ELEN4002: Digital Estimation of Body Mass Index

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Abstract: The following reports the design and implementation of an application used to estimate Body Mass Index from a photograph. The total duration of the project was six weeks. The application consisted of a feature extraction layer and a machine learning layer. The dataset collected to train the machine learning layer consisted of 465 anonymised people's photographs. The program detected a reference object of known dimensions located in each photograph, and subsequently estimated the dimensions of the person in the photograph. Dimensions were chosen at the location of common body fat deposits, and along with person's estimated silhouette area and estimated height, were used to train three Multilayer Perceptron (MLP) models that estimated BMI – one for the front photograph, another for the side photograph, and finally, one that compensated for errors between the front and side estimations, and was the final output of the program. The results of the final model BMI estimation showed a mean estimation accuracy ranging between 79% and 92% for the various categories of BMI, namely Underweight (< 18.5), Healthy (18.5 – 25), Overweight (25 – 30), or Obese (> 30). Furthermore, the spread of error showed that about 61% of participants had an error less than 10%, and about 89% of participants had an error less than 25%. Predictions on the total dataset had a mean absolute error of 3.2, and standard deviation of 3.9.

I. INTRODUCTION

The Body Mass Index (BMI) is a screening tool used to indicate whether one's body mass is healthy for their corresponding height [1]. Whilst not an accurate diagnostic tool, the BMI provides a healthy body mass range for a particular height as it takes natural body shape variations into account [1]. Unfortunately, the distance between rural areas and clinics prevent inhabitants of that area from regular medical checkups, where a medical practitioner might require to measure and track ones height and mass. A solution to both the above mentioned problems would be the creation of a tool that would provide a medical practitioner with this information without the need for the patient to be physically present. The following report presents the design and implementation of program that estimates BMI from a front and side photograph using a mixture of Computer Vision and Machine Learning. The School of Electrical and Information Engineering (EIE) have collaborated with the Peri-Natal HIV Research Unit (PHRU) for this project.

II. BACKGROUND

The Assumptions, Constraints, and Success Criteria have been re-evaluated and refined from that which was described in the Project Plan in Appendix 3. Note that the Optional Criteria for this project (Section IID of Appendix 3) remain unchanged.

A. Project Concept

The aim of this project is to estimate the BMI of a person by creating a program which accepts a front and side photograph of that person. The program will extract body shape data from the photographs with the use of Computer Vision, and estimate their BMI based on their body shape data using Machine Learning. The purpose of such a tool has vast applications in the medical field, whether it be used as a time-efficient means of tracking the progress of a disease/disorder that affects ones mass, or for a simple indication of ones own health. Furthermore, a possible extension of this tool would be using it to classify which category of BMI one falls into: Underweight (< 18.5), Healthy (18.5 – 25), Overweight (25 – 30), or Obese (> 30).

B. Assumptions & Constraints

- As to provide the least chance of a false human body outline being detected, we assume that any person being photographed is staged in front of a uniform background, such as a wall whose colour significantly contrasts with that of the patient and their clothes. All photographs used

to train the machine learning algorithm should abide by the same assumption.
- In order to provide a measurement reference, the person in each photograph should be standing next to a reference object (RO) of known dimensions, such as a piece of standard A4 paper. The colour and dimensions of the piece of paper should be the same throughout the training dataset.
- This RO is present in the photographs during testing or usage of the application.
- All subjects in the photographs stand alongside and in line with the RO, i.e. if the RO is stuck to a wall, the subject is standing against the wall.
- The distance between the camera and the subjects being photographed is constant and far enough away to capture the subject's full body photograph.
- Subjects have a maximum height of two meters.
- The time frame for this project is six weeks, with a total budget of R1200.

C. Success Criteria

- The program should provide an average accuracy of 75% for it to be classified as a potential viable solution.
- To be considered a working prototype, it should provide an average accuracy of 85%.
- To be considered a completed product, it should provide a minimum average accuracy of 95% across all age, gender, and mass groups.
- BMI estimation can occur with photographs of clothed people.
- The final solution is a robust desktop application that can be easily used by a medical practitioner.
- The solution should be camera resolution-independent.

III. LITERATURE REVIEW

The following literature were those most relevant to the estimation of BMI or relevant to the design choices made. Further literature was consulted, the findings of which can be seen in the "Literature Review" section of Appendix 3.

A. Weight and Diameter Estimation of Apples

Comert et al. aims to estimate the mass of an apple through image processing and machine learning techniques [2]. The process involves performing edge detection on the original image using the Prewitt edge extraction algorithm, which creates a binary image containing the edges in the original image. The binary image then undergoes Closing, filtering and Opening.

Closing is the process of performing Dilation followed by Erosion on an image, whilst Opening is the process of performing Erosion followed by Dilation on an image [3], [4]. Dilation is a morphological operation whereby the value (intensity) of a pixel is increased to that of the pixel in its neighbourhood with the highest intensity [5]. Erosion is a morphological operation whereby the value of a pixel is decreased to that of the pixel in its neighbourhood with the lowest intensity [5].

This is done in order to improve the image quality for feature extraction, since Closing an image improves the prevalence of contours, whilst Opening an image improves the uniformity of the spaces between contours. The above operations successfully segmented the image such that the pixels of the apple is white whilst the background is black.

Feature extraction is carried out such that the area and diameter of the apple are extracted. This feature extraction would then be performed on a set of apple photographs whose masses were known. Thereafter, the diameter and area of the apples were related to their recorded masses using a linear regression model. This method reported a 96.5% accuracy of estimation [2].

B. Types of Neural Networks

Mehta discusses the various types of neural networks and what applications in which they prove to be useful [6]. The summary is as follows: Feed-Forward neural networks were useful in situations with minimal data-sets, as well as data-sets that have a substantial amount of noise. The multi-layer perceptron is used when the training data-set is not linearly separable. Networks that make use of back propagation need large data-sets and is generally used in when the network needs to recall or retain information. Convolutional neural networks are used in applications such as object detection and image classification.

C. Estimation of BMI from Photographs Using Deep Convolutional Neural Networks

Pantanowitz et al. have conducted a similar undertaking to that described in this report. The paper discusses the estimation of BMI from a photograph using a Deep Convolutional Neural Network [7]. The analysis was performed on a dataset of 161 photographs that were used to create a set of silhouette images via manual marking as well as automated image processing techniques. The silhouette images were standardised to a particular pixel width without changing aspect ratio, and were thereafter padded appropriately and cropped to a square bounding box. The silhouette images were augmented via minimal rotations and width shifts, with the author stating that the model could only train sufficiently with augmentation. A rather complicated model consisting of 17 layers was used, details of which can be found in Ref. [7]. The results showed the BMI estimations having a correlation of 0.96 with the actual BMI values.

IV. SYSTEM DESIGN

The proposed solution comprises of two subsystems, namely the Extraction layer and the Machine Learning layer. These subsystems have no dependency on each other and are to be built independently of one another. Figure 1 in Appendix 5 provides a system diagram showing the inputs and outputs of each system, as well as the components of each system. The Extraction layer comprises of the Object Detection, Image Segmentation and Input Extraction components, whilst the Machine Learning layer comprises of the Front View, Side View and Weighted Averaging components.

A. Extraction Layer

A front and side view photograph of a person with the aforementioned RO in the top left corner is the input into the system. For the sake of clarity and simplicity, the RO chosen is a standard A3 cardboard, and its chosen colour is black for the sake of high contrast with the assumed light coloured wall in the background. The Object Detection component will isolate the two objects in the photograph, namely the person and the RO, and return the bounding box for each. The width of the bounding box surrounding the RO is measured in pixels. Knowing its physical width allows us to calculate the pixels per meter ratio for that photograph. In other words, all objects that exist in line with the RO will be represented by approximately the same number of pixels per meter as that object. This technique was inspired by Ref. [8].

For both the front and side view photographs the Image Segmentation component will receive the locations of the RO and the person in the form of their bounding boxes. Using the bounding boxes, both the RO's and person's pixel mask (all pixels belonging to an object) will be extracted for both the front and side photographs.

Using the pixels per meter found earlier the Input Extraction component performs feature extraction on the person's front and side pixel masks. Six features are extracted from each pixel mask:

- Their approximate height in meters.
- The approximate two dimensional area contained within their shape (silhouette) in squared meters.
- The maximum thickness of their thoracic region in meters.
- The maximum thickness of their abdominal region in meters.
- The maximum thickness of their pelvic region in meters.
- The maximum thickness of their upper leg region (thigh) in meters.

Note that from front images, the 'thickness' is hereafter referred to as 'width' whilst from the side images, 'thickness' is hereafter referred to as 'depth'. The four body regions mentioned above have been chosen strategically as to represent common areas of body fat deposit. In other words, this study explores the use of Computer Vision and Machine Learning to relate the common regions of body fat deposit to BMI by extracting information about these regions from photographs. The output of the Extraction layer is two vectors, namely the front view vector (FVV) and side view vector (SVV). Both FVV and SVV will contain the above mentioned features extracted from their respective photograph.

B. Machine Learning Layer

All the outputs of the Extraction layer mentioned above are provided as inputs into the Machine Learning layer. The FVV and SVV are passed into the Front View and Side View components respectively, both of which are neural network models trained on a dataset of FVV's and SVV's, respectively. Both networks will have been trained to estimate BMI independently until an

acceptable accuracy is achieved, or falling short of that, the best possible accuracy is achieved.

The estimated BMI from the Front View and Side View component are then used as inputs into a final neural network, the Error Correction / Compensation model, which performs a weighted averaging between the Front and Side BMI estimations. This network will have been trained to estimate BMI by deciding the contribution that the Front and Side view estimates should make towards a final BMI estimation with improved accuracy.

V. TRAINING DATA COLLECTION

As mentioned above, the layer of the system that performs the BMI estimation makes extensive use of neural network models. Thus in order to train these models, a dataset containing photographs of people with their corresponding BMI was required.

A. Ethics Approval

This study was approved by The University of the Witwatersrand Human Research Ethics Committee (Medical), Certificate Number M190539. The committee approved the anonymised collection of the height, mass, age, sex, and a single front and side-facing full-body photograph of 500 fully clothed participants.

B. Collaboration with the PHRU

The PHRU provided clinical research staff who aided in the collection of the above data. Each person was issued an arbitrary subject number that was attached to each anonymised photograph. The dataset was collected at three sites:

- PHRU MDR Tuberculosis (TB) Research Clinic in Klerksdorp.
- PHRU TB Clinic in Chris Hani Baragwanath Academic Hospital in Soweto.
- The Chamber of Mines building at the University of the Witwatersrand.

Data was collected at the last site by the two principal investigators of the study.

