optimized code for basic vision infrastructure. No more reinventing the wheel.
- ➔ Disseminate vision knowledge by providing a common infrastructure that developers could build on, so that code would be more readily readable and transferable.
- ➔ Advance vision-based commercial applications by making portable, performance-optimized code available for free – with a license that did not require code to be open or free itself.

The first alpha version of OpenCV was released to the public at the IEEE Conference on Computer Vision and Pattern Recognition in 2000, and five betas were released between 2001 and 2005. The first 1.0 version was released in 2006. A version 1.1 "pre-release" was released in October 2008. The second major release of the OpenCV was in October 2009. OpenCV 2 includes major changes to the C++ interface, aiming at easier, more type-safe patterns, new functions, and better implementations for existing ones in terms of performance (especially on multi-core systems). Official releases now occur every six months and development is now done by an independent Russian team supported by commercial corporations. In August 2012, support for OpenCV was taken over by a non-profit foundation OpenCV.org, which maintains a developer and user site. In May 2016, Intel signed an agreement to acquire Itseez] a leading developer of OpenCV. In July 2020, OpenCV announced and began a Kickstarter campaign for the OpenCV AI Kit, a series of hardware modules and additions to OpenCV supporting Spatial AI.

- MATLAB:

MATLAB (an abbreviation of "MATrix LABoratory") is a proprietary multi-paradigm programming language and numeric computing environment developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages. Although MATLAB is intended primarily for numeric computing, an optional toolbox uses the MuPAD symbolic engine allowing access to symbolic computing abilities. An additional package, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems. As of 2020, MATLAB has more than 4 million users worldwide. MATLAB users come from various backgrounds of engineering, science, and economics.

- Deep Learning:

Deep learning (also known as deep structured learning) is part of a broader family of machine learning methods based on artificial neural networks with representation learning. Learning can be supervised, semi-supervised or unsupervised. Deep-learning architectures such as deep neural networks, deep belief networks, deep reinforcement learning, recurrent neural networks and convolutional neural networks have been applied to fields including computer vision, speech recognition, natural language processing, machine translation, bioinformatics, drug design, medical image analysis, material inspection and board game programs, where they have produced results comparable to and in some cases surpassing human expert performance. Artificial neural networks (ANNs) were inspired by information processing and distributed communication nodes in biological systems. ANNs have various differences from biological brains. Specifically, artificial neural networks tend to be static and symbolic, while the biological brain of most living organisms is dynamic (plastic) and analogue. The adjective "deep" in deep learning refers to the use of multiple layers in the network. Early work showed that a linear perceptron cannot be a universal classifier, but that a network with a nonpolynomial activation function with one hidden layer of unbounded width can. Deep learning is a modern variation which is concerned with an unbounded number of layers of bounded size, which permits practical application and optimized implementation, while retaining theoretical universality under mild conditions. In deep learning the layers are also permitted to be heterogeneous and to deviate widely from biologically informed connectionist models, for the sake of efficiency, trainability and understandability, hence the "structured" part.

- <u>U-Net:</u>

  U-Net is a convolutional neural network that was developed for biomedical image segmentation at the Computer Science Department of the University of Freiburg. The network is based on the fully convolutional network and its architecture was modified and extended to work with fewer training images and to yield more precise segmentations. Segmentation of a 512 × 512 image takes less than a second on a modern GPU. The U-Net architecture stems from the so-called “fully convolutional network” first proposed by Long, Shelhamer, and Darrell. The main idea is to supplement a usual contracting network by successive layers, where pooling operations are replaced by upsampling operators. Hence these layers increase the resolution of the output. What's more, a successive convolutional layer can then learn to assemble a precise output based on this information. One important modification in U-Net is that there are a large number of feature channels in the upsampling part, which allow the network to propagate context information to higher resolution layers. As a consequence, the expansive path is more or less symmetric to the contracting part, and yields a u-shaped architecture. The network only uses the valid part of each convolution without any fully connected layers. To predict the pixels in the border region of the image, the missing context is extrapolated by mirroring the input image. This tiling strategy is important to apply the network to large images, since otherwise the resolution would be limited by the GPU memory.

- <u>Residual Neural Networks or Res-Nets:</u>

  A residual neural network (ResNet) is an artificial neural network (ANN) of a kind that builds on constructs known from pyramidal cells in the cerebral cortex. Residual neural networks do this by utilizing skip connections, or shortcuts to jump over some layers. Typical ResNet models are implemented with double- or triple- layer skips that contain nonlinearities (ReLU) and batch normalization in between. An additional weight matrix may be used to learn the skip weights; these models are known as HighwayNets. Models with several parallel skips are referred to as DenseNets. In the context of residual neural networks, a non-residual network may be described as a plain network. There are two main reasons to add skip connections: to avoid the problem of vanishing gradients, or to mitigate the Degradation (accuracy saturation) problem; where adding more layers to a suitably deep model leads to higher training error. During training, the weights adapt to mute the upstream layer, and amplify the previously-skipped layer. In the simplest case, only the weights for the adjacent layer's connection are adapted, with no explicit weights for the upstream layer. This works best when a single nonlinear layer is stepped over, or when the intermediate layers are all linear. If not, then an explicit weight matrix should be learned for the skipped connection (a HighwayNet should be used). Skipping effectively simplifies the network, using fewer layers in the initial training stages. This speeds learning by reducing the impact of vanishing gradients, as there are fewer layers to propagate through. The network then gradually restores the skipped layers as it learns the feature space. Towards the end of training, when all layers are expanded, it stays closer to the manifold and thus learns faster. A neural network without residual parts explores more of the feature space. This makes it more vulnerable to perturbations that cause it to leave the manifold, and necessitates extra training data to recover.

5. Details and Snapshots of the Final Project

Plethysmography is the volumetric measurement of an organ, resulting from fluctuations in the amount of blood or air it contains. The change in blood volume is synchronous to the heart beat, so it can be used to detect heart rate. Photoplethysmography is just a means of plethysmography that uses optical techniques. There are two basic types of photoplethysmography: transmittance and reflectance.Devices such as pulse oximeters use transmittance photoplethysmography. On the other hand when vitals are taken through mobile phones using flashes as illumination source, reflectance photoplethysmography is utilized.

