A Real-Time Detection System Using Advance Imaging Techniques to Automatically Detect Lipohypertrophy in People with Insulin Dependent Diabetes

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Abstract- Insulin Dependent Diabetes is a chronic condition that affects over 200 million people worldwide. While, there is no treatment for this specific condition, diabetic patients keep control of the disease by administering external Insulin hormone through multiple daily injections (MDI). One of the key challenges of MDI is the buildup of adipose tissue under the skin. This fat-build is called Lipohypertrophy and is very painful and reduces the absorption of insulin. Lipohypertrophy goes largely undetected since it is not visible to the naked eye and is hard to detect till the condition gets really severe. Many insulin dependent diabetics have no idea of these fat regions (Lipohypertrophy) and continue to administer MDI into these low insulin absorption areas. This leads to further aggravation of the condition, long-term complications and really poor diabetes control for patients (as seen by elevated levels of HbA1C). This project focuses on automated detection of Lipohypertrophy in insulin dependent patients. The approach is to use ultrasound technology to gather images of regions affected by Lipohypertrophy. Then utilizing an optimized edge detection algorithm one can detect the existence of fat-buildup and pinpoint the location of severe Lipohypertrophy. To test the developed algorithm, images from Lipohypertrophy study done in Profil Institute for Metabolic Research were used. The results were very promising and detection accuracy was over 85%. In conclusion, this project proved that automatic detection of Lipohypertrophy could be done using existing Ultrasound equipment and a custom detection software. The future goal of this work is to equip doctor offices with this solution. This will greatly improve the control of diabetes patients and decrease complication from the disease.

Keywords - Insulin-Dependent Diabetes, Lipohypertrophy, Management of Diabetes, Ultrasound Imaging

I. INTRODUCTION

Insulin Dependent Diabetes is a chronic condition where the body needs external administration of insulin throughout the day to manage blood glucose levels. This can affect any patient with diabetes, both type 1 and type 2. There are more than 200 million insulin-dependent diabetics throughout the world. Management of Type 1 Diabetics is measured through a test called, HbA1C. This is a test that determines the management of diabetics over the past 3 months and show doctors the overall management of blood sugar levels. HbA1c of 8 or higher are not considered good management and create many complications in the future.

Lipohypertrophy is a medical term that refers to a lump under the skin caused by accumulation of extra fat at the site of many subcutaneous injections of insulin. It may be unsightly, mildly painful, and may change the timing or completeness of insulin action. This problem occurs in almost every single diabetic patient, since they will all have to give injections on a daily basis.

Lipohypertrophy is more prominent in Diabetics that use insulin pumps rather than MDI (Multiple Daily Injections) since the pump is in the same region of the dermis for 3-4 days. There are many issues that occur with Lipohypertrophy. Some of these issues are; delayed and reduced reaction of insulin in the body, reduction of space to give insets and insulin shots. The skin gets damaged as well and there is no treatment available that is able to fix the skin completely.

When the Lipohypertrophy becomes very severe, the only method of treatment for these patients is a liposuction. This would get rid of the access fat build-up in the subcutaneous fat layer. Choosing a spot to give an injection site is hard for diabetic patients. This is because they have no idea where their skin is healed or damaged. Along with the difficulty in choosing a spot, many doctors or endocrinologists are not aware of these regions. This is certainly an overlooked problem. The doctors or nurses would not worry about these regions, and they would continue to increase the insulin delivered into the body or blindly rotate their sites for insulin injections. This is the only way that diabetics can go around and attack this problem.

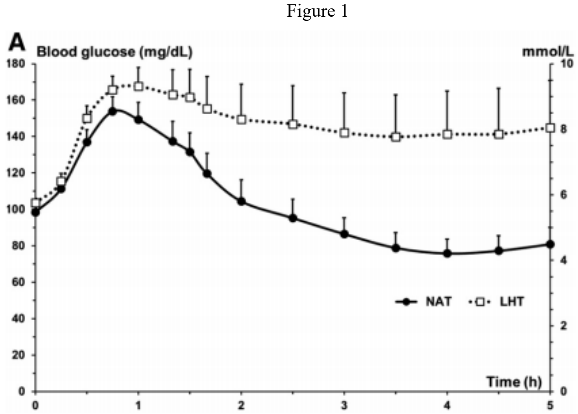
Unmanaged diabetes can lead to many complications in the future such as eye disease or amputations. There are three main complications that are the most correlated to bad management of insulin-dependent diabetes. Diabetic Retinopathy, which is the development of small dot like bulges or "micro-aneurisms", this can lead to blood leakage into the surrounding areas of the eye. This can eventually lead to blindness, and this can come as early as the age of 14. Diabetic Neuropathy is the loss of feeling the fingers or feet, which eventually can lead to amputations so that the nerve damage does not travel. This is very common if the management of diabetes is so bad throughout someone's entire life. Finally, Diabetic Nephropathy is a slow deterioration of the kidneys and kidney function, which, in more severe cases, can eventually result in kidney failure.