C. Data Point Composition

As mentioned above, the data collected was as follows:

- A front and side photograph of the subject. Both photographs had the RO in the top left corner of the image.
- The height and mass of each person. These were captured simultaneously and linked to the persons subject number using the *REDCap* application.
- (Optional) Sex of person in each photograph. Whilst this characteristic is not an input into the system, it was recorded for statistical purposes. Furthermore, to achieve the optional criteria discussed in preceding sections, data points must be labelled as male/female to train separate models.
- (Optional) Age of person in each photograph. This characteristic, despite only being recorded for statistical purposes, is by far the largest contributor to the distribution of BMI, as seen in Ref. [9]. Knowing the distribution of the age of the subjects may provide a range of ages where the program is likely to provide the most accurate estimation.

With the ultimate aim in mind for this program to be a universal BMI estimator, it was encouraged that the data-set of subjects who volunteer to be photographed be spread in terms of sex, ethnicity and age. The final dataset that was used contained 465 photographs, taken with multiple cameras.

VI. METHODOLOGY

Drawing from the previously discussed literature, the following sections describe methodology employed to achieve each component and subsystem implementation described above. The chosen technology for this system is Python, due to its open-source nature, large online community support, and its growing popularity in the Machine Learning field.

A. Extraction Layer

1) Reference Object Detection and Segmentation: The first task for these components is to extract the pixels per meter metric from the photograph, since this metric is used for all subsequent data extraction in the succeeding components such as the person's height, silhouette area, widths and depths. Two methods have been used to extract the RO from the photograph, both of which make extensive use of the OpenCV-Python library. Method One is the primary operation, while Method Two is activated if Method One fails during run-time. Method One is as follows:

- Knowing that the RO is black, the image was filtered of all pixels whose 8-bit colour fell outside of the gray range of 0 – 130, where 0 is pure black and 255 is white, such that the remaining pixels were considered as the 'black' pixels of the image. The value of 130 was chosen experimentally, as to account for lighting in the photographs causing the RO to appear slightly lighter than it should.
- The filtering produced a binary image which showed the positions of black pixels in the image. Edge detection (using the OpenCV implementation of the Canny algorithm) was performed on the filtered image, returning all contours in the image.
- OpenCV's Polygon approximation was then performed on the contours that were returned. This returned all contours in the photograph that have four vertices (rectangular). The contours were ordered from left to right, and the left most contour was assumed to belong to the RO, and returned it.

This method is precise since it searches for a specific type of contour from a specific subset of the pixels in the image, and was partially inspired by Ref. [10]. Unfortunately, whilst this method works for most images there are instances where the lighting in the room caused the pixels which comprise the RO to be so brightened that it fell outside the range of gray specified above. In this case, no rectangular contours would be returned, triggering Method Two as a fail-safe. Method Two is as follows:

- The image is first converted to grayscale and slightly blurred to reduce noise.
- Morphological closing is performed on the image to fill in gaps that may prevent contour detection.
- Edge detection was performed, and returned all contours in the image, ordered from left to right.
- Smaller contours arising from noise were excluded on the basis of the pixel area contained within.

This method (inspired by Ref. [8]), whilst more reliable in finding the contour of the RO, is far more susceptible to noise in the image. As a result, it is susceptible to returning a

distorted RO contour. Furthermore, it is also susceptible to non-rectangular objects appearing to the left of the RO being falsely returned as the RO (due to the left most object being assumed as the RO). Using the known dimensions of the RO, the pixels per meter metric is found and returned.

2) Person Detection and Segmentation: The final task for these components is to return the pixel mask of the person in the image and extract that the aforementioned FVV and SVV. Using the key assumption stated earlier that the person in the photograph is standing in front of a uniform background, the following method was developed, partially inspired by Ref. [11]:

- The Mask-RCNN model developed in Ref [12] was used to detect the Region of Interest (ROI) that contained the person – their bounding box. This pre-trained model has been trained on the MS COCO dataset to detect people, among other common objects, and return an approximate (rough) pixel mask of the person [13].
- The bounding box returned from the Mask-RCNN was then used to perform foreground extraction on the corresponding ROI in the original image (using the OpenCV implementation of the GrabCut algorithm), returning the pixel mask of the extracted foreground.
- The foreground-produced mask more accurately defines the silhouette but is susceptible to noise due to nearby objects, whilst the CNN-produced mask provides an approximate shape of the person but is almost unaffected by nearby objects.
- These two pixel masks are combined using the bit-wise AND operation, such that the final pixel mask only contains pixels found in both the foreground-produced and CNN-produced masks.

The returned pixel mask was rid of zero rows as to crop the top and bottom of the mask. The number of rows in the remaining image was taken as the pixel height of the person, and converted using the pixels per meter metric to a physical height. The pixels per meter metric was used to calculate physical area per pixel. The pixels in the mask were summed and then converted to physical area using this metric.

The image was then approximated into eight sections, to represent the eight distinct regions of the body: Head, Neck, Thorax, Abdomen, Pelvis, Upper Leg, Lower Leg, Foot [14]. The row with the largest number of pixels (maximum thickness) of the Thorax, Abdomen, Pelvis and Upper Leg regions were then extracted and converted to physical dimensions. Altogether, these features made the FVV and SVV. This method of data extraction and composition of FVV and SVV were inspired by Ref. [2]. A visual representation of the entire Extraction Layer can be seen in Figure 1.

B. Machine Learning Layer

1) Model Choice and Evaluation: As per consulting the aforementioned Literature Review, it was found that the simplest type of Neural Network that may account for a noisy, small, and potentially linearly inseparable data-set is the Multilayered Perceptron (MLP). The Front, Side and Compensation models were all MLP's. The models were evaluated by a weighted scoring system that took the maximum deviation from the mean as well as the Mean Absolute Error (MAE) into account. MAE (measured in BMI) was considered as the main metric of
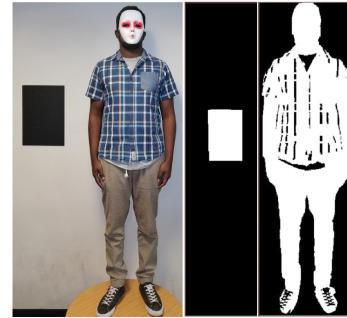

Fig. 1. Example photograph (left), reference object segmentation (middle), person segmentation (right).

model loss, since in this particular application, the accuracy of individual results was more important than evaluating the spread of BMI estimations [15].

2) Training and Final Performance: The program filtered the dataset of features of points that contained errors from the Extraction Layer, leaving 427 points in the feature dataset. Before training, 20% of the feature dataset was removed to be used later as unseen data during model evaluation. The remaining data was used with both the Classical Test-Train split and (Stratified) k-Fold cross validation methods to train the models. The Classical method used a 70/30 train/test split for training, whilst the Cross Validation methods used 10 folds. Different models were trained using different shuffles of data as well as different training parameters such as learning rate, batch size and number of epochs. At the end of each complete training cycle, the models were evaluated by exposing them to the unseen data. The model which had the lowest combination of MAE and maximum deviation when exposed to completely unseen data was saved as having the best performance. The final Validation Model Loss and Training Method for the best performing models were as follows:

- Front: Trained using Stratified Cross Validation using 10 folds, Mean Absolute Error (MAE) — 3.32
- Side: Trained using Cross Validation using 10 folds, MAE – 2.77
- Compensation: Trained using the Classical Test/Train Split, MAE – 2.58

Note that the Front and Side View models were first trained, and the best performing models were used to generate data to train the Compensation model. The full implementation of the system can be found at Ref [16], and features a graphical user interface (GUI) for desktop computers.

VII. Sources of Error

As expected when performing feature extraction on a photographic dataset, the system design either had to account for or circumvent various errors in the dataset. The following errors were circumvented by creating a Method One as described in Section VI-A1:

- Poorly lit photographs, or non-uniform low-contrasting backgrounds that cause the RO to be confused with the background.
- The person being too close to or making contact with the RO.
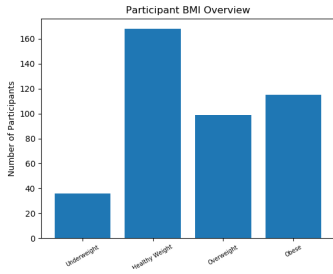- Another object being more to the left of the photograph than the RO.

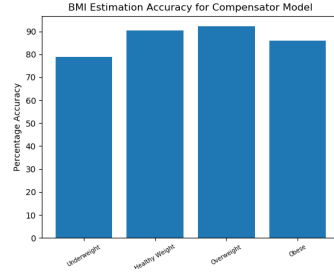Fig. 2. Number of people in dataset according to BMI categories described in Section II-A.

Fig. 3. Average accuracy of Final BMI Model estimations for total dataset according to BMI categories described in Section II-A.

Fig. 4. Frequency of Percentage Error for Final Model BMI Estimations performed on the Full Dataset.

The following errors were circumvented by combining the masks produced by foreground extraction and the Mask-RCNN:

- The person being in contact with another object that would affect normal edge detection.
- The photograph containing other large objects that were in the foreground with the person.

Unfortunately there are some errors that could not be accounted for or circumvented, and must be prevented in any future data collection:

- Taking front and side photographs from an angle such that the RO is seen as behind the person instead of alongside them, creating a distance perspective error.
- A more pronounced distance perspective error in all side photographs due to the RO being a person-width behind the side surface of the person being photographed. This results in the RO dimensions being slightly under-estimated, and the person's side dimensions being slightly exaggerated.

VIII. FINDINGS & ANALYSIS

The models that were described has having the best performance to unseen data in Section VI-B2 was used to make BMI estimations for the entire dataset of 427 people. Figures 2 and 3 show the BMI category composition of the dataset and average accuracy of the final BMI estimation (i.e. from the Compensator model), respectively, for each category. Predictions on the total dataset had a mean absolute error of 3.2, and standard deviation of 3.9.

The first thing to be noted from Figure 2 is the sheer under-representation of the Underweight population in the dataset. It thus comes as no surprise that the lowest BMI estimation accuracy comes from this group. This is also seen in the low Front and Side model accuracies, as seen in Figures 6 - 17 in Appendix 5. As seen, the performance of the Side model to Underweight participants had only 29% of its category with an estimation error of less than 10%.