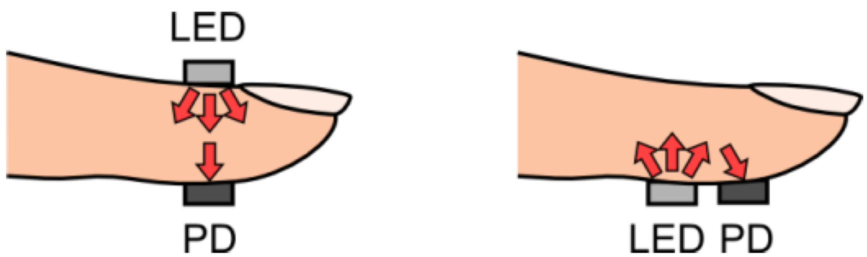

Figure 6: Transmittance (left) and reflective (right) photoplethysmography

For the present application, a mobile phone camera was used to capture the photoplethysmograph of the subject by recording video signals of 15-30 seconds long. The finger of the subject was placed on top of the camera so as to ensure that the flash was also present on the same side as the camera to obtain reflectance photoplethysmograph. This is illustrated in the figure below. As a consequence of this exercise three light phenomena occur. The intensity is directly proportional to blood intensiveness and here, the reflected light is of primary importance.

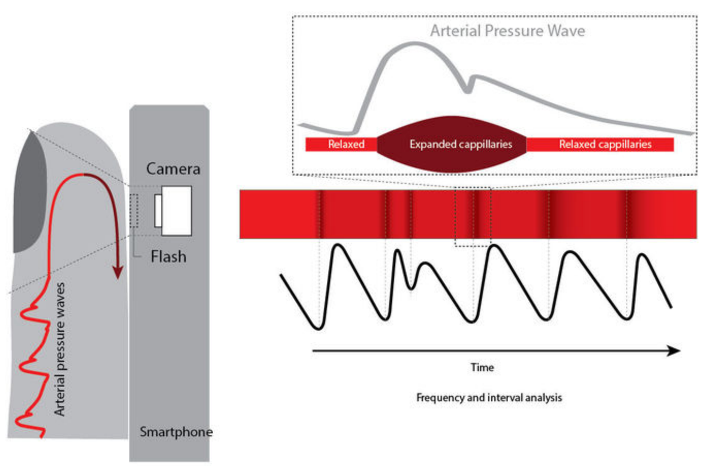

Figure 7: Illustration of PPG signal being obtained using mobile camera

The resulting signal is the PPG signal. The reflected light varies with blood volume and low reflection is characterized by more blood. Similarly, high reflection is characterized by more blood. After noise is removed from the signal and it is ground normalised, various parameters such as heart rate can be obtained from it by suitable well established algorithms.

In the present chapter, three sections are presented for the three parameters detected during the course of the commercial training, namely: Heart rate, SpO2, and Blood Pressure. A detailed analysis of each of these parameters followed by their approach of determination is presented.

5.1 Heart rate

Heart rate is the speed of the heartbeat measured by the number of contractions (beats) of the heart per minute (bpm). The heart rate can vary according to the body's physical needs, including the need to absorb oxygen and excrete carbon dioxide, but is also modulated by a myriad of factors including but not limited to genetics, physical fitness, stress or psychological status, diet, drugs, hormonal status, environment, and disease/illness as well as the interaction between and among these factors. It is usually equal or close to the pulse measured at any peripheral point.

The American Heart Association states the normal resting adult human heart rate is 60–100 bpm Tachycardia is a high heart rate, defined as above 100 bpm at rest. Bradycardia is a low heart rate, defined as below 60 bpm at rest. During sleep a slow heartbeat with rates around 40–50 bpm is common and is considered normal. When the heart is not beating in a regular pattern, this is referred to as an arrhythmia. Abnormalities of heart rate sometimes indicate disease. Thus it can be concluded that heart rate is a parameter of vital importance for body predicament extrapolation.

In the present project, the heart rate was measured as a consequence of the fluctuations in the blood volume. Each heartbeat corresponds to an increase in brightness (red DC level) following a period of reduced brightness. In order to determine this parameter, the methodology used by Elgendi et al [6] was employed. In their paper, they propose a novel algorithm that can detect systolic peaks under challenging conditions, as in the case of emergency responders in tropical conditions. Accurate systolic-peak detection is an important first step for the analysis of heart rate variability. Algorithms based on local maxima-minima, first-derivative, and slope sum are evaluated, and a new algorithm is introduced to improve the detection rate. With 40 healthy subjects, the new algorithm demonstrates the highest overall detection accuracy (99.84% sensitivity, 99.89% positive predictivity). The proposed algorithm presents an advantage for real-time applications by avoiding human intervention in threshold determination. For best performance, it is shown that a combination of two event-related moving averages with an offset threshold has an advantage in detecting systolic peaks, even in heat-stressed PPG signals.

The above algorithm was needed because in order to obtain the heart rate from a PPG signal, it is imperative to detect the high and low light intensity peaks that, as described above, correspond to blood inflow and outflow. This is because these peaks are directly analogous to the heart rate. Now, while several methodologies exist, most of these are constant dependent and non-robust. In order to create a dynamic and robust approach the event related moving average methodology was used. A PPG signal along with its peaks and notches is illustrated below for reference:

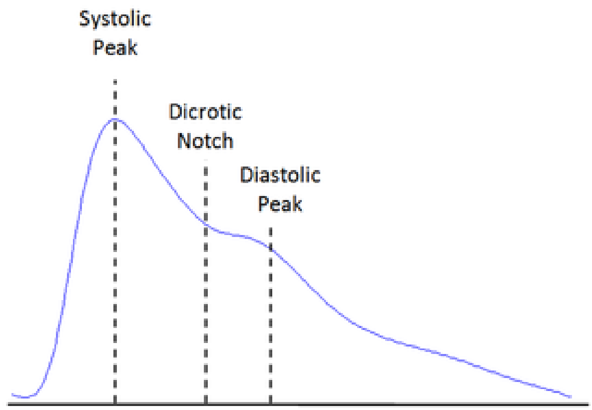

Figure 8: Photoplethysmography signal, labelled.

Here, the systolic peak is a result of the direct pressure wave traveling from the left ventricle to the periphery of the body and the diastolic peak (or inflection) is a result of reflections of the pressure wave by arteries of the lower body. The dicrotic notch is a small downward deflection between the systolic and diastolic point of a PPG cycle. The pulse interval represents the relationship between the contribution that the wave reflection makes to the systolic arterial pressure and the reflected wave coming from the center. Since the systolic peak is the parameter that has to be determined, smoothing and filters have to be applied so as to prevent the erroneous detection of a diastolic peak as well. This, if it happens, would cause error to creep into the heart rate estimations. This problem is solved by Elgendi et al's approach without requiring hard coded parameters.