Imaging technologies have been proven to be effective in methods for determine tissue thickness of this sub-cutaneous fat regions. There are two viable methods currently published that are able to determine these regions, light and ultrasound. Light or Near Infrared has been used to penetrate the skin and has been used to determine low-cost imaging of many regions in the body. Currently there are possibilities of imaging fat thickness with a device using photodiodes and transmitters. Ultrasound has been used to image thickness of athletes' fat regions. Current research requires doctors to determine these regions by measurements done by doctors and physicians. There is not autonomous method in determining these regions. Ultrasound has a variable depth and has a variety of applications. This method has been proven to image these regions properly.

II. PROBLEM

Lipohypertrophy is the buildup of adipose tissue underneath the skin and these areas are not visible to the naked eye. This fat layers develop with the many subcutaneous injections of insulin into an Insulin Diabetic. These regions may be unsightly, or unpleasant. The biggest issue with these regions is that this leads to blunted or reduced insulin absorption or kinetics, which can lead to bad management of diabetes. [Figure 2] The current solution to this problem is either to rotate injection sites or to increase the total daily insulin. Since these regions are invisible to the naked eye, many insulin-dependent diabetics continue to give into these regions, further aggravating the issue. Studies have shown that injection into these regions has led to an increase in blood glucose levels by about 50-150 points [Figure 1] , which can greatly increase the HbA1C. Elevated HbA1C can lead to many complications in the future, the most severe as blindness, amputations and kidney failure.

Figure 1



IV. MATERIAL AND METHODS

4.1 Image Gathering / Basic Data Set

Ultrasound was the method that was taken to properly analyze these regions in the body. Ultrasound imaging was proven that it could image and determine areas of sub-cutaneous fat regions with different applications such as, quick and easy body weight calculations, and determination of brown fat in the stomach or other regions. A study was done at the Profil Institute for Metabolic Research to determine the delayed absorption due to LHT regions throughout the body. This study used ultrasound to verify regions of LHT after nurse examinations. These ultrasound images were taken using a linear probe and the regions of the LHT were already identified with a measurement in the ultrasound machine. This data was then gathered from this

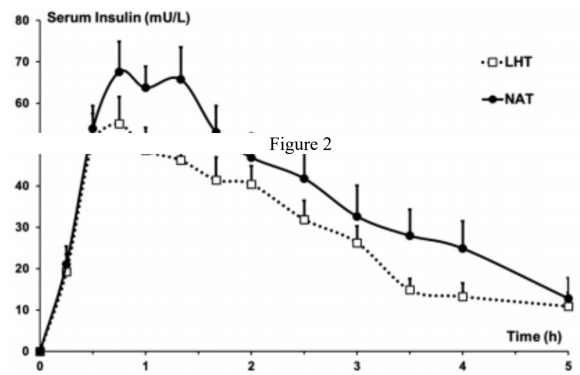


Figure 2

III. OBJECTIVE

The purpose of this project is to create a real-time system for detection of Lipohypertrophy in Insulin Dependent diabetes. An algorithm must be made that is able to effectively and accurately detect Lipohypertrophy based upon Ultrasound Images gathered. The algorithm should be able to diagnosis and determine the optimal site of injection for people with Lipohypertrophy, based upon the subcutaneous regions. The system should contain a mobile application that is able to quickly and effectively detect these regions with a portable ultrasound device. The final system should have a high accuracy and reliability of properly diagnosing Lipohypertrophy regions in people with Insulin Dependent Diabetes.

study, where nurses and endocrinologists have proved that these areas have Lipohypertrophy. Then algorithms can be implemented on this to automatically determine the LHT in these regions.

4.2 Analyzing Image Set

Images have to be analyzed in a certain fashion, and there would be two main approaches to this. Machine Learning, Deep Learning could be applied to the image set to determine LHT or not in regions. This would not be the best option due to the limited image set, along with the issue that all of the images are from the LHT regions.

The next approach would be through edge detection. Edge detection is a method to find the outlines of objects within images; there are very common edge detection algorithms that are used for almost any application. There are three ways in which edge detection would work: discontinuous in depth, surface orientation, and changes in material properties. Edge detection is a fundamental tool in image processing, machine vision and computer vision, particularly in areas of feature detection and extraction.

This is an image of a possible application of edge detection. The image above has been analyzed through variety of processing algorithms. This would be able to show the application of this into the specific instance of ultrasound images.

Edge detection can be broken up into two main categories, single derivatives, or simple edge detection processes, or zero crossing based, which is a second derivatives. These zero crossing algorithms are more complicated and are more used for complicated or unclean images.

The two image processing techniques that would be used in this application would be either Sobel Edge operator, with either a V or H addition or the canny edge detection technique. These would be the best edge detection technique that could be used for this certain application.