Despite this, it appears that the results from the final compensation model show there is a definitive relationship between the maximum width and depth of the common areas body fat deposit and BMI, in reference to the well represented areas of the dataset, namely those of Healthy Weight and those Overweight. This is seen in the mean estimation accuracy ranging between 79% and 92% throughout the BMI categories. A more comprehensive view of the performance of the final model can be seen in the distribution of error of BMI estimations in Figure 4.
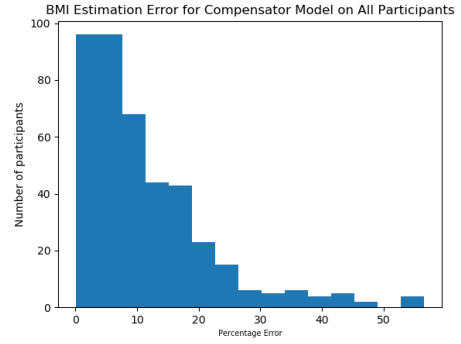
These figures show that approximately 61% of all participants had an estimation error of 10% or less – the vast majority of which having measurement errors between 0 and 6%. With regards to the success criteria of a minimum mean accuracy of 75%, these figures show that about 89% of all participants had an estimation error of 25% or less i.e. an estimation *accuracy* of 75% or more.

One notable misrepresentation shown by Figure 3 however, is that there are approximately five people with a BMI over 45, seen in the data scatters in Appendix 5. As expected, these outliers performed poorly in comparison to the categories where the majority of data was located, and has thus exaggerated the average error of the Obese category. A better representation would be to evaluate the accuracies between an Obese BMI of 30 and 40, as they are better represented in the dataset, and extend the remaining points to differing levels of obesity.

Finally, we see that Figure 19 in Appendix 5 shows a slight 'flattening' or constant prediction across a small range of inputs. This is most likely due to 'ReLu Neuron Death', which occurs when a ReLu-activated neuron receives an overall negative input, causing it to produce zero [17]. It then follows that the constant output is produced since the constant bias term in a layer makes the majority (if not all) of the contribution to the output. Alternatives that mitigate this are the Leaky/Parametric ReLu functions [17], and should be considered in future to prevent this phenomenon.

IX. ADDITIONAL FEATURES

The program allows for height and mass models to be trained, as to provide another means of BMI estimation. The training and evaluation is the same as described above, producing the highest performing model.

The program also provides the user with the option to visualise the data being extracted from the image for the purpose of error detection. This can be extended in future versions of the program to interactively choose a reference object in the photograph.

X. WORKFLOW AND PROJECT MANAGEMENT

Appendix 1 contains the Division of Work, and Appendix 3 contains the original project schedule and allocated resources, all of which remained unchanged during the course of the project. The project cost breakdown can be found in Appendix 5. However it is worth noting that during the time allocated for Image Processing and Neural Network Testing, shown in Appendix 3, multiple extra tasks were completed, putting the

group slightly ahead of schedule. This included the Additional Features, unit testing on all non-library dependant elements of the software, and the design of the GUI for desktop use.

Using Git as source control, each group member worked on two separate trunks for each program layer. Upon completing a task, the other group member reviewed the branch and approved merges into the master-branch when satisfied. The use of GitKraken, which has a built-in own difference viewer, precluded the need to make use of pull requests on GitHub.

XI. Recommendations

In accordance with Section VII, as to improve the quality of the training data as well as model performance, the following minor changes must be implemented when creating a dataset for this system in future:

- There must be at least half a meter of space to the left of the RO in the photograph, as well as to the right of the person in the photograph. Having other objects vertically below the RO (especially of the same colour) or between the persons head and shoulder in the picture may interfere with detection.
- Consider making the RO a bright, distinctly coloured object worn on the person. This would improve the system's ability to locate the RO by first detecting the person, and using the same ROI to find the RO. This would also significantly reduce the distance perspective error discussed in Section VII.

With regards to the speed of execution and resource usage of the program, the following changes should also be implemented in future:

- The program should be parallelised as far as possible. Processes such as RO detection and person detection are not required to be sequential.
- Instead of using the pre-trained Mask-RCNN model that is trained on 81 classes, train a new model on the same MS COCO dataset but only on two classes: person and background. This would decrease the size of the model, as well increase the speed of person detection.

XII. Conclusion

The design and implementation of a software system that estimates BMI from a photograph has been presented. This was accomplished by relating BMI to features including the estimated dimensions of common areas of body fat, silhouette area, and height. These features were extracted using Computer Vision to perform Object Detection, Image Segmentation, Foreground Extraction and Size Estimation on front and side photographs of fully clothed people. The features were then used to train three MLP models to perform BMI estimation. The BMI estimation results of the final model showed a mean estimation accuracy ranging between 79% and 92% across BMI categories, fulfilling the minimum success criteria of 75% mean accuracy. Furthermore, the spread of error showed that 61% of participants had an error less than 10%, and 89% of participants had an error less than 25%. Finally, this software has been presented with a GUI for medical practitioners to easily use. It was noted that an increase in the size of the dataset as well as a revised placement and choice of reference object would result in more accurate feature extraction. Hopefully in future, the additional features of height and mass estimation can be used alongside the BMI model to even more accurately determine these important metrics of health without patients needing to leave their home.

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Appendix 1: ELEN4002 Group Reflection

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TABLE I
DIVISION OF WORK

Task	Darrion Singh (Author)	Sachin Govender (Partner)
Dataset Preparation:		
Preparing Photograph Dataset Folder	✓	✓
Checking Photograph Dataset for Discardable Images	✓	✓
Extraction Layer:		
Object Detection	✓	
Image Segmentation	✓	
Foreground Extraction	✓	
Size Estimation	✓	
Feature Extraction	✓	
Machine Learning Layer:		
Research		✓
Front & Side Model Design		✓
BMI Model Design		✓
Height & Weight Model Design (Additional Features)		✓
Training	✓	✓
Analysis of Results		✓
General Tasks:		
Creating Code Modules	✓	
GUI	✓	

The division of work is shown in Table I. The author of this reflection is hereafter referred to as the 'author', whereas the second group member, Sachin Govender (1036148) is hereafter referred to as the 'partner'. While the work was split, both group members separately came up with total system solutions during project planning. Afterwards, the solutions were presented to each other, and each member noted the strengths and weaknesses of the approach. Finally, the strengths of each solution proposal were amalgamated to produce the final project plan, the outcome of which can be seen in Appendix 3.

Deciding upon the division of work was simple, as both members revealed their particular strengths and prior experience. The author, having seen and experienced basic Image Processing during his Biomedical undergraduate years, as well as having seen and made basic use of Python – the technology decided upon by both members – volunteered to work on the Extraction layer. Since the Extraction layer required to be functional in order to produce data for the Machine Learning layer, it was hoped that the authors prior experience in both areas of Image Processing and Python would result in the shortest possible time to generate training data. The partner, having no experience with Python beforehand volunteered to learn both Python and the machine learning libraries during the time in which the author completed the Extraction layer, such that when the author finished data generation, the Machine Learning layer training scripts were already written and ready to produce models.

Upon meeting to work on the project, both group members started the working session by telling the other what task they were working on, an approximate time frame as to when their current task would be completed, and what they hoped to accomplish by the end of the day. During these updates, each member had the opportunity to question the other on the reasons for their task, therein learning the processes involved for tasks and components that were not in their division of work.

During the week, both members met at the Fourth Year study on the first floor of the Chamber of Mines building to work. During most weekends, working sessions took place at the residence of the partner, who was extremely hospitable and flexible with the long working hours that occurred at his residence. At all times during the undertaking of this project, there was a mixture of encouragement, assistance, and productive argument regarding design processes and implementations. This thorough work checking between the author and the partner occurred in an attempt to produce work of excellent quality.

There was open communication of problems that were encountered, often resulting in both members providing full attention until a viable solution or alternative was decided upon. This was done as to prevent the project from going off-schedule from that established in the project plan, seen in Appendix 3.

As planned, when the author completed data generation, the partner had already gained a functional understanding of Python and had already written the model training scripts. commenced with training the models. During this time, the author proceeded with code cleanup and documentation and creating the GUI.

Throughout the undertaking of this project, both members very easily made concessions during times when one could not make a working session, and an alternative day was quickly arranged. At no point during the project did the author have

any fear that the partner would not finish in time. This kind of trustworthiness has proven to be invaluable to any project undertaking.

This experience has highlighted the importance of having clear lines of communication during a project, particularly during the beginning stages where falling behind schedule is all too easy. It also highlighted the importance of teamwork during planning, as the solutions that either of us presented prior to the start of the project would not have been successful, as there existed major design flaws in both solutions. Whilst this project experience was already enjoyable due to the software nature as well as the collaboration with a research clinic, it was even more enjoyable due to the lack of precarious positions one might find themselves in when completing complex projects. This is a direct result of the effortless teamwork between the author and partner.

Appendix 2

School of Electrical and Information Engineering
University of the Witwatersrand, Johannesburg
ELEN4002/4012: Project Specification Outline

To be completed by the supervisor
Assessment:
☐ Deficient ☐ Acceptable
☐ Good ☐ Excellent

Project Title: ___Digital Estimation of Body Mass Index___

Group Number:	35	Supervisor Name:	Prof Scott Hazelhurst
Student Name A:	Sachin Govender	Student Name B:	Darrion Singh
Student Number A:	1036148	Student number B:	1056673

Ethics: ☐ Request for a waiver (does not involve human participants or sensitive data)

_____ ☐ Copy of ethics application attached (Non-medical) – School Committee

Supervisor Signature ✓ Copy of ethics application attached (Medical) – University Committee

Project Outline: *(give a brief outline such that ethics reviewers understand what will be done, 100 words maximum)*

There is a need for an accurate way for medical practitioners to document the Body Mass Index (BMI) of a patient without having to set up measurement apparatus or asking that patient to remove their clothes. This is particularly cumbersome in a non-urban clinic environment whereby there is a large volume of people who require consultation and limited time to for practitioners to provide consultation. This project aims to provide a means of accurately estimating the BMI of a person from a photograph of them. The person would not have to remove their clothing, and there would be no need for a measurement related equipment to be set up to take the BMI measurements.

Project Specification:

Overview:

Weight measurement is an effective way of tracking progression or identifying the presence of an illness as well as tracking malnutrition. Physical equipment has their own constraints through accessibility (i.e. patient being physically unable to be assessed on equipment), measurement errors and the time required to take the patient's weight. In situations where these constraints prove to be consequential, a robust solution is required to accurately measure one's weight with a high level of certainty. In efforts to pursue this solution the School of Electrical and Information Engineering alongside the Perinatal HIV Research Unit have requested the development of software that make use of various images of a patient in order to retrieve their weight, height and subsequently their Body Mass Index (BMI) with a high level of accuracy.