The heart rate determination process involves the detection of the PPG signal using a recorded video of the fingertip. A number of samples each from groups of 10 second, 20 second, and 30-second videos were used for testing. No appreciable effect on accuracy was observed with video length alterations. The overview of the process pipeline is presented below:

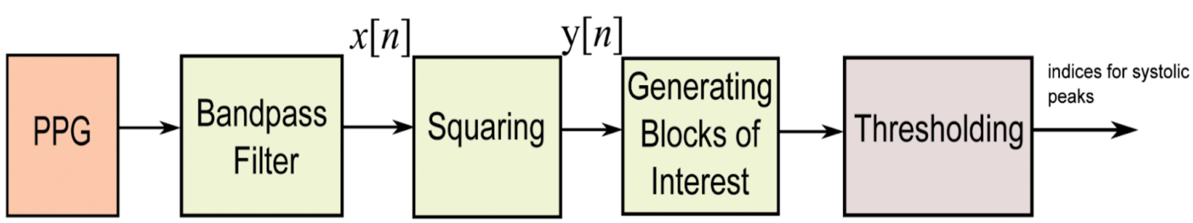

Figure 9: Peak detection pipeline for heart rate

A pre recorded video of the fingertip was obtained. This video was then stratified framewise and the red spectrum intensity of each such frame was calculated and stored as an array. This array is the PPG signal that was processed. After obtaining the PPG signal, bandpass filtering was employed to concentrate the signal in the appropriate region viable for observations. This was followed by signal squaring to emphasize the large differences resulting in the systolic wave. Following this, a two-moving average-based method is used to demarcate areas of interest. Peaks are detected in these areas and this helps calculate the heart rate. PPG signals at each of the above described stages are shown in the figure below:

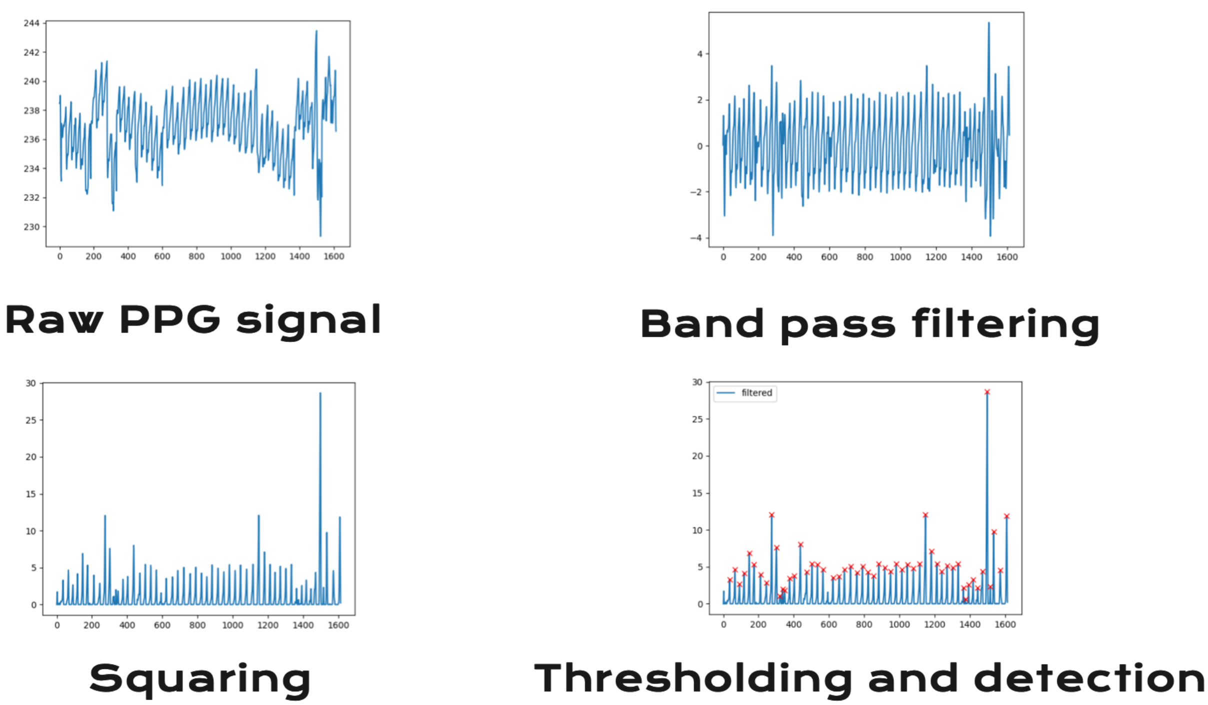

Figure 10: PPG signals at each stage of processing for heart rate determination

For signal extraction, a bandpass filter, namely a zero-phase second-order Butterworth filter is used. This approach helps to attenuate frequencies that lie in spectrums beyond our scope of consideration. The PPG signal thus obtained is then subject to squaring. Squaring helps the subsequent operation of obtaining areas of interest. This is because this operation enhances the signal characteristics arising out of the systolic component while suppressing the diastolic component.

Following this, areas of interest are calculated in the signal. These areas of interest correspond to signal segments where systolic heartbeat areas lie. This detection is done using two event-related moving averages. The first is used to emphasize the systolic peak area whereas the second is used to emphasize the beat area to be used as a threshold for the first moving average. Following this, a thresholding mechanism is employed that based on anticipated systolic wave width rejects the blocks that contain diastolic wave and noise. After the signal is preprocessed in accordance with the above steps and the areas of interest are detected and suitable thresholded, a simple peak detection algorithm without any hard coded parameters is applied to the signal. This helps detect the required signal peaks. This is shown in the figure below:

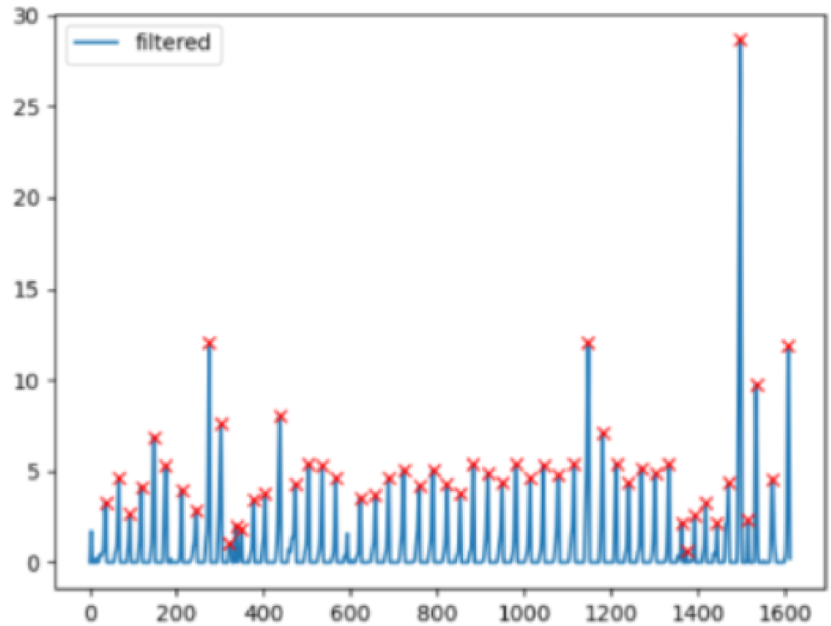

Figure 11: Successful peak detection in filtered PPG

Once the number of peaks is calculated, using the length of the signal, the BPM or the heart rate value can be suitably obtained. This is done by using the following formula where the result comes out in BPM or beats per minute:

$$Heart\ Rate = \frac{Number\ of\ Peaks\ Detected\ in\ the\ Signal}{Duration\ of\ the\ PPG\ Signal}$$