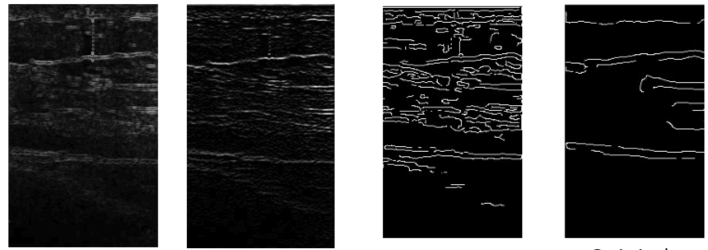
ALGORITHM DEVELOPMENT

4.3 PRE-PROCESSING IMAGE SET

The image data set that was gathered had extraneous information that was unnecessary when trying to develop the algorithm, so there were many pre-processing steps that were taken to properly format the image so that the algorithm will be able to run properly. Parameters from the image like size and ultrasound depth were extracted and provided as inputs for cropping the image to the appropriate size. The editing mechanism was optimized to not lose any useful information of the image. The result of this editing mechanism would gather the information critical to the image processing, and then crop the image to the correct size. This mechanism developed would make sure that any image that was uploaded into the algorithm will be able to be processed.

4.4 EDGE DETECTION TECHNIQUE

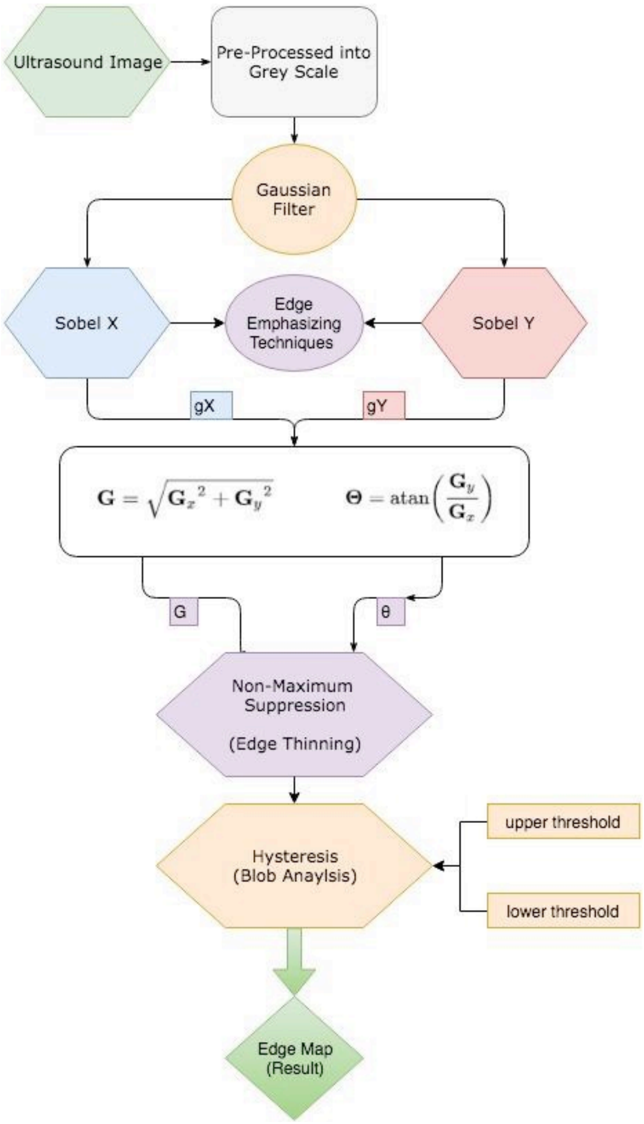
This technique uses various mathematical models that aim at identifying points in an image at which the image brightness changes sharply. More than 10 different edge detection techniques were evaluated including Roberts, Sobel, and Canny. Overall Sobel and Canny had the best results and these two techniques were further analyzed to have the best results.



Sobel | Sobel-H | Cannyedge | Optimized Cannyedge

These were the four edge detection algorithms that were tested and processed to determine which had the best results. From Sobel – Canny there a huge difference, since Sobel is more like the original ultrasound image where Canny is more a black and white image that is processed. Further optimization of the Canny Edge Detection System will result in more reduction of noise. (*Seen in the difference between Canny Edge and Optimized Canny Edge*).

Eventually Canny Edge detection system had the best results in the early stages of the algorithm. The Canny Edge detection system was further analyzed to determine the right filtering coefficient that is able to reduce the correct amount of noise. Since if it was too high, the subcutaneous fat lines would be lost, and if it was too low, there would too much noise for proper analysis.



The above flowchart that depicts the process of the Canny Edge Detection System. This system is able to be modified at the Gaussian Filter Stage so that more or less noise reduction can occur.