Objectives:

- Obtain weight, height and BMI through images of a patient
- Accuracy of BMI must be within 2%
- Data/Image collection of the patient must be done in a minimal time to maintain robustness of solution – a good estimation would be less than 30 seconds
- Should cater to patients who are not minimally dressed or wearing tight fitting clothes
- Camera is only equipment for data collection of patients

Assumptions

- Patient can stand in necessary positions for data collection
- Software does not need to be implemented on an application
- Patient does not need to obtain BMI immediately after image capture
- Patient is willing to remove excess clothing items such as a jacket, jersey and head accessories – provided that the weather conditions permit so
- Cameras on modern smartphones have enough image quality
- The school will provide height and weight measurement equipment when required
- Training data is provided (discussed is methodology) and has a broad spectrum of subjects in terms of gender, age height and weight
- Computer used for image processing requires a suitably high-performance GPU
- Computer will not be sponsored by the university (i.e. required to find a suitable PC or use our own)
- Software used for machine learning development is open-source or has been provided the university.
- Collected data must be confidential and anonymised

Methodology:

- Prof. David Rubin of the School of Electrical and Information Engineering has graciously offered us to use his dataset. This dataset contains silhouettes of people without clothing, and their associated height and weight.
- In addition to that, pending ethics clearance, we hope to collect the photographs, height and weight of at least 40 students within the Faculty of Engineering and the Built Environment. These students will be clothed.
- Various Neural Network (NN) models will be researched and the most appropriate will be used. Now, it appears that the types that have the highest likelihood of success is the Convolutional Neural Network, Feedforward Neural Network, and the Kohonen Self Organizing Neural Network.
- The NN models will be trained with the baseline training data provided by Prof. Rubin, as they will would contain a baseline model of the human body BMI relationship without clothes.
- Once the NN's are trained, further training will be conducted with a portion of the clothed dataset. At this point, testing will be performed with the original dataset and the portion of the dataset just used to train the NN.
- This step will be repeated with new portions of the clothed dataset until the clothed dataset has been used both in training and testing.
- This methodology provides us with the most amount of testing data, which will be tracked between tests.
- In this way, we can track the performance of the various NN models, and therefore choose which model, as well as which version of the model, is the most generalized and therefore the most likely to return the most accurate BMI estimation.

Milestones:

- Ethics application approved
- Receive initial training data
- The neural network implemented and trained with training data
- Collection of data from enough subjects (Range of 40-50 is suitable)
- Initial Assessment of the neural network's performance with collected normal clothing data achieved
- The neural network is further trained with collected data
- Accuracy within 2% is achieved

Preliminary Budget & Resources:

- Two smartphones with cameras with specifications of 20-megapixels and 16-megapixels respectively.
- Two computers with enough capability of image processing:

Specification	PC 1	PC 2
Storage	128 Gb SSD + 1 Tb HDD	500 Gb SSD+ 1 Tb HDD
RAM	8 Gb	16 Gb
GPU	Intel-integrated 620	NVidia GTX-1050 TI
Processor	Intel i5 7200	Intel i7 7700k

- Open-source software (Python, TensorFlow, Keras)
- Fully licensed access to MATLAB and all relevant toolboxes
- Weight and height measurement equipment provided by the school
- Training data provided by Prof. Rubin

Risks / Mitigation:

- Ethics approval could be delayed and affect project progression – this could be mitigated through submitting ethics application as soon as possible.
- 2 % accuracy may be excessive considering the amount of data available – cannot be mitigated unless revised success criteria is considered.
- Insufficient time to complete project – mitigate through finishing data collection and software-related research before allocated 6 weeks.
- Measurement equipment provided may not record data accurately – cannot be mitigated.
- Delay in collecting enough data due to people being uncomfortable with pictures and weight recording – mitigate through explicitly telling subjects that their data will be confidential, and images will be pixelated for anonymity.

Appendix 3: ELEN4002 Project Plan

Darrion Singh (1056673) and Sachin Govender (1036148) – Group 35

Abstract—**This report contains a project plan to implement an image-based digital Body Mass Index (BMI) estimator. The estimator is to be a robust and accurate alternative BMI estimation to the classical height and mass measurement. The major benefit of the estimator is the neccessary ability to assess large groups of people in a relatively quick manner. Literature related to image processing and neural networks were consulted to propose a system to accurately estimate BMI. The proposed solution consists of taking a front and side view image of participants and using feature extraction methods such as Object Detection and Image Segmentation to obtain various measurements across the body. Thereafter the measurements should be passed into two independent neural networks that estimate BMI based on front view data, separately from side view data. These two independent BMI estimates are passed through a neural network that provides an averaged weighting to obtain a final BMI estimate. In order to create the proposed system, a data-set of photographs, mass, height, and optionally race and sex will be obtained from research clinics in order to train and test the models in the system. Image processing and machine learning will be carried out in Python with the aid of the OpenCV, Tensorflow and Keras libraries. The project is expected to be concluded within six weeks and must aim to meet the success criteria of having a maximum of 2% error. Difficulties are expected in the form of time limitations, data-set inadequacy and potential over-fitting. These issues can be mitigated through extending the data collection time, increasing the size of the data-set and ensuring a relatively equal distribution of participants in terms of age, race and gender.**

I. INTRODUCTION

The Body Mass Index (BMI) is a metric used as an indication of whether one's body mass is healthy for their corresponding height [1]. Whilst not an accurate diagnostic tool, the BMI provides a healthy body mass range for a particular height as it takes into account natural body shape variations [1]. Unfortunately, the accurate collection of ones height and mass is time-consuming, especially when considering the time required to collect this data for large amounts of people. This project investigates the potential for a digital estimation of one's BMI from a photograph, using a mixture of Computer Vision and Machine Learning. The following report contains the proposed methods and respective schedules associated with the undertaking of this project.

II. BACKGROUND

A. Project Concept

The aim of this project is to estimate, to a reasonable degree of accuracy, the BMI of a person from their photograph. This is to be achieved by the creation of a program which accepts a photograph of a person, extracts body shape data from the photograph and with the use of a machine learning algorithm, predict one's BMI based on their body shape data. The purpose of such a tool has vast applications in the medical field, whether it be used as a time-efficient means of tracking the progress of a disease/disorder that increases/decreases ones mass, or for a simple indication of ones own health.

The success of this project would result in the production of a mobile BMI estimator which precludes the need for a subject to remove their clothes, saving practitioners time for BMI measurement. In large rural clinics, where large patient volumes combined with time taken to undress and redress for accurate height and mass measurements, this digital solution may result in a significant reduction in the time taken for consultations. Furthermore, this solution would not be affected by measurement errors resulting from incorrect calibration.

B. Assumptions & Constraints

As to provide the least chance of a false human body outline being detected, we assume that any person being photographed is staged in front of a uniform background, such as a wall of distinct uniform colour. As such, all photographs used to train the machine learning algorithm should abide by the same assumption. In order to provide a distance reference, each photograph should contain a shape of known dimensions. For consistency, the shape should be the same in all pictures, as well as having the same colour and the same dimensions. This reference object must be present both during training and live testing. Furthermore, the distance between the camera and the subjects being photographed should remain static and be far enough away to capture the subject's full body photograph, where the subject is a maximum of two meters tall. The time frame for this project is seven weeks, with a total budget of R1200.

C. Success Criteria

As this solution means to be time efficient, it aims to negate the need for one to remove their clothes as is usual with regular BMI measurement. Thus, the program should be able to operate with pictures of people who are clothed. The estimation should also be possible using pictures of varying resolutions, i.e. the solution must work for multiple cameras. The specified success criteria error has been given as 2%, however the upper limit of the BMI is generally given as 40 [1]. This translates to an absolute error of 0.8 such that for an actual BMI of 20, an estimated value between 19.2 and 20.8 will be considered as accurate enough.

D. Optional Criteria

Since the purpose of digital estimation of BMI is the production of a solution that is mobile and not time-consuming, it would be ideal if the software and it's trained neural network models were exported to either a mobile application or desktop

executable. In this way, one could select a photograph from their cellphone/desktop gallery and the program could perform estimation on the chosen picture.

Furthermore, to improve the robustness of the design it would also be most ideal if the application/executable could receive pictures from a connected camera. In the case of the mobile application, it would access the cellphone's camera and perform a BMI estimation from a photograph taken in-app. This would potentially expand the use of the machine learning algorithm to be used by the general consumer with minimal effort.

As seen in Ref. [2], there are significant statistical variations in the BMI of male and females across age groups. Provided that there is sufficient training data, one final manner of decreasing the effects of sex bias in the data from the photographed subjects would be to train two separate models for male and female data points. The exclusion of the male data from the female model and visa-versa will improve accuracy by modelling a specific BMI distribution for each sex, as to statistically correlate with Ref. [2].

III. TRAINING DATA COLLECTION

A. Data Types

The data to be collected are as follows:

- A front and side photograph of the subject. Both photographs should have the reference object in the top left corner of the image. As mentioned above, the background of the image should be a uniform surface such as a wall. This is to ensure that the image pre-processing techniques described in the succeeding sections of this report can be carried out without error.
- The height and mass of each person. These must be captured simultaneously and attached to the front and side photographs. Data survey applications such as *REDCap* may be useful in achieving this.
- (Optional) Sex of person in each photograph. Whilst this characteristic is not an input into the system, it should be recorded for statistical purposes for later quantification of algorithmic bias. Furthermore, to achieve the optional criteria discussed above, data points must be labelled as male/female to train separate models.
- (Optional) Race of person in each photograph. This characteristic could also be recorded for statistical purposes. Furthermore, it opens an avenue for further research into how ethnicity can be used to narrow BMI distribution and hence provide more accurate BMI estimations.
- (Optional) Age of person in each photograph. This characteristic, despite only being recorded for statistical purposes, is by far the largest contributor to the distribution of BMI, as seen in Ref. [2]. Knowing the distribution of the age of the subjects will provide a range of ages where the program is likely to provide the most accurate estimation.

With the ultimate aim in mind for this program to be a universal BMI estimator, it is encouraged that the data-set of subjects who volunteer to be photographed be spread in terms of sex, ethnicity and age.

B. Obtaining Data

It is possible to find such images of people on the internet, however it is unlikely for these images to have the corresponding height and mass on record. The chosen method for obtaining the data is to illicit the help of a medical research group who have access to large amounts of people, along with properly calibrated height and mass measuring equipment.

It should be noted that obtaining data in this manner requires prior clearance from a recognised ethics committee, as well as the permission of those in charge of the proposed sites such as research clinics. As with most neural network related projects, it is encouraged for a large data-set to be collected, and it was decided that a reasonable minimum number of subjects would be 100.

IV. LITERATURE REVIEW

Before deciding on the proposed solution described in the succeeding sections, various academic literature regarding image processing and machine learning were consulted. The following provides a summary of findings that were considered when deciding upon the final solution.

A. Weight and Diameter Estimation

Comert et al. aims to estimate the mass of an apple through image processing and machine learning techniques [3]. The process involves using the Prewitt edge extraction algorithm in order to obtain a binary image. The binary image goes through Closing, filtering and Opening.

