



3D reconstruction with Kinect to evaluate neck lymphedema

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BSc Report

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July 2019

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1 Introduction

Lymphedema is a condition of localized fluid buildup and tissue swelling caused by a damaged lymphatic system. Therapy consists of manually lymph drainage, compression therapy or bandaging. However, this therapy is still insufficiently substantiated in the neck area because there is no highly reliable instrument to measure the degree of change in the neck volume. A frequently practised method is using a measuring tape to acquire the circumference of the neck, or bio-impedance to measure the amount of fluid in the neck.

For this project, the goal is to replace the current methods of measuring by 3d reconstructing the neck using a Kinect as depth sensor. This will result in a 3D model of the neck which will be used to measure the volume of the neck more accurately. When using two different 3d models at different times the amount of change will also be measured, this is to give the doctor a better indication of the status.

The research questions that will be dealt with in this project:

- How many images from different angles need to be taken to create a point cloud that can be used for detecting lymphedema?
- How accurate and precise is this method for detecting change in volume in the neck area caused by lymphedema?

In chapter 2 the background of the situation will be further elaborated, in chapter 3 the problem is analysed, chapter 4 consists of two solutions, chapter 5 contains the results from these two solutions and this is discussed and concluded in the last two chapters.

2 Background

According to NCI (2017), neck lymphedema is a side effect of the removal of lymph nodes due to cancer. If the lymph nodes are removed, the flow of lymph may be slower and the lymph could collect in the tissues, causing swelling.

As it was told in the introduction there is no highly reliable instrument to measure the degree of change in the neck volume. The current method consists of measuring the circumference of the neck which gives an indication of the volume in the neck. This procedure is done by a doctor with a measuring tape. This procedure is error-prone since it relies on the doctor. What they usually do is have the same doctor do the tape measurement at defined intervals since a different doctor might use a slightly different location which influences the diagnosis. For bio-impedance the same as the tape measurement occurs, the doctor has to take the measurement exactly at the same locations every defined interval.

The measurement is done with a specified positioning protocol. The setup is outlined according to paper Purcell et al. (2016):

1. Body position on the bed: lying face up, no pillow, crown of head aligned with the bed edge.
2. Head position: head aligned to form a 90° intersection between a ruler and a set square. Set square: horizontal edge on the bed perpendicular to the subject; 90° corner closest to the subject; vertical edge aligned with the inferior margin of the tragus. Ruler: place the ruler at the patient's inferior nose resting against the base of the spine of the nose.

This position can be seen in figure 2.1

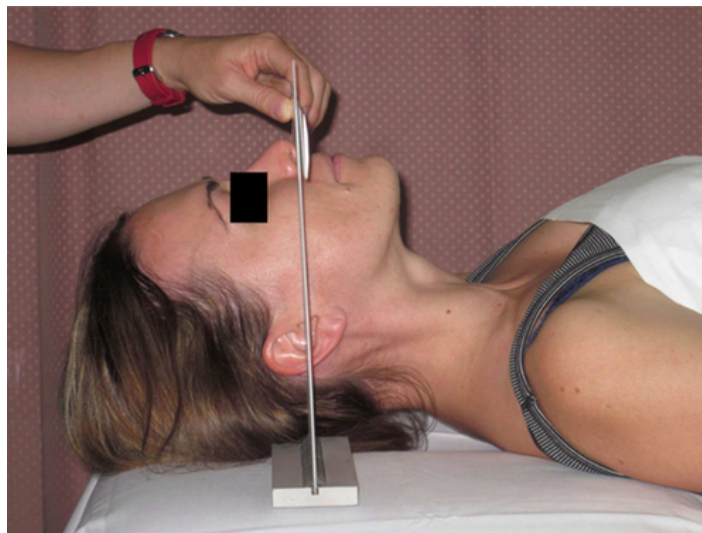


Figure 2.1: Set up position (Purcell et al., 2016)

The measurement tape was used to get the following measurements:

1. Lower neck circumference.
2. Upper neck circumference.
3. Length from ear to ear.
4. Length from lower lip edge to lower neck circumference

All these measurements are there to get an indication of the volume of the neck. The goal is to replace the old method mentioned above and replace it by calculating the volume of the neck using 3D imaging tools.

3 Analysis

The problem is that there is no reliable instrument to measure the status of neck lymphedema. The solution will be to calculate the volume using a different way of measuring using the Kinect camera.