The Canny Edge detection system had the best results, and therefore was selected over the other edge detection techniques. Another benefit of the Canny Edge Detection system was the ability to modify the filter, increasing or reducing the amount of line present in the image. This flexibility led to further development of the algorithm to make it more accurate and highly reliable.

4.5 Feature Extraction

Feature extraction involves reducing the amount of resources required to describe a large set of data. When performing analysis of complex data one of the major problems stems from the number of variables involved. Analysis with a large number of variables generally requires a large amount of memory and computation power, also it may cause a classification algorithm to over fit to training samples and generalize poorly to new samples. Feature extraction is a general term for methods of constructing combinations of the variables to get around these problems while still describing the data with sufficient accuracy.

There are two main cases of feature extraction in the algorithm, these would Canny Summation, and Matrix Hysteresis.

Canny Summation – This is the process in which the algorithm was able to further optimize the Canny Edge Detection System for the best results. The Canny Edge Detection System has the capability of having multiple filters that increase or reduce the amount of noise reduction present. This advantage of the Canny Edge system was used to properly intensify the lines that are needed and reduce the intensity of the lines that are unnecessary.

The most basic approach to solve this issue would be to find the sigma that would yield the best results, but to increase the accuracy of the algorithm and make it more applicable into real life scenarios, a unique approach was taken. This unique approach was essentially adding the Canny Edges that have different sigma, this process would have two major outcomes. First, the edges that are the subcutaneous are the longest and the most emphasized in the basic edge detection method. By summating the Canny Edge Detection Sigma, these edges were more emphasized, and spanned the entire image which would increase the accuracy. Second, this would increase the intensity of the lines that were present in all of the sigma, which would also increase the accuracy of the algorithm.

Matrix Hysteresis – This is the process in which extraneous lines that are unnecessary for the algorithm would be removed. This would remove lines in the subcutaneous fat region that were small in length and intensity, so there could be a more accurate diagnosis of Lipohypertrophy.

Initially, the matrix would be summated into a horizontal array. This would show where the lines are on the in the image down to the specific pixel. Now since a pixel is an extremely small measurement the each line of the algorithm would be a summation of the next 5 pixels, this was a method of hysteresis. This method reduced the error of one line that deepen throughout the image and makes sure that the entire line is captured by the algorithm. Now, there would be specific lines that could be determined and the proper IMT distance was calculated.

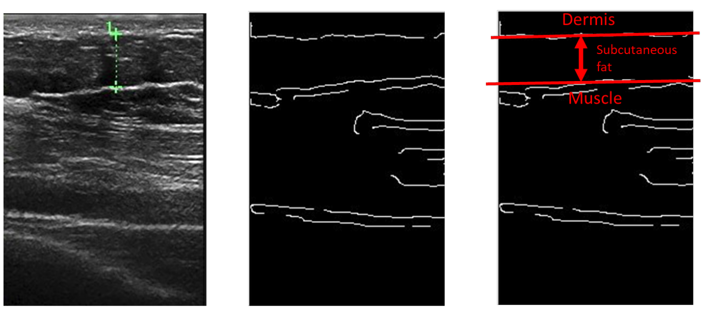
```
Lipo 001 06102014 06.jpg
315
258

18 130
27 166
140 132
302 124
0 0
0 0
0 0
0 0
0 0
0 0
first Line = 27
Second Line = 140
Imt pixel = 113
inter-media thickness = 10.760000
error  = -0.560000
```

As seen in the image the algorithm is able to summate the image into a 1 by *Pixel Length* matrix. Now for each line of the matrix it shows the distance (width) of the image. This is calculated by the intensity present. The algorithm is now gets rid of the lines that are irrelevant to the processing.

This deletion of line would occur where the line would have a low intensity and would span less than a certain width of the image. For example, shown in the image above, the line at 18 pixel had a length that was less than a certain threshold, so it was taken out of the calculations. This method increased the accuracy of the algorithm greatly and led to proper diagnosis of Lipohypertrophy.

Overall, the feature extraction method was one of the unique parts of the overall algorithm that was able to increase the accuracy in detection greatly.