Closing is the process of performing Dilation followed by Erosion on an image, whilst Opening is the process of performing Erosion followed by Dilation on an image [4], [5]. Dilation is a morphological operation whereby the value (intensity) of a pixel is increased to that of the pixel in its neighbourhood with the highest intensity [6]. Erosion is a morphological operation whereby the value of a pixel is decreased to that of the pixel in its neighbourhood with the lowest intensity [6]. This is done in order to improve the image quality for feature extraction, since Closing an image improves the prevalence of contours, whilst Opening an image improves the uniformity of the spaces between contours. Figure 1 shows the segmentation stage of the apple image.

Feature extraction is carried out such that the area and diameter of the apple are extracted, thereafter the diameter and the recorded masses are used in a linear regression model. Figure 2 shows the diameter extraction from the images.

B. Weight Estimation Using Image Analysis and Statistical Modelling

Similar to the requirements of the BMI system, Kollis et al. discusses a robust image analysis based mass estimation of pigs in large scale livestock farming [7]. The software of choice for image processing is MATLAB in which the Image Processing Toolbox V4.1 is used. Object detection occurred
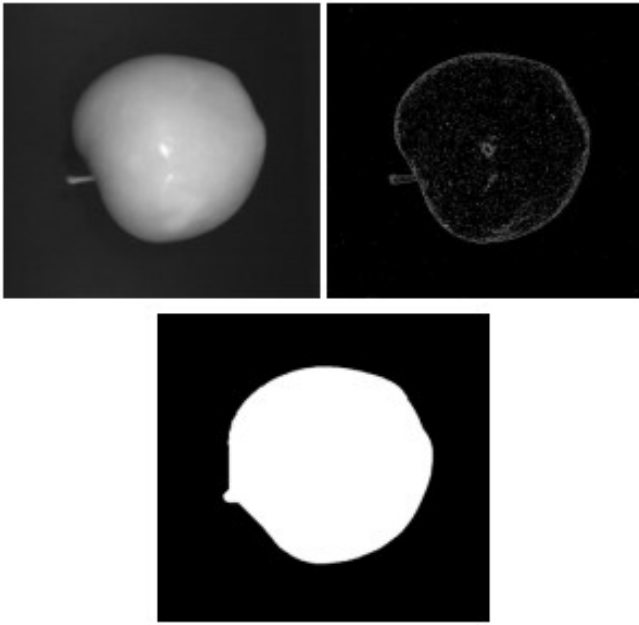
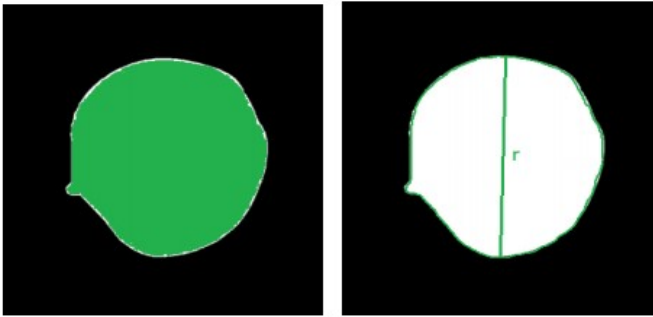Fig. 1. Segmentation techniques to isolate the apple in the image [3].

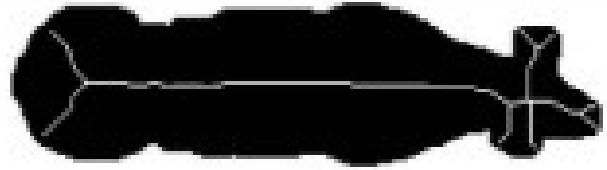

Fig. 2. Apple Area and Diameter Extraction [3].

Fig. 3. Skeletonisation function implemented on pig binary image [7].

C. Human Weight from a RGB-D Image

Nguyen et al. explores human mass prediction through a single RGB-D image [8]. The camera in question uses a depth sensor to create a separate depth image. This extra image proves to be useful in object detection due to depth allowing an accurate trace of the human body shape with the aid of the 2D RGB image.

This method is more accurate than the common rectangular object identification method. This silhouette is passed through similar image processing methods used in the aforementioned papers. However, mass prediction is different in this scenario as the author used various mathematical relationships relating body width, height and area with Support Vector Regression – as opposed to machine learning – to predict the mass of the person through the extracted features.

D. Types of Neural Networks

Mehta discusses the various types of neural networks and what applications in which they prove to be useful [9]. In summary: Feed-Forward neural networks were useful in situations with minimal data-sets, as well as data-sets that have a substantial amount of noise. The multi-layer perceptron is used when the training data-set is not linearly separable. Networks that make use of back propagation need large data-sets and is generally used in when the network needs to recall or retain information. Convolutional neural networks are used in applications such as object detection and image classification.

V. SYSTEM DESIGN

The proposed solution comprises of two subsystems, namely the Extraction layer and the Machine Learning layer. These subsystems have no dependency on each other and are to be built independently of one another. Figure 4 in the Appendix provides a system diagram showing the inputs and outputs of each system, as well as the components of each system. As seen, the Extraction layer comprises of the Object Detection, Image Segmentation and Input Extraction components. The Machine Learning layer comprises of the Front View, Side View and Weighted Averaging components.

A. Extraction Layer

A front and side view photograph of a person with a reference object in the top left corner is the input into the system. Object Detection will isolate the two objects in the

through comparison between the camera environment without the pig and with the pig. This results in a binary image that undergoes segmentation, filtering and opening to get a clear image for feature extraction.

Feature extraction in this paper is particularly useful as the body shape of the pigs is more complex than the apple described in the previous review. The feature extraction method is comprised of the skeletonisation function in MATLAB which generates a skeletal structure of the object in question. Figure 3 shows the skeletonisation process for the image of the pig.

Using this process the spine (main branch) is used to estimate the length of the pig by counting the pixels which comprise the spine. Thereafter the estimated length and recorded masses were used in a linear regression model to estimate mass.

photograph, namely the person and the reference object [10]. The dimensions of the bounding box surrounding each object, measured in pixels, will be converted into meters using the known physical dimensions of the reference object. This is done by computing the meters per pixel metric [10]. The vertical dimension of the person's bounding box, i.e. their height, is one of the outputs of the subsystem.

For both the front and side view photographs, each original unprocessed image will undergo Image Segmentation separately. The Image Segmentation process will locate the pixel mask – all pixels belonging to an object – of the two objects in each photograph, although only the masks of the person is required [11], [12]. Using the meters per pixel found in the previous component, different horizontal slices of the person's pixel masks will be extracted as the width (for the front view photograph) and depth (for the side view photograph) of the person at their corresponding heights above the ground. The final number of width/depth measurements as well as the height at which they will be taken is unknown, and it is only through testing that the optimum number of slices/heights can be determined. Finally, using the meters per pixel metric, the pixel masks will be converted into a physical two dimensional area.

The output of the Extraction layer will two vectors, namely the front view vector (FVV) and side view vector (SVV). The FVV will comprise of the person's front view area, and the person's width at various heights. The SVV will comprise of the person's side view area, and the person's depth at various heights. It is important to note that the chosen heights for the width/depth measurement **must** be the same, such that corresponding indices of the FVV and the SVV refer to the same height above the ground.

B. Machine Learning Layer

All the outputs of the Extraction layer mentioned above are provided as inputs into the Machine Learning layer. The front view and side view outputs are passed into the Front View and Side View components independently, both of which are neural networks. Both networks will be trained to estimate BMI independently until an acceptable accuracy is achieved, or falling short of that, the best possible accuracy is achieved.

The estimated BMI from the Front View and Side View component are then used as inputs into a final neural network, the Weighted Averaging component. This network will be trained to estimate BMI by deciding the contribution that the front and side view images should make to obtain a final BMI estimation with improved accuracy.

VI. METHODOLOGY

The above processes can be done using multiple image processing libraries with languages such as Python, R, MAT-LAB etc. However, due to its open-source nature, large online community support, and its growing popularity in the Machine Learning field, this project will be created using Python. Currently, there is no indication that any other language or software package will be required to implement this project,

however, any deviations from this statement will be minimised as far as possible and be documented. The following section breaks down the methodology employed to achieve each component and subsystem implementation, as well as the potential tools that may be used.

A. Extraction Layer

1) Object Detection: The ultimate purpose of the Object Detection component is to extract the meters per pixel metric from the photograph, since this metric is used for all subsequent data extraction in the succeeding components such as the person's height, width and depth. The manner in which this is to be performed, using the OpenCV-Python library, is as follows: The image is first converted to grayscale (commonly referred to as a black and white image), and slightly blur it [10]. The purpose of this is to decrease the effects of noise in the picture, which manifests as random sharp changes in the picture such as a scratch on a uniform surface – a distinct line that does not contribute to the contour of any object.

Closing is then performed on the image to remove any gaps in a border line that might prevent contour detection [10]. All contours in the image are then detected and ordered from left to right [10]. As mentioned in the previous sections, the reference object must be placed in the top-left corner – this choice was to facilitate contour detection, and ensuring that the reference contour is always evaluated first. We then discard false contours detected by OpenCV by setting a minimum contour length [10]. This value needs to be sufficiently small to prevent the reference object from being discarded, but large enough that minute details about the person is discarded, such as their eyes and mouth.

The reference object bounding box and person object bounding box is then extracted from the image [10]. Using the known dimensions of the reference object, extract the physical vertical dimension of the person object bounding box, and provide it as an output of the Extraction layer.

2) Image Segmentation: The ultimate purpose of the Image Segmentation component is to extract the width and depth of a person from the front and side view photographs respectively, since these two characteristics (at specified heights) are data points for the FVV and SVV respectively. The manner in which these are extracted, using the OpenCV Python library, is as follows: Using a trained masking model such as ENet or Mask R-CNN, the images will have instance or semantic segmentation performed on them [11], [12]. Due to the assumption that only one person will exist in the photograph, with the rest of the image in the background, there will only ever be one instance of a person in the image, and as such, either semantic or instance segmentation should be sufficient to extract the mask.

Once the pixel mask has been isolated, the pixels along a certain row (specified height) of the mask will be summed and converted to distance, yielding the width/depth for front/side pictures. Finally, a simple pixel to area conversion will yield the mask's corresponding physical area after summing the number of pixels in the entire mask. These widths, depths,

and areas will be extracted and provided as outputs of the Extraction layer.

B. Machine Learning Layer

As per consulting the aforementioned Literature Review, it must be noted that the simplest type of Neural Networks that may account for a noisy, small, and potentially linearly inseparable data-set are the Feed Forward or Artificial Neural Network, and the Multilayered Perceptron. These network models are relatively simple to implement due to their lack of kernel requirements or back propagation, and as such are conducive to implementation via a well documented medium such as Python. In particular, libraries such as TensorFlow and its complementary libraries such as Keras are thoroughly documented in the field of Machine Learning. These libraries will be used to create and train the Front View and Side View component models, as well as the Weighted Averaging component model.