5.2 SpO2 or Blood Oxygen Saturation

Oxygen saturation (SpO2) is a measurement of how much oxygen your blood is carrying as a percentage of the maximum it could carry. For a healthy individual, the normal SpO2 should be between 96% to 99%. High altitudes and other factors may affect what is considered normal for a given individual.Oxygen saturation is the fraction of oxygen-saturated hemoglobin relative to total hemoglobin (unsaturated + saturated) in the blood. The human body requires and regulates a very precise and specific balance of oxygen in the blood. Normal arterial blood oxygen saturation levels in humans are 95–100 percent. If the level is below 90 percent, it is considered low and called hypoxemia.

Arterial blood oxygen levels below 80 percent may compromise organ function, such as the brain and heart, and should be promptly addressed. Continued low oxygen levels may lead to respiratory or cardiac arrest. Oxygen therapy may be used to assist in raising blood oxygen levels. Oxygenation occurs when oxygen molecules (O2) enter the tissues of the body. For example, blood is oxygenated in the lungs, where oxygen molecules travel from the air and into the blood. Oxygenation is commonly used to refer to medical oxygen saturation.

The SpO2 was, just like the heart rate, measured as a consequence of pulsatile blood volume fluctuations. Photoplethysmograph signals of varying lengths (10 seconds, 20 seconds, 30 seconds) were obtained from both fingertip and cheek area of facial recordings for this measurement. In the heart rate parameter, only contact plethysmography from the fingertip was used for vital detection. On the other hand, in the case of SpO2, both contact and contactless methodologies were used for oxygen saturation determination.

For both contact and contactless photoplethysmography, given a PPG signal, for each video frame, the following parameters are calculated: mean of red color component (mr), mean of blue color component (mb), the standard deviation of red color component (sdr), and the standard deviation of blue color component (sdb). Here, mr corresponds to the red DC value, mb to the blue DC value, sdr to the red AC value, and sdb to the blue AC value. These values are substituted in the following equation to obtain the SpO2 estimation for the given signal.

$$SpO_2 = A - B\frac{AC_{RED}/DC_{RED}}{AC_{BLUE}/DC_{BLUE}}$$

Figure 12: Formula for SpO2 calculation from PPG

In the above equation, A and B correspond to calibration contents. The values for these can be obtained by plotting the predictions and ground truths on a graph for a suitably large sample space. In the present case, the value of A was determined to be 98 and the value of B was found to be 1.64838404. For the determination of SpO2 from face video, the same parameters to obtain Ac and Dc components of the blue and red spectrums are used. Once these values are obtained, they are substituted in the following equation:

$$RR = \frac{AC_{\lambda 1}/DC_{\lambda 1}}{AC_{\lambda 2}/DC_{\lambda 2}} \qquad SpO_2 = \alpha \cdot RR + \beta$$

Figure 13: RR ration and SpO2 formulas

Here, λ1 corresponds to the red spectrum and λ2 corresponds to the blue spectrum and α and β correspond to calibration constants. Their values were taken to be 38.1 and 68.5 respectively.

The difference between contact and contactless photoplethysmography approaches lies in the method by which the PPG signals were obtained and then filtered and analysed before being processed. For contact photoplethysmography, a fingertip video was recorded just like in the case of heart rate and this video was framewise analysed for PPG signal determination. Following this a four order bandpass filter was applied to lose the noise. After this, the SpO2 could be determined using the equation in the figure 12 and 13 above.

On the other hand, for contactless photoplethysmography, face videos were used. The front face camera was used to obtain the PPG signal. This was done using the dlib library. Face detection combined with object tracking is used to produce a set of face rectangles, which are sampled in the later stages of the pipeline for color variations. The average of the color, in a region of interest (ROI) chosen on the face, represents a signal which corresponds to the PPG. THe ROI for the present application were the cheeks. This is illustrated in the figure below:

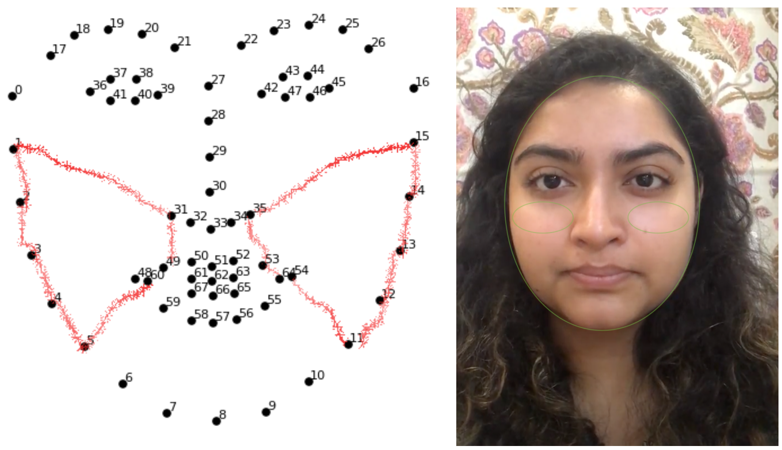

Figure 14: Cheek ROI detection using dlib

Once the determination of the ROI is done, the PPG signal from here is obtained. Following this, the filtering and oxygen saturation detection technique is exactly identical to the contact/ fingertip photoplethysmography as explained above.

8.3 Blood Pressure

Blood pressure (BP) is the pressure of circulating blood against the walls of blood vessels. Most of this pressure results from the heart pumping blood through the circulatory system. When used without qualification, the term "blood pressure" refers to the pressure in the large arteries. Blood pressure is usually expressed in terms of the systolic pressure (maximum pressure during one heartbeat) over diastolic pressure(minimum pressure between two heartbeats) in the cardiac cycle. It is measured in millimeters of mercury (mmHg) above the surrounding atmospheric pressure.

Blood pressure is one of the vital signs—together with respiratory rate, heart rate, oxygen saturation, and body temperature—that healthcare professionals use in evaluating a patient's health. Normal resting blood pressure in an adult is approximately 120 millimetres of mercury

(16 kPa) systolic over 80 millimetres of mercury (11 kPa) diastolic, denoted as "120/80 mmHg". Globally, the average blood pressure, age standardized, has remained about the same since 1975 to the present, at approx. 127/79 mmHg in men and 122/77 mmHg in women, although these average data mask significantly diverging regional trends.