Original Image   Optimized Canny Edge   Feature extraction

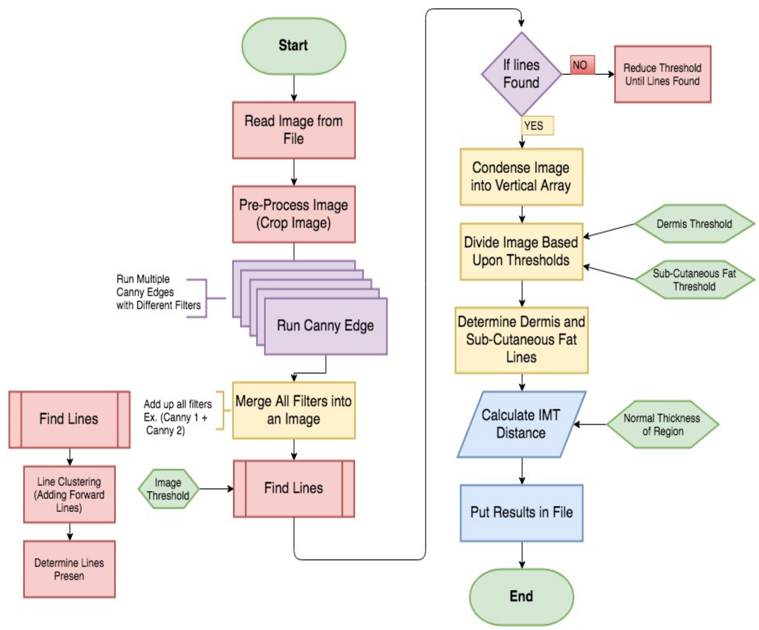
The feature extraction method is demonstrated a proper analysis of the image and would result in proper calculations of the IMT distance shown in the image above.

4.6 Classifier

The final step of the algorithm was to develop a robust classifier that is able to utilize the edge detection and feature extraction techniques to predict the presence of Lipohypertrophy. This classifier would use the rest of the calculated material and test this against a pre-published data set. This is where proper diagnosis of Lipohypertrophy will take place. The classifier takes the lines that were determined by feature extraction and determines the distance between them based upon the depth of the image and the pixel length of the image. Now, once the depth of the sub-cutaneous region is determined this is cross-referenced with the normal depths based upon a pre-published study. The algorithm would then determine if Lipohypertrophy is detected in the specific region of the body.

4.7 Algorithm

The algorithm is a modified edge detection algorithm with matrix calculations to compute the subcutaneous fat of images and detect Lipohypertrophy. This was implemented in Python on Google compute engine



The flowchart (shown above) shows the process in which each image is processed and analyzed, and how it comes to the result of the diagnosis of LHT or not.

Pre-Processing – This is where the image is read from the file uploaded, cropped, and important information about the image is gathered.

Canny Edge Detection – This is where the image processing occurs and the canny edge is taken from multiple sigma and added together to create the best results. These images are merged and create one final image that is able to be processed with high accuracy.

Find Lines – The find lines function determines how many lines are in the image. This function is modified based upon the thresholds of the image. This would find lines by adding the next 5 pixels together and calling that one line. This is to avoid hundreds of lines since fat lines can span more than one pixel. If there are no lines found or if there are too many lines found. The threshold for the width of image will be changed and this will result in the algorithm finding more or less line, respectively.

Matrix Summation – This is a series of processes that reduces the shorter lines that are not fat layers. The use of conditions makes it possible to get rid of small pieces of adipose tissue, and

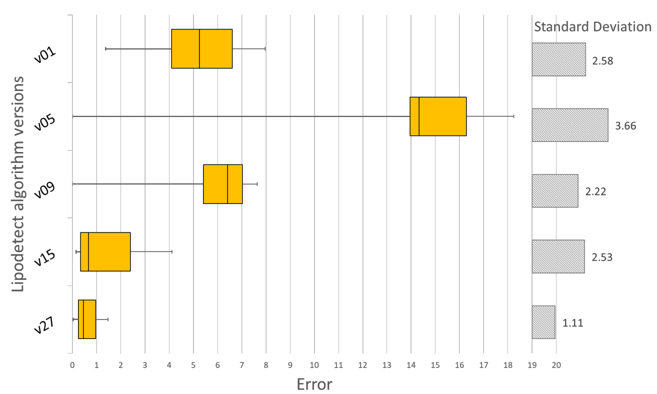
this would greatly increase the accuracy of the algorithm. There are thresholds that are determined based on the depth of the image and divide the image so that more detailed analysis could be done of each region. The epidermis threshold is a threshold that rids the lines near the top of the image if they were to occur. This would be an irrelevant line and reduce the accuracy of the algorithm, so based upon the depth of the image the algorithm determines the threshold that should be placed. This same process occurs for the sub-cutaneous region so that the algorithm is not determining lines in the muscle tissue.
Once this feature extraction takes place, the algorithm then determines the first and second line, which is then processed through the classifier to get diagnosis.

Depth of Sub-cutaneous Fat Regions – This is where the thickness of the subcutaneous region is calculated based upon the depth of the image and pixel length. These thresholds are inputted into the algorithm and a final inter-media thickness distance is calculated.

Classifier- Based upon the length that was inputted into the algorithm, the classifier determines the diagnosis of Lipohypertrophy or not. The diagnosis depends on the age and the normal depth of the regions. The normal depth of each region of the body is in a pre-published data set. Comparing against these values the diagnosis of Lipohypertrophy takes place.

4.8 Error Reduction of Algorithm

The lipodetect algorithm was iteratively improved to reduce error. A total of 27 versions of the algorithm were developed and the final algorithm demonstrated the best results. These algorithms were iterations of edge detection possibilities along with feature extraction methods.