3.1 Doctor meeting

Halfway when working on the thesis a meeting with Dr. C.M. (Caroline) Speksnijder from UMC Utrecht was conducted. During this meeting, a small demo was given about what could be realized using the Kinect. During the meeting, she gave some feedback on the current plan on determining the status of neck lymphedema. The plan at that time was to use one image and conduct the same measurements as mentioned in the background section. Her advice was instead of using those measurements use the volume of the neck to determine the status of neck lymphedema. This was based on the fact that when lymphedema is located at the arms, the method to determine the status is by submerging the arm in water to measure its volume. In order to get the volume of the neck a full 3D is required, and to do this more than one depth image is required. That is why from that point the focus of the thesis was on creating a full 3D using two different angle images.

3.2 The Kinect

The Kinect is a gaming accessory made by Microsoft made for the Xbox 360 platform. There are two versions of the Kinect, Kinect v1 and Kinect v2. The first version of the Kinect uses infrared light pattern projections, while the second version uses a time of flight method according to Immotionar (2018). The Kinect v2 projects infrared light and on return determines the phase shift to calculate how long the light beam has been traveling. The Kinect v2 is the one used for this project. Besides the Kinect there are other methods of obtaining depth information, namely:

- Real Sense by Intel (2018), this is a depth sensor similar to the Kinect. It can be extended to also estimate its position using an accelerometer and gyroscope. This can be useful when reconstructing a full 3D model by moving the camera.
- Stereo vision, this method uses two cameras and by finding the same points in both the images the depth can be estimated using trigonometry.

The Kinect was used above Real Sense because the Kinect was already available, and since both almost behave the same this is not an issue. Stereo vision is very susceptible to surrounding conditions because it has to find the same point in both pictures. Creating a good and reliable depth image using stereo vision is already worthy of creating a thesis about.

Current researcher have already done some work using the Kinect, below a couple of them are listed:

- ReconstructMe by Heindl et al. (2015), this is a software that creates real-time 3D models. This method is not available for Kinect v2 but only for Kinect v1 and some other imaging tools. ReconstructMe uses the accelerometer that is present on the Kinect v1 to estimate the location of the camera and merge depth images based on this.
- KinectFusion by A. Newcombe et al. (2011), this uses Iterative Closest Point (ICP) to merge the depth images in real-time.

These methods are all about constructing a full 3D model of a scene or object. KinectFusion would be perfect for the application to determine the status neck lymphedema but unfortunately is not open-source.

3.3 Merging of point clouds

To create a full 3D model of the neck to calculate the volume, multiple depth images need to be merged. A couple of methods can be used for this:

- Point cloud registration, this was used for KinectFusion where they used ICP to register the point cloud to a reference frame. ICP minimizes the difference between two point clouds by transforming one point cloud iteratively. Once a minimum has been found the transformed point cloud can be merged with the reference point cloud.
- When the camera position is already known compared to the reference frame the transformation matrix does not have to be found using point cloud registration. The transformation matrix can simply be calculated and applied to the point cloud to merge it into the reference frame.

For merging the point clouds the second option has been chosen. When using ICP, or any other method of registering a point cloud, both point clouds already require to be very similar. In our case, not more than two point clouds will be used, which means that the point clouds are not that similar. In our case, the camera position compared to the human body is fixed, namely the front of the patient and the back.

3.4 Measurements on one angle point cloud

When only one depth image is taken it results in a one angle point cloud. This means that with this method the volume can not be calculated, but half of the circumference of the neck can be. Half of the circumference of the neck might still give information about the status of the neck lymphedema. To get half the circumference of the neck the edge points of the neck first have to be found to conduct the measurement. To get these points two methods are presented below:

- Take the derivative of each row of the image and find the two peaks in the derivative with the highest prominence. The prominence of a peak measures how much the peak stands out due to its height and its location relative to other peaks. Collect all these points and conduct the measurement.
- Use the points shown above to find an average depth of the edges. Then find the two points that match this depth as closely as possible for each row.

After some testing, the first option gave a decent result but it varied too much, the depth of each point was inconsistent. That is why the second option was introduced, this option gives all the points at the same depth and makes the measurement more consistent.

3.5 Measurements on 3D point cloud

When two depth images are taken and also merged into one 3D point cloud, the measurements can be conducted. To get the volume of the neck the area of each slice from top to bottom will first be calculated. Then a choice has to be made on where the neck begins and where it ends, this can be done by getting some reference points from the image. The reference points that can be used can be shown below:

- In the graph of the area of the patient the minimum can be found, this minimum corresponds to the minimum area of a layer from the neck of the patient. After this, the begin- and endpoint can be a fixed distance up and down of this minimum point. The advantage

of this is that it is a simple method and reliable in a normal situation. The disadvantage is that neck lymphedema can cause swelling exactly at this minimum point which causes the minimum to shift and make the results unreliable.