Traditionally, blood pressure was measured non-invasively using auscultation with either an aneroid gauge, or a mercury-tube sphygmomanometer. Auscultation is still generally considered to be the gold standard of accuracy for non-invasive blood pressure readings in clinic. However, semi-automated methods have become common, largely due to concerns about potential mercury toxicity,although cost, ease of use and applicability to ambulatory blood pressure or home blood pressure measurements have also influenced this trend. Early automated alternatives to mercury-tube sphygmomanometers were often seriously inaccurate, but modern devices validated to international standards achieve an average difference between two standardized reading methods of 5 mm Hg or less, and a standard deviation of less than 8 mm Hg. Most of these semi-automated methods measure blood pressure using oscillometry.

Blood pressure is influenced by cardiac output, systemic vascular resistance and arterial stiffness and varies depending on situation, emotional state, activity, and relative health/disease states. In the short term, blood pressure is regulated by baroreceptors which act via the brain to influence the nervous and the endocrine systems. Blood pressure that is too low is called hypotension, pressure that is consistently too high is called hypertension, and normal pressure is called normotension. Both hypertension and hypotension have many causes and may be of sudden onset or of long duration. Long-term hypertension is a risk factor for many diseases, including stroke, heart disease, and kidney failure. Long-term hypertension is more common than long-term hypotension.

For blood pressure estimation, the use of a deep learning-based approach was made. A combination of an approximation followed by a refinement network is done to generate the ABP waveform. This ABP waveform can then be used to approximate the systolic and diastolic blood pressure. The overview of the processing pipeline for the used approach is provided below:

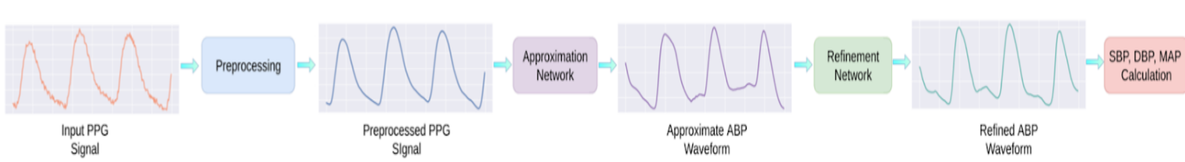

Figure 15: Blood Pressure detecting pipeline

For this approach, the use of a subsection of Physionet's MIMIC II dataset (Multi-parameter Intelligent Monitoring in Intensive Care) is done. The preprocessed version of this dataset can be obtained in the repository indicated by []. Each of the PPG signals is then wavelet denoised and mean normalized.

$$SBP = max(ABP)$$

$$DBP = min(ABP)$$

$$MAP = mean(ABP)$$

Figure 16: Blood Pressure detection equations

A snippet of the output produced on running the code is also shown below:

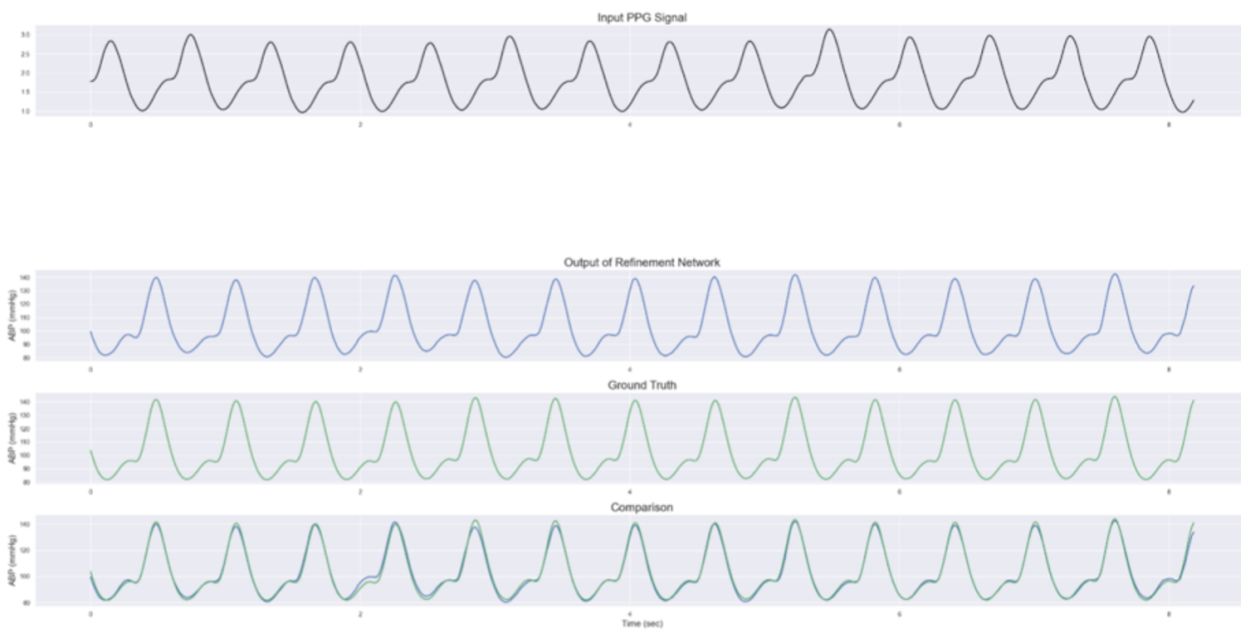

Figure 17: Blood Pressure detection waveforms

For BP detection methodology, the data used is Physionet's MIMIC II dataset (Multi-parameter Intelligent Monitoring in Intensive Care). More information about the data can be found in the website linked at [18]. For the current algorithm, a subset of the dataset consisting of about 25% of the actual data amounting to 1.8-2 GB was used. The processing performed can be found detailed in [19].