This image shows the results of the iterative process that created the final algorithm, v27. This graph highlights the error and the variation of the error and how both have reduced. The five algorithms shown above are where major changes have been implemented.

The algorithm was continuously improved and eventually was able to reduce the error and standard deviation of the error greatly. Each of the versions demonstrated show the progression of the algorithm and these are when major changes occurred.

Lipodetectv01 – This version of the algorithm was the first, and the edge detection techniques were still being modified and determination of Sobel or Canny would be based upon the results. Version 1 used the Canny Edge with a Sigma of 4, the sigma that had the best results out of the many others. There was still a high average of error and there was a lot of variation present in the error.

Lipodetectv05 – This algorithm used the other edge detection technique the Sobel Edge Detection method. Based upon the results it is clear that this technique was not used due to the large amount of error and variation.

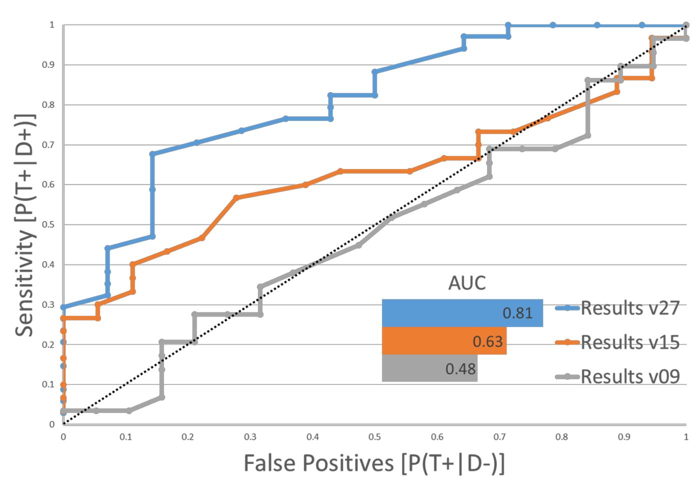
Lipodetectv09 - This version of the algorithm implemented Canny Edge since that was the method of edge detection that was selected based upon results. The addition of the find lines function was in place, which would reduce the error if lines spanned more than one pixel. This slightly increased the accuracy from v1.

Lipodetectv15 – This version of the algorithm was built upon the v9, which did not have any feature extraction. This is when the beginnings of feature extraction in the algorithm. This is the algorithm where the matrix summation process was implemented into the algorithm. As shown, the algorithm had betters results as the errors were starting to decrease.

Lipodetectv27 - This was the final version of the algorithm which had the best results. This algorithm implanted the entirety of feature extraction, including the addition of Canny Sigma. This addition greatly increased the accuracy and led to the best results.

4.8 ROC Curves

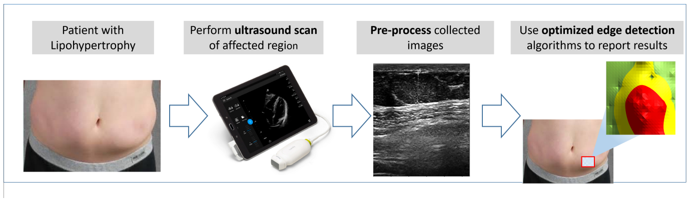
The following shows Receiver operator characteristics (ROC) curves of different iterations of the lipodetect algorithm. The final version (v27) shows the highest Area under curve (AUC).



This was another analysis of the results to determine which algorithm had the highest accuracy. Based upon this and the Box Plot, algorithm v27 was chosen. The final algorithm, Alg27 had the best results in both of the graphs. There was the least error, variation and highest accuracy and this was the algorithm that was implemented into the real-time detection system.

SOLUTION: DEVELOPING A REAL-TIME DETECTION SYSTEM

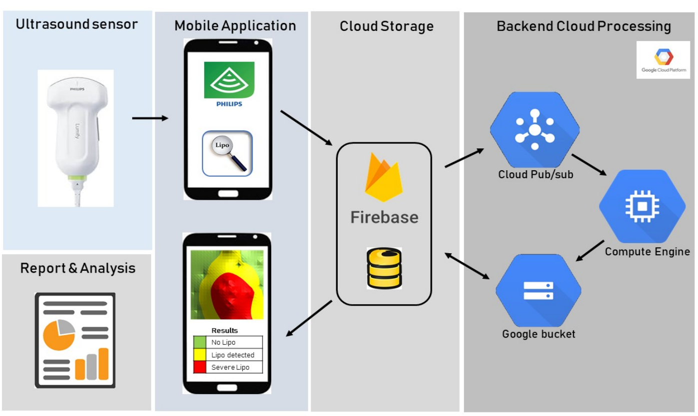
4.8 SOLUTION OVERVIEW



The solution consists of four major steps. These steps include patient with Lipohypertrophy being scanned with the ultrasound and then these images being processed and results would be given back to the patient.