The data-set will be split into 70% used for training, and 30% for testing and validation. Training will halt via the early stopping mechanism, which stops a model from training past a certain metric – in this case being the Mean Absolute Error [13]. This early stopping will prevent over-fitting of data points and thus aims to improve generalisation of the model.

Finally, it is important to note that whilst the Front and Side View models are to be trained with the data from the Extraction layer, the Weighted Averaging layer can only be trained once the Front and Side View models are trained. This is due to the fact that the Weighted Averaging model training data-set is to be generated from the output of the Front and Side View models.

VII. PROJECT MANAGEMENT

As stated above, six weeks have been given to deliver a working solution. Due to time being limited, it is imperative to optimise the productivity of the development of the project through scheduling and resource allocation.

The working hours on the project have been summarised as follows:

- The work weeks consist of the five weekdays.
- Working hours lies between 10:30 and 18:00.
- Time spent on the project during weekends and times outside of working hours are considered as overtime.

The resources available for the project are:

- The Primary Investigators.
- Supervisors.
- Clinic Staff.
- Smartphone cameras with a minimum quality of 15 megapixels.
- Three Laptop/Desktop computers with a minimum processing speed of 2.5GHz, 8GB of RAM, two of which have GTX-1050 GPUs.
- Cloud storage sufficient to store photograph backups.

Figure 5 in the Appendix provides a Gantt chart that summarises the work breakdown during the course of the project. The tasks allocated to the primary investigators are as follows: Darrion Singh is allocated the Extraction layer (Image Processing) and Sachin Govender is allocated the Machine Learning layer (Neural Network). The time allocated to the project is split as shown in Figure 5, however there is a possibility of both investigators facilitating each other on their respective tasks due to unforeseen circumstances such as task difficulty or slack in a parallel task.

VIII. EXPECTED CHALLENGES

An neural network based model is only as good as the size and quality of the data set used for training. Due to the limited time available for data collection, there is possibility that the data acquired may not create a model that meets the success criteria. Excluding time sensitivity, the data acquisition can be further hindered by multiple factors such as clinic facilitators/data collectors not following procedure correctly, resulting in the reduced quality and size of the data-set. Preventative measures for data collection errors cannot be mitigated as the primary investigators for this project being unable to provide thorough supervision over the data collection, as per the project schedule not allowing for it.

Another issue relevant to the neural network is over-fitting. There is a possibility of the variety of participants (according to age, gender, race and body type) being has unequally distributed across the total data-set. Thus, over-fitting could occur due to the presence of dominant groups with similar traits. Despite having specified a minimum number of participants for data-collection, there is no finite number of data points that can guarantee good results - in other words, the minimum number of participants may be insufficient for good results.

If training the neural network is to be successful with a lack of participants, a large number of width/depth extractions from the Image Segmentation component may be required. However, knowing that each measurement contains some error, it stands to reason that more width/depth extractions from the same image will result in a higher the overall measurement error.

IX. RECOMMENDATIONS

As stated above this project is conducted in a limited time of 6 weeks, which affects the scheduling of the project in a manner that reduces the time to obtain a sufficient data-set in terms of size and quality. It is recommended that when planning future projects of this nature, that it either be conducted in a longer time frame as to guarantee a sufficiently large and well-spread data-set, or alternatively to only commence on a project of this nature once the data-set has been collected.

Quality of the data set could be improved through ensuring that there is minimal biases in terms of composition of the total data set. Biases come in the form of minimal variations in race, sex and age. Due to the nature of the project being potentially used for clinics in rural areas, there should be a demographic study on the areas that the software will be implemented in to better select the data used for the network.

It is also worth noting that neural networks could also be used to classify participants according to their body type – an attribute that could improve the estimation of a subject's BMI due to having its own BMI distribution. If a larger data-set is available, consideration should be made to incorporate a body type classifier into the BMI estimation.

X. Conclusion

The above report has presented a plan for the implementation of a digital Body Mass Index Estimator. It is intended for this project to be implemented using Python, via the OpenCV, TensorFlow and Keras libraries, among others. The system is divided into a data extraction layer (Extraction) and a neural network layer (Machine Learning). To create data for the training of the Machine Learning layer of the system, a data-set of photographs of a subject labelled with their height, mass and optionally age, sex and race must be pre-processed. The data-set is to be collected from a research facility during the course of the project. This pre-processing can be accomplished by Object Detection and Image Segmentation as shown regarding the Extraction layer above. Training of the various components of the Machine Learning layer is to be controlled by an early stopping mechanism to prevent over-fitting. The largest challenge that may be experienced over the course of the project is the inability to collect a sufficiently good data-set in terms of image quality, volume of data (subjects), and the spread of age, sex and race among the subjects, which may create inaccuracies in the system.

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Appendix

The following pages contain an appendix for the report titled "ELEN4002 Project Plan" by Darrion Singh and Sachin Govender. All images in this Appendix have been referenced in the main report. This Appendix contains the system block diagram of the BMI estimation program, as well as Gantt Chart describing the time allocation to tasks to be undertaken in the project.

Input
Images

Front View

Side View

Extraction
Layer

Object
Detection

Image
Segmentation

Front Area

Front View Vector

Height

Side View Vector

Side Area

Machine
Learning
Layer

Front View Neural
Network

BMI

Side View Neural
Network

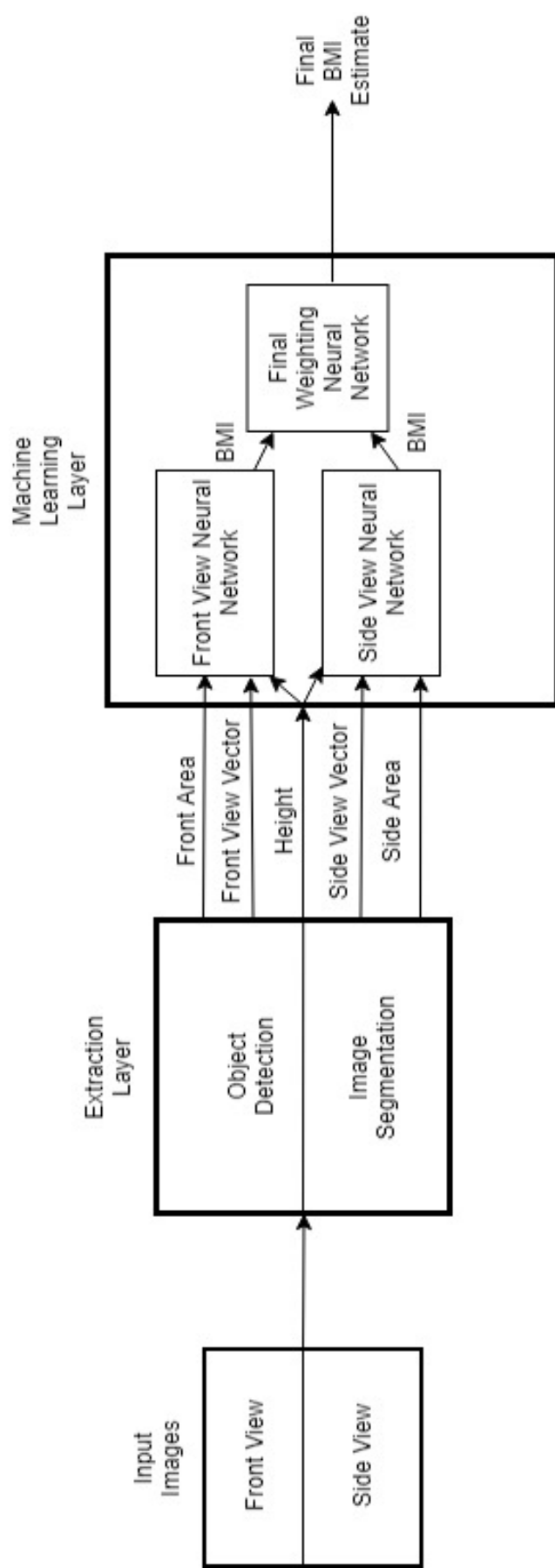BMI

Final
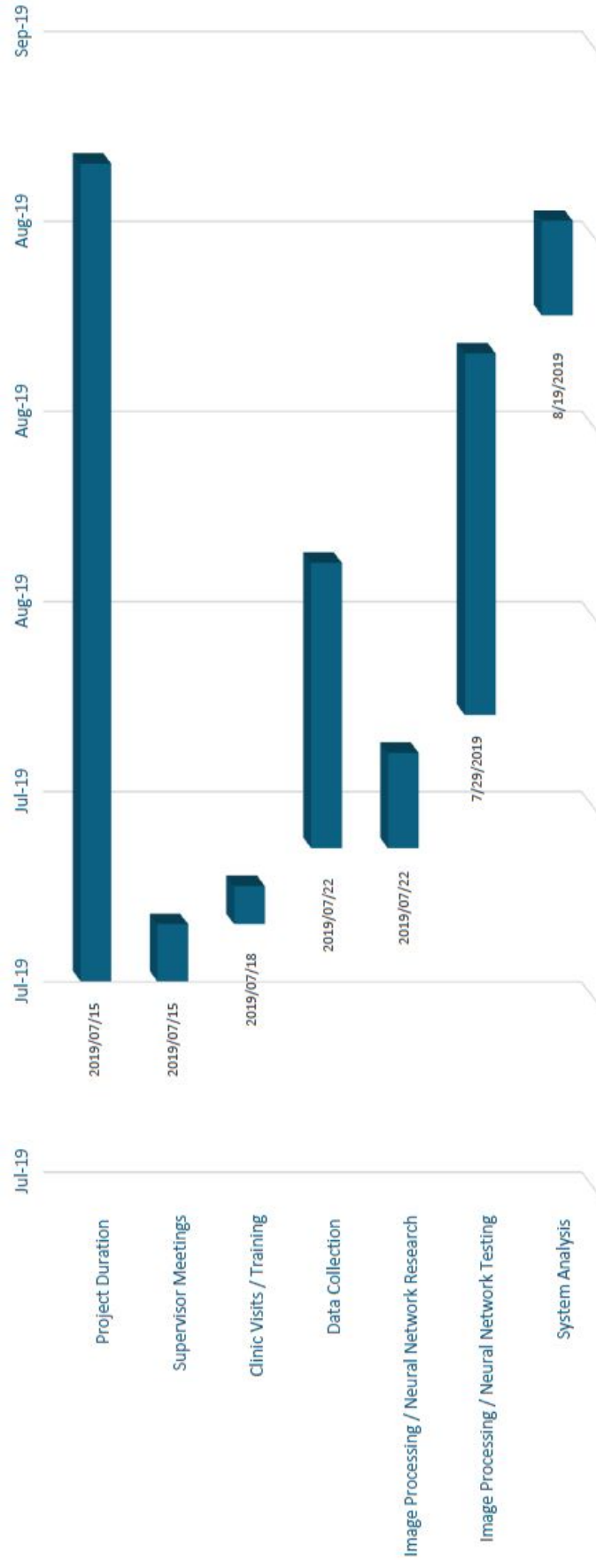Weighting
Neural
Network

Final
BMI
Estimate

Fig. 4. System Block Diagram

Fig. 5. Gantt Chart showing project task breakdown and time allocation.