6. Results and Conclusions

According to the methodologies expanded upon in the previous chapter, the models were built and then subjected to trials on about 30 test subjects. The results of this were tabulated and are presented as follows. For the heart rate contact plethysmography, the following were the results obtained:

Video Name	Actual BPM	Predicted BPM	Error	Error Percentage	Mean Error
102ajay	102	97.88	4.12	4.04	6.80
104ajay	104	91.44	12.56	12.07	
106ajay	106	92.12	13.88	13.09	
20210616finger_80 bpm	80	74.71	5.29	6.61	
20210616finger_85 bpm(1)	85	75.18	9.82	11.55	
20210616finger_85 bpm	85	78.96	6.04	7.11	
64hr_12rr_98spo2_ft	64	58.78	5.22	8.16	
65karan	65	67.23	2.23	3.43	
66karan	66	63.28	2.72	4.12	
70karan	70	66.30	3.70	5.28	
71karan	71	66.58	4.42	6.23	
93ajay	93	87.77	5.23	5.62	
98spo2_70bpm	70	63.87	6.13	8.76	
HC_10	85	76.30	8.70	10.24	
HC_3	83	78.68	4.32	5.21	
HC_4	80	72.71	7.29	9.12	
HC_5	75	74.84	0.16	0.22	
HC_6	80	77.17	2.83	3.54	
HC_7	70	63.87	6.13	8.76	
HC_Dro_2	96	86.54	9.46	9.86	
HC_nit_1	85	81.97	3.03	3.57	

HC_shr_1	107	56.19	50.81	47.49	
HC_Son_2	68	60.48	7.52	11.06	
hr100	100	87.77	12.23	12.23	
hr65+	65	66.58	1.58	2.42	
hr65_2	65	67.23	2.23	3.43	
hr65_3	65	63.28	1.72	2.65	
hr70	70	66.30	3.70	5.28	
KL_rj_1	54	60.52	6.52	12.08	
KL_sha_1	64	63.51	0.49	0.77	
video2	72	75.73	3.73	5.18	
video3	80	71.77	8.23	10.29	
video4	77	73.82	3.18	4.13	
video5	80	77.07	2.93	3.66	
video6	85	75.18	9.82	11.55	

Table 2: Results of the trials for the contact heart rate model

As can be seen from the table above, the mean error was around 6.8%. A graph showing the error distribution for the above table is also shown below:

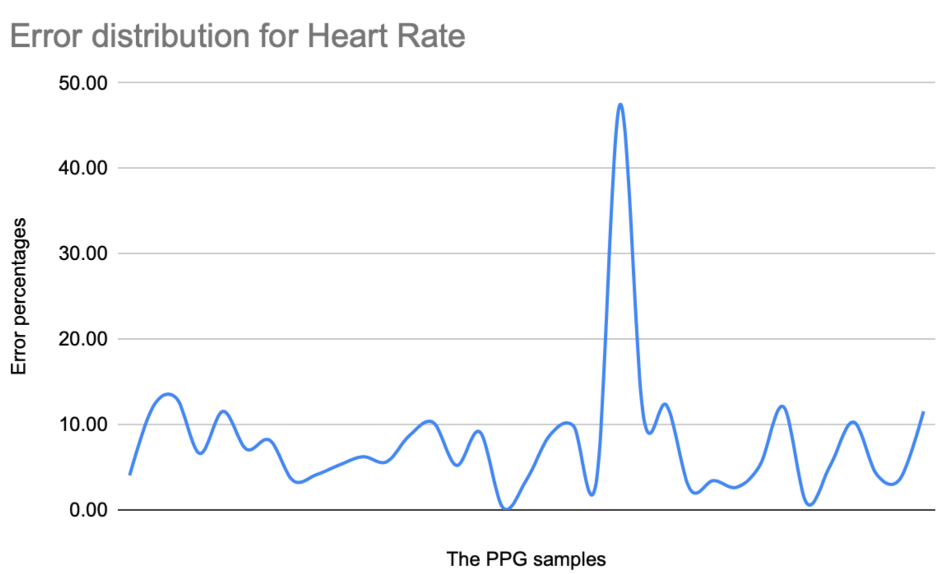

Figure 18: Error distribution for heart rate

The error results for trials of the oxygen saturation model are tabulated below:

NAME	Actual SpO2	Predicted SpO2	Error Percentage	Mean Error
HC_4.mp4		97		1.0125
104ajay.mp4		98		
HC_5.mp4		97		
HC_6.mp4		97		
20210616finger_80bpm.mp4		97		
HC_7.mp4		97		
20210616finger_85bpm(1).mp4		97		
HC_Dro_1.mp4	99	97	2.02	
20210616finger_85bpm.mp4		97		
HC_Dro_2.mp4	98	98	0	
64hr_12rr_98spo2_ft.mp4		98		
HC_Son_1.mp4	99	97	2.02	
65karan.mp4		97		
HC_Son_2.mp4	99	98	1.02	
66karan.mp4		98		
HC_Sum_1.mp4		97		
70karan.mp4		98		
HC_nit_1.mp4		98		
71karan.mp4		97		
HC_shr_1.mp4		97		
KL_rj_1.mp4	98	98	0	
98spo2_70bpm.mp4		97		
KL_sha_1.mp4	97	97	0	
HC_1.mp4		97		
VID_20210615_180226264.mp4		98		
HC_10.mp4	98	97	1.02	
HC_13.mp4		98		
hr65+.mp4		97		
hr65_2.mp4		97		

HC_2.mp4		97		
hr65_3.mp4		98		
HC_3.mp4	99	97	2.02	
hr70.mp4		98		

Table 3: SpO2 contact plethysmography results

For contactless photoplethysmography, the trail result snippet is as follows:

Video Name	Actual SpO2	RR value for signal	Predicted SpO2	Error Percentage	Mean Error
video1.mp4	98	0.05712976607	100	2.04	1.27
video2.mp4	99	0.05453523164	100	1.01	
video3.mp4	98	0.0915427457	99	1.02	
video4.mp4	99	0.03758427041	100	1.01	

Table 4: SpO2 contact-less plethysmography results

As can be seen from the table above, the mean error in the case of the face approach was around 1.2%(approx). The mean error for the face approach was found to be 1.2% (approx). The error metrics for the detection of SBP or systolic blood pressure and DBP or diastolic blood pressure are highlighted in the table below. Here, ME stands for the mean error for the test data and STD is the standard deviation for the computed errors.

```
---------------------
|   AAMI Standard   |
---------------------
-----------------------
|     |  ME   |  STD  |
-----------------------
| DBP | 1.619 | 6.859 |

| SBP | -1.582 | 10.688 |
-----------------------
```

Figure 19: Error approximations for blood pressure detection models

The visualization of errors for both SBP and DBP can be seen according to the graphs below. The error was computed with the AAMI standards. AAMI develops standards documents aimed at enhancing the safety, efficacy, safe use and management of medical devices and health technologies.