4.8 SYSTEM ARCHITECTURE

The detection system consists of a portable ultrasound that connects to a mobile device. The mobile app sends images to the cloud. The backend applications processes the images and sends results to the mobile device. The system is able to scan and detect regions of Lipohypertrophy in real-time.



The developed system contains an ultrasound sensor that is connected to a mobile application. This mobile application communicates with the cloud through a firebase storage system. The cloud system is where the images are processed through the algorithm and results are sent back to the phone.

SYSTEM DEVELOPMENT

4.8 ULTRASOUND DEVICE EVALUATION - There were a variety of ultrasound devices that were analyzed through criteria and constraints. Eventually Phillips Lumify Ultrasound device was chosen due to the deployment ability of the code on the final system, along with benefits of portability and cost.

Ultrasound Device	Phillips Lumify	EDAN DUS Portable Ultrasound	SonoSite Portable Ultrasound	Clarius Device	Cardio Tech CT-30 Diagnostic
					
Portable	+	0	+	+	-
Resolution	0	+	-	-	+
Cost	+	-	+	0	-
Deployability	+	-	0	0	-

The Phillips Lumify Ultrasound Device had the best qualifications for this project with its portability, resolution, low cost, and the algorithm was able to be easily deployed with the Lumify Device.

4.8 MOBILE APP DEVELOPMENT – Developed a fully functional android app that incorporates Phillips Lumify that connects to cloud software. This app sends images for processing and retrieves results automatically when processing is done. This user-friendly product is utilized for accurate detection of Lipohypertrophy.

The mobile application was developed in android studio and this application connected the algorithm to the ultrasound transducer. The app uses Firebase console to upload and retrieve results from the Google Compute Engine. The application is connected to the Lumify Device and is able to gather the images scanned quickly and effectively. The mobile application is a consumer device that is able to create a real time detection system.

4.8 BACKEND CODE – The code implements the lipodetect algorithm in python. When an image is uploaded, the Pub/Sub software triggers the Google Compute Engine to run the algorithm on the image. Once the image is processed the results are placed into a Compute Engine Bucket, which are then be retrieved by the mobile app.

PubSub – This is the main method that creates a closed-loop system that is able to detect Lipohypertrophy in real time. Once an image is uploaded into the Google Compute Engine Bucket, a notification is triggered. This notification tells the algorithm to pick up the file from the bucket and process the image. This produces the results that are then placed back in the google compute bucket where the files are retrieved from the mobile applications.

CLINICAL EVALUATION AND RESULTS

There were two phases of the study conducted, a pilot study and a Clinical Evaluation of the real-time detection system.

OBJECTIVES –

Primary - To confirm the applicability of the Real-Time System determined by the accuracy of the diagnosis of Lipohypertrophy

Secondary – Understand the Development of Lipohypertrophy in Multiple Patients along with providing accurate data on optimal injection locations

STUDY HYPOTHESIS –

The Real-Time Detection System will have diagnosis accuracy and depth detection accuracy of over 85% and will be able to properly identify the thickness of the subcutaneous fat regions.

OUTCOME MEASURES –

Primary – The primary outcome of the study will be if the diagnosis by the detection software was accurate. This will be verified by endocrinologists along with ultrasound technicians.

Secondary – There are many secondary outcomes of the study, The Depth of Sub-Cutaneous Tissue (mm), along with the proper identification of optimal injection regions

EVALUATION OF SUBJECTS – There will be both Diabetic and Non-Diabetic Subjects imaged and processed.

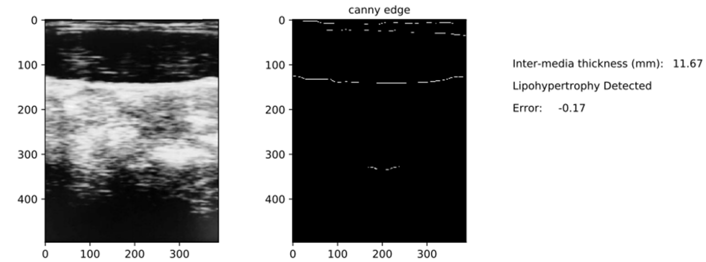
PROTOCOL SUMMARY – The patients will be scanned trying to determine Lipohypertrophy in highly injected regions of the body. The patient will be scanned in four regions of the body where most of the injections are given. Based upon this, regions of 5cm by 5cm will be scanned to create optimal injection regions for that area. After the region have been scanned, ground truths for the IMT distance will be gathered. Once these ground truths have been gathered the study is complete.