Appendix 4: Project Meeting Minutes

The following minutes record meetings between Darrion Singh (1056673), Sachin Govender (1056673) and Prof. Scott Hazelhurst, who supervised this project. All changes to the attendees of the meetings have been recorded under the heading "Changes to Attending".

Date: 19 March 2019
Location: Prof. Hazelhurst's Office, Chamber of Mines Building, University of the Witwatersrand.
- Enquired about potentially acquiring Prof. Rubin's dataset for machine learning component of project.
- Prof. Hazelhurst informed us that he would confer with Prof. Rubin about obtaining his dataset, and that we should make contact with Prof. Rubin to confirm.
- Prof. Hazelhurst informed us of the processes involved for obtaining ethics approval for the study, advising us to aim for the early May ethics application.
- Prof. Hazelhurst informed us that if we obtain Prof. Rubin's dataset, even if the dataset may not necessarily require ethics approval, we still require to make an application.
- Prof. Hazelhurst provided the following preliminary ideas:
    - The person in the photograph should some standard object on either side of them such as two brightly coloured balls on either side of them.
    - The program should detect the ball as a reference object.

Date: 2 May 2019
Location: Cafeteria, Wits Medical School.
Changes to Attending: Dr. Neil Martinson from the Peri-Natal HIV Research Unit Present in attendance.
- Prof. Hazelhurst informed us that after conferring with Prof. Rubin, it was confirmed that the dataset was unavailable.
- Dr. Martinson offered his research clinics and clinical staff to us for the purpose of data collection.
- The issue of whether participants should be clothed was discussed and it was decided that all participants should be clothed as to contribute to creating a robust solution.
- The group members expressed a concern that asking people to disrobe would make ethics approval significantly harder.
- It was decided that only adults could participate in the study.
- Dr. Martinson informed the group that they would need to go to the clinic sites and train the staff to collect photographs correctly.
- Dr. Martinson informed the group that they should create a Standard Operating Procedure (SOP) document.
- It was decided that a reasonable number of participants would be 500.
- It was decided that anonymity would be achieved by the use of facial masks.
- Dr. Martinson was requested to provide a letter of approval for the study to be conducted at PHRU clinics.

Date: 15 July 2019
Location: Prof. Hazelhurst's Office, Chamber of Mines Building, University of the Witwatersrand.
Changes to Attending: Dr. Neil Martinson has phoned in for the meeting.
- Following email confirmation of receiving the Ethics Certificate, Dr. Martinson has suggested Thursday 18th July and Friday 19th July to visit the Klerksdorp and Soweto sites, respectively.
- Dr. Martinson has asked to print out the SOP, Certificate of Ethics Approval in order to create a site file for each site.
- It was decided that data collection should proceed for at least four weeks, starting on Monday 22 July.
- Prof. Hazelhurst began a brief review of the project plan with the group.
- The preliminary idea for a reference object was presented as a piece of paper being stuck next to the person in the photograph.
- Prof. Hazelhurst commented on the fact that people using this application may not have walls or the means to stick a piece of paper on walls.
- The group informed Prof. Hazelhurst that the program's current method of object detection is highly sensitive to objects in contact.
- Prof. Hazelhurst commented that if two reference balls are used, each with a different colour, the coloured pixels could be detected in the photograph without a problem.

- The group commented that the choice of a reference object not being in contact with the person decreases the chance of the object being obscured from view.
- The idea of splitting the input into separate front, side and compensation models was presented.
- Prof. Hazelhurst commented that the group should consider using a single model with both front and side inputs given to it, as the model effectively aims to create a three dimensional relationship between the inputs.
- The group commented that they were attempting to spilt the input data in order to prevent model overtraining due to the small dataset and large number of inputs.

Date: 26 July 2019
Location: Sydney Brenner Institute of Molecular Biology, University of the Witwatersrand

- The group presented prototype of the feature extraction from test images.
- The feature extraction consisted of a pixel mask of both the reference object and person, as well as a print out of the dimensions along the persons height.
- The group noted that the use of a CNN instead of contour detection resulted in a smooth silhouette in the pixel mask, and was not representative of the persons actual contour.
- The group informed Prof. Hazelhurst that the machine learning element of the project was still in testing stages, and mock data was being used to simulate model performance.
- It was noted that by the end of the weekend, it was expected that feature data generation should be complete, provided there are no problems when moving to the clinic photographs.

Date: 14 August 2019
Location: Prof. Hazelhurst's Office, Chamber of Mines Building, University of the Witwatersrand.

- The group presented preliminary results for the model training only using the dataset gathered at Wits.
- The group presented an improved method of feature extraction that combined the masks of the CNN and Foreground extraction techniques in response to reduced performance due to poor clinic photographs.
- The group noted that the core functionality of the project was completed, and all that remained was to find the best performing model.

Date: 16 August 2019
Location: Prof. Hazelhurst's Office, Sydney Brenner Institute of Molecular Biology, University of the Witwatersrand
Changes to Attending: Sachin Govender unable to attend due to family responsibility.

- Prof. Hazelhurst commented that during this time the group should take advantage of being ahead of schedule, and reflect on any changes that should be made in the closing stages of the project.
- Prof. Hazelhurst noted that for the sake of reporting the findings of the program, statistical measures should be written in, and that simply reporting a accuracy was not adequate.
- Prof. Hazelhurst commented on the need for good documentation practices, such as placing the code on GitHub and documenting the repository at least using a readme file in markdown, as well as testing.
- Darrion Singh informed Prof. Hazelhurst that a basic user interface was in development in preparation for open day and should be completed shortly.

Date: 23 August 2019
Location: Prof. Hazelhurst's Office, Chamber of Mines Building, University of the Witwatersrand.

- The group informed Prof. Hazelhurst that a working demonstration for Open Day including the user interface and the best performing models were ready.
- Prof. Hazelhurst requested that the group send him a preliminary poster for open day as soon as possible.
- The group commented that Prof. Hazelhurst would receive the preliminary poster on Monday 26 August or Tuesday 27 August.
- Prof. Hazelhurst informed the group that documentation was not necessary for Open Day but should be completed by project hand-in.

Appendix 5: Supplementary Information to ELEN4002 Report

I. INTRODUCTION

The following pages contain an appendix for the report titled "ELEN4002: Digital Estimation of Body Mass Index" by Darrion Singh. All images in this Appendix have been referenced in the main report.
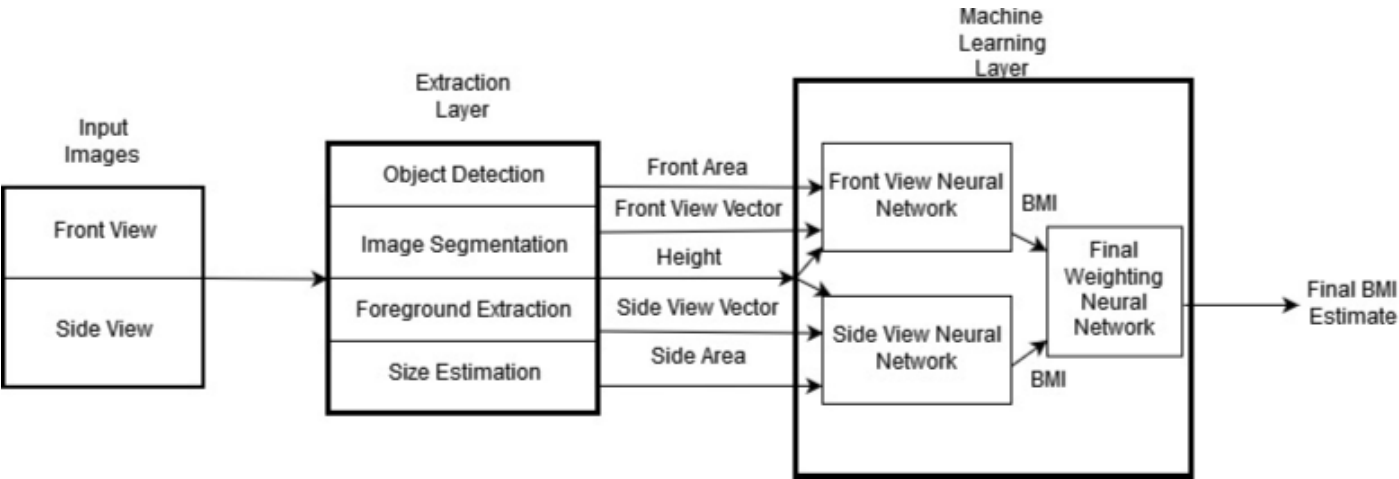
II. SYSTEM BLOCK DIAGRAM

Fig. 1: System Block Diagram showing the processes input images undergo to estimate BMI.
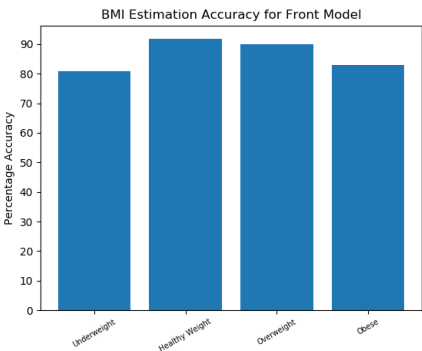
III. MODEL ESTIMATION ACCURACY FOR TOTAL DATASET

Fig. 2: Estimation Accuracy Across BMI Categories for Front Model.
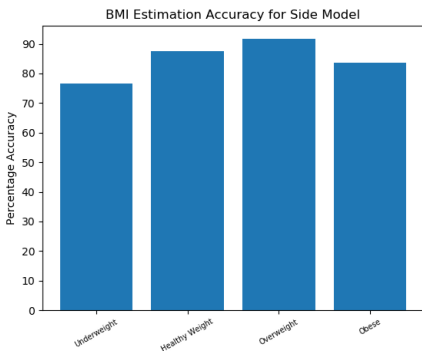
Fig. 3: Estimation Accuracy Across BMI Categories for Side Model.