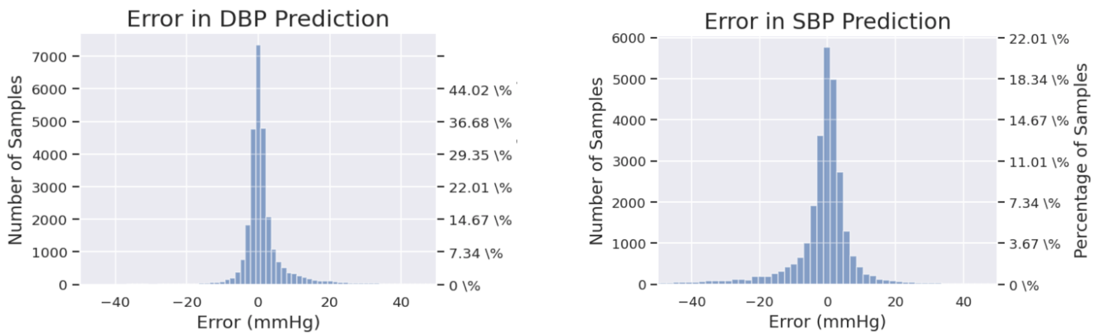

Figure 20: Error visualisations for DBP and SBP model

A standard may recommend to a manufacturer the information that should be included with a product, basic safety and performance criteria, and conformance measures that can be used to assess compliance. The inclusion of design specifications in a standard is permitted when circumstances warrant, but design specifications usually are avoided as they can hinder the advancement of technology. A standard may provide clinical users with guidelines for the use, care, evaluation, or processing of medical devices.

7. Futurescope

- Biomedical signals obtained from the human body can be beneficial in a variety of scenarios in a healthcare setting. For example, physicians can use the noninvasive sensing, recording, and processing of a heart's electrical activity in the form of electrocardiograms (ECGs) to help make informed decisions about a patient's cardiovascular health. A typical biomedical signal acquisition system will consist of sensors, preamplifiers, filters, analog-to-digital conversion, processing and analysis using computers, and the visual display of the outputs.

- Given the digital nature of these signals, intelligent methods and computer algorithms can be developed for analysis of the signals. Such processing and analysis of signals might involve the removal of instrumentation noise, power line interference, and any artifacts that act as interference to the signal of interest.

- The analysis can be further enhanced into a computer-aided decision-making tool by incorporating digital signal processing methods and algorithms for feature extraction and pattern analysis. In many cases, the pattern analysis module is developed to reveal hidden parameters of clinical interest, and thereby improve the diagnostic and monitoring of clinical events.

- During the last five years, we've witnessed advancements in sensor technologies, wireless technologies, and material science. The development of wearable and ingestible electronic sensors mark the fifth generation of biomedical signal analysis. And as the Internet of Things (IoT) framework develops further, new opportunities will open up in the healthcare domain. For instance, the continuous and long-term monitoring of biomedical signals will soon become a reality. In addition, Internet-connected health applications will impact healthcare delivery in many positive ways. For example, it will become increasingly effective and advantageous to monitor elderly and chronically ill patients in their homes rather than hospitals.

- These technological innovations will provide great opportunities for engineers to design devices from a systems perspective by taking into account patient safety, low power requirements, interoperability, and performance requirements. It will also provide computer and data scientists with a huge amount of data with variable characteristics.

- The future of biomedical signal analysis looks very promising. We can expect innovative healthcare solutions that will improve everyone's quality of life.

8. Weekly training report

In this section, a week wise summary of the tasks performed and the feedback obtained is tabulated. The internship was 3 months in duration. Consequently, a record of 12 weeks shall be presented in the following tables.

➔ **Week 1:**

Description of activity, task, duty, or responsibility.	**Performed with team**	**Performed alone**	**Time spent**
Establishing virtual accounts and setting up work environments.		✅	2 hours
Obtain credentials and login to accounts. Also set up trello task boards.		✅	2 hours
Team brainstorming sessions to define goals.	✅		5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
The team brainstorming session went particularly well. It was interesting meeting new team mates and being exposed to a variety of different ideas and point of views.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Incorporating everybody's idea and vetoing certain proposals without offending anyone.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By inculcating more team work centric values.

➔ **Week 2:**

Description of activity, task, duty, or responsibility.	**Performed with team**	**Performed alone**	**Time spent**
Establishing the final internship tasks goals list for all the team members		✅	3 hours
Task division amongst the intern team during	✅		1 hours

weekly meetings.			
Preliminary research on assigned tasks: determination of heart rate, spO2, and blood pressure.		✅	8 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
The task division.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Conducting preliminary blind research on assigned topics.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By being more steadfast and thorough while conducting the preliminary research.

➔ **Week 3:**

Description of activity, task, duty, or responsibility.	Performed with team	Performed alone	Time spent
Conducting specific research in heart rate determination.		✅	5 hours
A filtering and peak detection approach consolidated for heart rate detection coded.		✅	8 hours
Daily meeting for updates on tasks.	✅		5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
Coding of the heart rate approach

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Collecting data to evaluate the results

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By being more proactive and systematic in data collection and better at time management.

➔ **Week 4:**

Description of activity, task, duty, or responsibility.	Performed with team	Performed alone	Time spent
Further enhancement of the heart rate model.		✅	5 hours
Detailed analysis of the obtained model and error detection in a base dataset.		✅	3 hours
Daily meeting for updates on tasks.	✅		5 hours
Looking for alternative non-hard coded approaches.		✅	4 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
Successful mitigation of a potential deterrent of non-robust model.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Looking for alternative to baseline peak detection approach.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By being more farsighted and anticipate future development issues.

➔ **Week 5:**

Description of activity, task, duty, or responsibility.	Performed with team	Performed alone	Time spent
Monthly meeting for team building.	✅		2 hours
Moving average based dynamic approach is consolidated and the smoothening and filters are implemented.		✅	3 hours

Daily meeting for updates on tasks.	✅		5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
Smooth start of the new approach.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Balancing the time and managing other activities also convincing the project manager that a dynamic approach is better than the already developed peak detection approach.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
Being more level headed and careful while developing the code.

➔ **Week 6:**

Description of activity, task, duty, or responsibility.	Performed with team	Performed alone	Time spent
Implementing filtering, smoothing and cleaning of the PPG signal for heart rate according to a new dynamic approach.		✅	8 hours
Generating results and consolidating the new heart rate model.		✅	3 hours
Daily meeting for updates on tasks.	✅		5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
The coding cycle for the approach and the projected waveforms.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
The code is quite large and sizeable so keeping track of all the segments and scripts is hard.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By being resilient and sticking up for what I believe in team meetings instead of being completely complacent.

➔ **Week 7:**

Description of activity, task, duty, or responsibility.	Performed with team	Performed alone	Time spent
Building the finalisation report for heart rate.		✅	3 hours
Starting the research on possible SpO2 models.		✅	8 hours
Beginning and finishing the development of the finger based contact photoplethysmography model.		✅	5 hours
Consolidating the model on the existing dataset and creating a final report.		✅	4 hours
Daily meetings for task updates.	✅		5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
The contact/ finger based photoplethysmography model was developed and benchmarked.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Balancing the time.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By developing a better work-time balance.