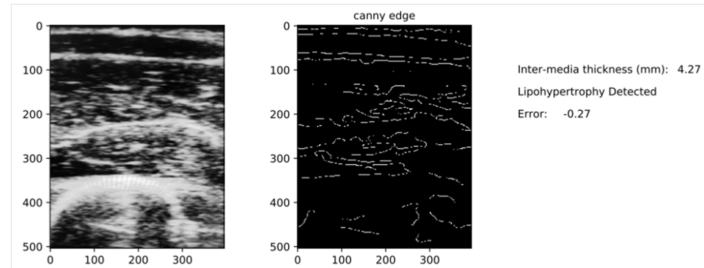
To test the results of the algorithm and the diagnosis of the Lipohypertrophy, they will first be compared against the ground truths. This will determine the accuracy of the algorithm in the real life scenario. Furthermore, to prove that the algorithm is providing accurate results, the results will be verified by both an endocrinologist and an ultrasound technician.

4.10 PILOT STUDY

LIPOHYPERTROPHY TESTING

This algorithm was tested in two human patients: a patient with Insulin Dependent Diabetes and one without. This was to test the applicability of the solution. The type 1 diabetic was tested in the thigh areas to determine where Lipohypertrophy was in the patient. Using a handheld ultrasound, the area was determined and then compared against in the same area on a non-diabetic patient.

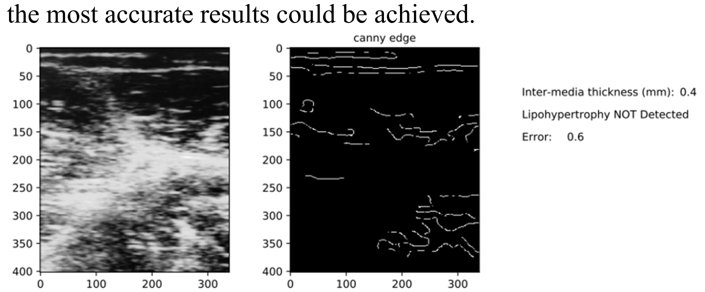




These were both images for LHT regions of the body of patient 1, type 1 diabetic. The closed loop system was able to determine that LHT was present in both of these images. As shown it is extremely prominent in the first image, and this is due to increased amount of injections in this region. The algorithm was able to find the IMT of both of these scans.

NON- LIPOHYPERTROPHY TESTING

To determine if the algorithm would be able to run in both environments, where Lipohypertrophy is not present would have to be tested. This patient had no Lipohypertrophy present, shown in the scan. This patient was tested in the same area of thigh so the most accurate results could be achieved.



As you can see, the IMT was only 0.4 mm, which is normal for someone who has muscular thighs; this difference is huge. The closed-loop system was able to determine where there was LHT and where there wasn't. This closed-loop system can be implemented into doctor's offices.

4.10 CLINICAL EVALUATION

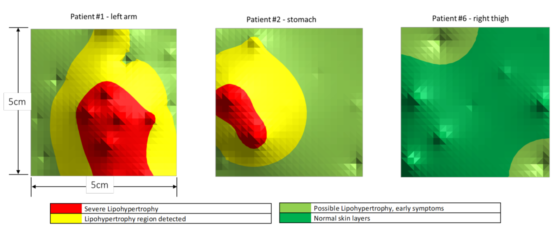
There were 10 patients in the clinical evaluation study, 5 people with diabetes and 5 people without diabetes. Both of these patients were scanned in regions of the body were most injections take place such as the arms and thighs. These regions were scanned in a 5 cm by 5 cm area and results were gathered. Each of the patient's inter-media thickness was determined by the algorithm.

A confusion matrix was created based upon the results gathered from the study, verified by licensed professionals.

CONFUSION MATRIX		Target	
		Positive	Negative
Model	Postitive	81	12
	Negative	5	58
		Sensitivity	*Specificity*
		94%	17%
		Accuracy	89%
		Error rate	11%

The algorithm had a high accuracy of 89% which supports the study hypothesis. Therefore the primary and secondary objectives were met, meaning that this device is an accurate detection system for Lipohypertrophy detection.

Along with creating a confusion matrix of the results each of the individual patients had an optimal injection contour map created. This contour map shows where injections should be given or where injections should not be.



This contour map shows three different patient and how specific regions of their body is affected by Lipohypertrophy.

Overall, the study was a success since the real-time detection system was able to meet all of the primary and secondary objectives. This means that the detection system meets the claim that it is an accurate and reliable model for detecting Lipohypertrophy in Insulin Dependent Diabetics.

V. CONCLUSION

The results demonstrate a real-time detection system for automatically detecting Lipohypertrophy in people with insulin dependent diabetes. This is proven through the Clinical Evaluation. The system developed was able to meet all of the criteria and constraints along with the primary and secondary objectives of the study. This means that the detection system is an accurate means of diagnosing Lipohypertrophy in people with insulin dependent diabetes. As a next step for the project, many more patient images are required to implement machine learning algorithms to further improve accuracy of lipodetect algorithm.

Application of this detection system is feasible in doctor offices as of today. This system can detect and notify patients of optimal injection regions along with undetectable and severe Lipohypertrophy. This can significantly improve the overall HbA1C, thereby reducing diabetes related complication in patients.

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