IV. MODEL ERROR DISTRIBUTION FOR TOTAL DATASET
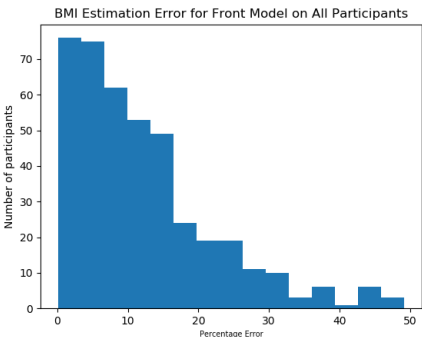
Fig. 4: Error Distribution Across BMI Categories for Front Model.
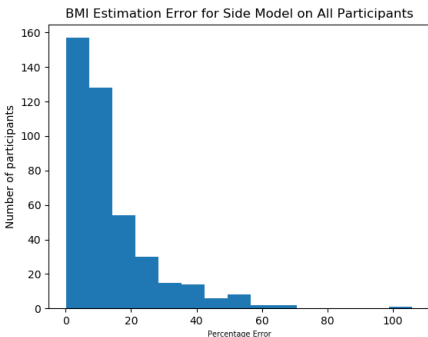
Fig. 5: Error Distribution Across BMI Categories for Side Model.

V. FRONT MODEL ERROR DISTRIBUTION
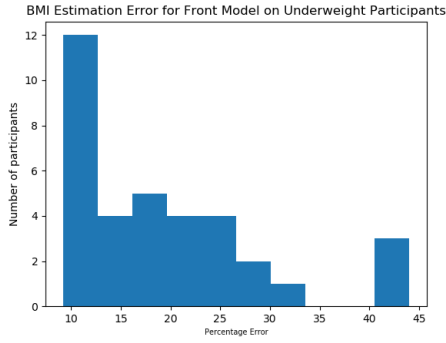
Fig. 6: Distribution of Percentage Error for Front Model BMI Estimations performed on the Underweight portion of the dataset.
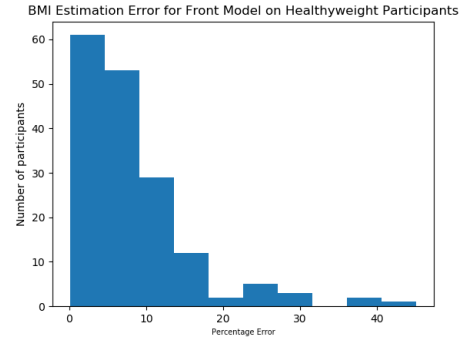
Fig. 7: Distribution of Percentage Error for Front Model BMI Estimations performed on the Healthy portion of the dataset.
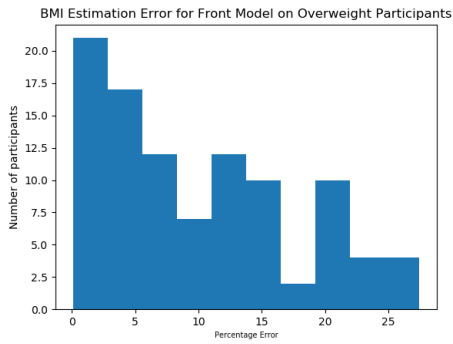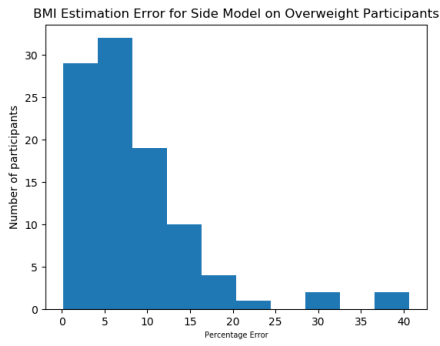

Fig. 8: Distribution of Percentage Error for Front Model BMI Estimations performed on the Overweight portion of the dataset.
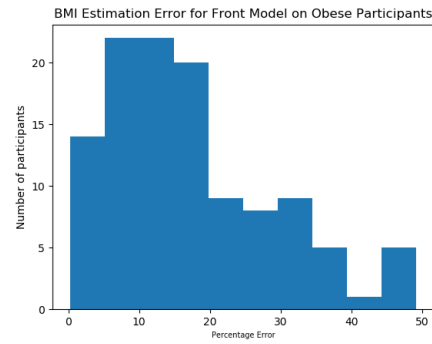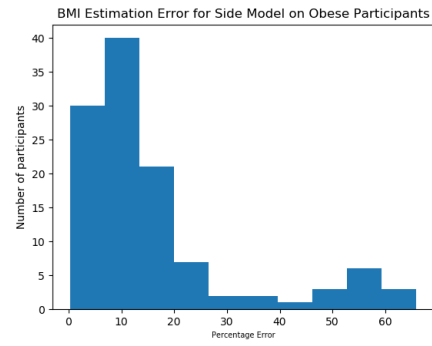

Fig. 9: Distribution of Percentage Error for Front Model BMI Estimations performed on the Obese portion of the dataset.

VI. SIDE MODEL ERROR DISTRIBUTION
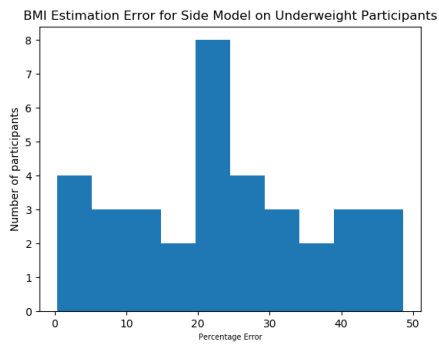
Fig. 10: Distribution of Percentage Error for Side Model BMI Estimations performed on the Underweight portion of the dataset.
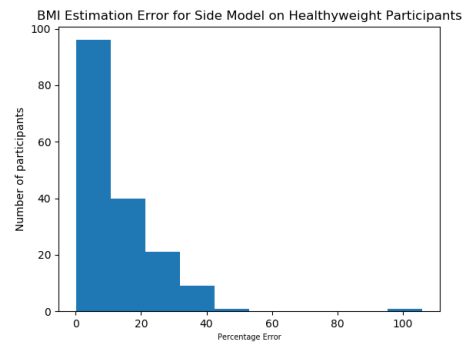
Fig. 11: Distribution of Percentage Error for Side Model BMI Estimations performed on the Healthy portion of the dataset.

Fig. 12: Distribution of Percentage Error for Side Model BMI Estimations performed on the Overweight portion of the dataset.

Fig. 13: Distribution of Percentage Error for Side Model BMI Estimations performed on the Obese portion of the dataset.

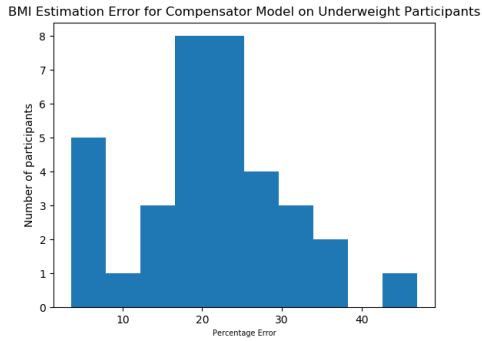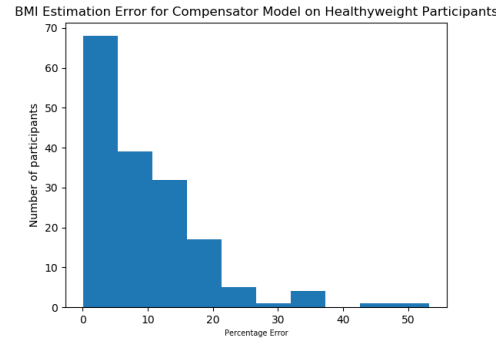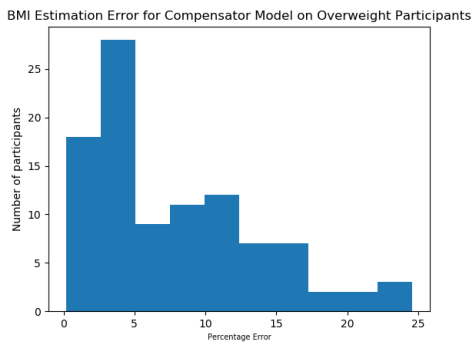## VII. FINAL/COMPENSATOR MODEL ERROR DISTRIBUTION

Fig. 14: Distribution of Percentage Error for Final Model BMI Estimations performed on the Underweight portion of the dataset.

Fig. 15: Distribution of Percentage Error for Final Model BMI Estimations performed on the Healthy portion of the dataset.

Fig. 16: Distribution of Percentage Error for Final Model BMI Estimations performed on the Overweight portion of the dataset.
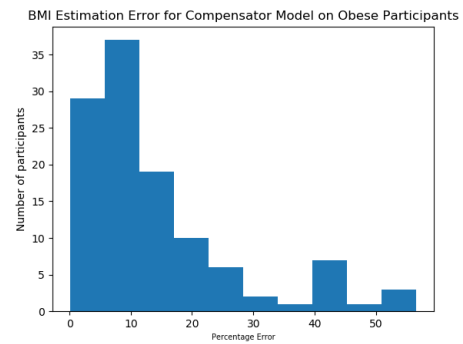

Fig. 17: Distribution of Percentage Error for Final Model BMI Estimations performed on the Obese portion of the dataset.

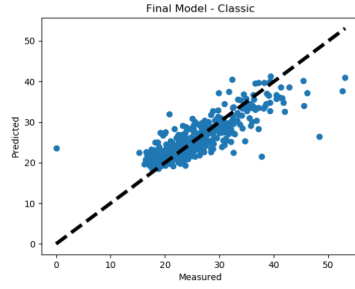# VIII. Model Performance for Total Dataset

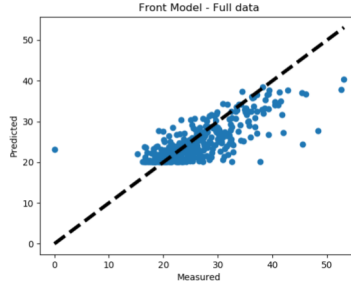Fig. 18: Final Model Performance for Total dataset.
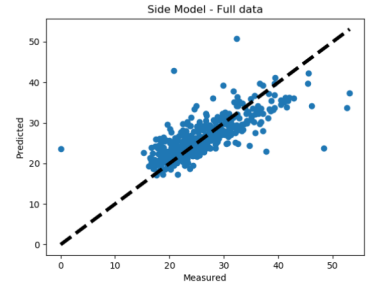

Fig. 19: Front Model Performance for Total dataset.

Fig. 20: Side Model Performance for Total dataset.