➔ **Week 8:**

Description of activity, task, duty, or responsibility.	Performed with team	Performed alone	Time spent
Beginning and finishing the development of the face based contact-less photoplethysmography model.		✅	5 hours

Consolidating the model on the existing dataset and creating a final report.		✅	4 hours
Daily meeting for updates on tasks.	✅		5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
The contact-less/ face based photoplethysmography model was developed and benchmarked.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Balancing the time.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By developing a better work-time balance.

➔ **Week 9:**

Description of activity, task, duty, or responsibility.	Performed with team	Performed alone	Time spent
Exploring blood pressure measurement techniques.		✅	10 hours
Consolidating the deep learning model to be used.		✅	3 hours
Daily meeting for updates on tasks.	✅		5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
Finding a model for blood pressuure detection without ussing accelerometers and gyrometers.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Convincing the management to use a deep learning based approach.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance

By being more convincing and confident in my assertion.

➔ **Week 10:**

Description of activity, task, duty, or responsibility.	**Performed with team**	**Performed alone**	**Time spent**
Training the deep learning model on the existing data.		✅	3 hours
Running code and evaluating the results.		✅	3 hours
Daily meeting for updates on tasks.	✅		5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
Model was successfully trained and results obtained.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Using limited resources to train convolution neural networks on upwards of twelve thousands hours of data.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
Being more creative and flexible in my approach. Revisiting and undertaking more study in the field of convolution neural networks.

➔ **Week 11:**

Description of activity, task, duty, or responsibility.	**Performed with team**	**Performed alone**	**Time spent**
Consolidating the results of the deep learning based blood pressure estimation approach.		✅	5 hours
Finalising all the reports for the three parameters detected.		✅	3 hours
Documenting the developed code.		✅	5 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
All tasks were completed soundly.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
Coding documentation was a hefty task.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By always documenting the code while writing it instead of leaving documentation for the end moment.

➔ **Week 12:**

Description of activity, task, duty, or responsibility.	Performed with team	Performed alone	Time spent
Finalising all the tasks performed.	✅		5 hours
Final presentation overseen by the project manager.	✅		2 hours
Final presentation for the entire department and the founding director.	✅		2 hours

List one thing that went particularly well this week (area of improvement, new task, etc)
All tasks and presentations completed properly.

List one thing that was the most challenging this week (issue, problem, difficulty, etc.)
None.

Self- Evaluation: *(Circle one)*

A+ A A- B+ B B- C+ C- D+ D D- F

List one way you can improve your performance
By making presentations more compact and including less information. By talking concisely during presentations.

9. Learning after Training

- The twelve week long industrial training was an extremely valuable industry experience. Although everyone does undertake outside the classroom study such as courses, online learning, etc., working in industry on real and relevant projects is a crucial experience that helps inculcate essential corporate working values into one's conduct. Although the training is now over, the interest in the subject of artificial intelligence in biomedical analysis and healthcare has only become stronger.

- In order to further enhance the knowledge of the topic, one can work on personal projects and undertake related online courses and classes. Moreover, the peer connections formed are extremely valuable.

- The training helped reinforce my interest in the field and it helped me consolidate my decision to undertake higher studies in the field of artificial intelligence in medicine.

10. References

[1] Vandenberk, Thijs & Stans, Jelle & Van Schelvergem, Gertjan & Pelckmans, Caroline & Smeets, Christophe & Lanssens, Dorien & De Cannière, Hélène & Storms, Valerie & Thijs, Inge & Vandervoort, Pieter. (2017). Clinical Validation of Heart Rate Apps: Mixed-Methods Evaluation Study. JMIR Mhealth Uhealth. 5. e129. 10.2196/mhealth.7254.

[2] Kanva, Avneendra & Sharma, Chandan & Deb, Sujay. (2014). Determination of SpO 2 and heart-rate using smartphone camera. International Conference on Control, Instrumentation, Energy and Communication, CIEC 2014. 237-241. 10.1109/CIEC.2014.6959086.

[3]*What are Standards*. (2018). Default. https://www.aami.org/standards/committee-contacts/what-are-standards

[4] A. de Fátima Galvão Rosa and R. C. Betini, "Noncontact SpO2 Measurement Using Eulerian Video Magnification," in IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 5, pp. 2120-2130, May 2020, doi: 10.1109/TIM.2019.2920183.

[5] Wikipedia contributors. (2021, September 30). *Heart rate*. Wikipedia. https://en.wikipedia.org/wiki/Heart_rate

[6] Elgendi, Mohamed & Norton, Ian & Brearley, Matt & Abbott, Derek & Schuurmans, Dale. (2013). Systolic Peak Detection in Acceleration Photoplethysmograms Measured from Emergency Responders in Tropical Conditions. PloS one. 8. e76585. 10.1371/journal.pone.0076585.

[7] Nabil Ibtehaz, M. Sohel Rahman: PPG2ABP: Translating Photoplethysmogram (PPG) Signals to Arterial Blood Pressure (ABP) Waveforms using Fully Convolutional Neural Networks. CoRR abs/2005.01669 (2020)

[8] Nara, Sanjeev & Kaur, Manvinder & Verma, Kundan. (2013). Novel Notch Detection Algorithm for Detection of Dicrotic Notch in PPG Signals. International Journal of Computer Applications. 86. 10.5120/15081-3520.

[9] Le, T. (2020, July 23). *What is oxygen saturation (SpO2)? What is the normal range for SpO2??* IHealth Labs Inc. https://ihealthlabs.com/blogs/faq/what-is-oxygen-saturation-spo2-what-is-the-normal-range-for-spo2

[10] Wikipedia contributors. (2021b, October 30). *Blood pressure*. Wikipedia. https://en.wikipedia.org/wiki/Blood_pressure

[11] Krishnan, S. (2021, January 29). *The Future of Biomedical Signal Analysis Technology*. Circuit Cellar. https://circuitcellar.com/insights/tech-the-future/the-future-of-biomedical-signal-analysis-technology/

[12] A. (2017). *Before, During, and After Training: Improving Knowledge Transfer in Your Organization in 3 Stages*. Shift E-Learning. https://www.shiftelearning.com/blog/improving-knowledge-transfer

[13] *Plethysmography*. (2016). Medline Plus. https://medlineplus.gov/ency/article/003771.htm

[14] *Plethysmography - an overview | ScienceDirect Topics*. (2021). Science Direct. https://www.sciencedirect.com/topics/nursing-and-health-professions/plethysmography

[15] https://myfitprint.in

[16] https://www.metflux.in

[17] https://github.com/nibtehaz/PPG2ABP

[18] https://archive.physionet.org/mimic2/

[19] https://github.com/nibtehaz/PPG2ABP/blob/master/codes/PPG2ABP.ipynb