- Before calculating some more specific points can be found first. For example, the lower lip can be a beginning point and the collarbones the endpoint. This would be a more reliable option when the neck starts swelling compared to the previous option. But this requires finding reliable points in a depth image, the lower lip is doable but the collarbone is hard to detect.

The first option was chosen because it is a simple solution to test how accurate and precise the solution is. But when it will be implemented to determine the status of neck lymphedema the second method has to be implemented.

4 Design

In this chapter, the final design of two different methods will be further elaborated. The first method is using one depth image to conduct measurements on, the second method merges two depth images to conduct measurements on.

4.1 One angle point cloud

In this section, a method for conducting measurements on a single angle point cloud will be explained. It is assumed that one imaging session was taken before, which will be used as the reference to compare with. This reference depth image is a depth image taken right after cancer has been removed. This image used for this can be seen in the result section. The flow of this method can be seen in the flowchart shown in figure 4.1.

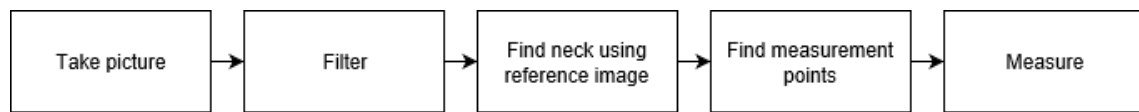


Figure 4.1: Flowchart of the method using one depth image

4.1.1 Position of the patient

The image will be taken from the front, this is due to lymphedema causing swelling mostly on the sides and front of the neck. The patient has to be standing in front of the camera at a fixed distance of one meter from the camera. The setup can be seen in figure 4.2.



Figure 4.2: Camera set up and patient location

4.1.2 Filtering

The depth image that has been taken has to be filtered to remove false measurements. This is done by detecting outliers using the function `filloutliers()` in MATLAB (2019). The function defines outliers as follows: An outlier is a value that is more than three scaled median absolute deviations (MAD) away from the median. The MAD is defined as:

$$\text{MAD} = \text{median}(|A_i - \text{median}(A)|) \quad (4.1)$$

and the scaled MAD: $\hat{\sigma}$, which is a consistent estimator for the standard deviation, is defined as:

$$\hat{\sigma} = k \cdot \text{MAD} \quad (4.2)$$

The function will operate on each column of the image, which is the vertical axis. It will use a moving window for detecting the outliers. Once found it uses linear interpolation, based on surrounding points, to replace the point. The size of the window can be varied to achieve the best result without any outliers.

4.1.3 Positioning the neck

Before comparing the neck with the reference image, taken in the previous session, the neck has to be located in the current image. The neck from the reference image can be used as a tool to find the neck in the current image. This can be realized using the normalized correlation coefficient. The normalized correlation coefficient can be computed as follows:

$$c[m, n] = \frac{\sum_{k,l} x[k, l] h[m - k, n - l]}{\sqrt{\sum_{k,l} (x[k, l])^2 g[m - k, n - l] - \frac{1}{KL} \left(\sum_{k,l} x[k, l] g[m - k, n - l] \right)^2}} \quad (4.3)$$

where $x[k, l]$ is the image, $h[m, n]$ is the neck mirrored on the horizontal and vertical axis from the reference image. K and L the size of h and $g[m, n]$ is a impulse response with same size as h but filled with only ones. This $g[m, n]$ will sum all the pixels in the sliding window. The normalized correlation factor will have values between -1 and 1, the larger the value the larger the similarity. After this, the pixel with the highest correlation factor can be found. Once it is found the neck image can be used for further measurements.

4.1.4 Measuring

As mentioned in the analysis the method of getting the start and endpoints to measure half of the circumference was achieved by first taking the derivative of each row and finding the two peaks with the highest peak prominence. After these peaks have been found for each row in the depth image, the average depth of all these points will be calculated. When this depth is known, the two points that are closest to this value will be used as begin and endpoints for each row to measure from. Finding one of these points is done in the following way:

$$P = \min \left(\sqrt{(x_i - \mu)^2} \right) \quad (4.4)$$

Where P is the value of the point, x_i indicates the signal of one row, μ is the average depth of the points found using the derivative. This P has the value of the point and what is required is the index, so this can be found by simply searching for the point that has this value. This method is applied to one half of the image and then to the second half of the neck image, splitting the image in the horizontal axis. This results in two index points for each row, these are shown in the results section.

Once the points have been found the length from point to point for each row can be calculated. This is done using Pythagoras formula, and is done in the following way:

$$y = \sum_{n=0}^{N-1} \sqrt{1 + |x[n] - x[n+1]|^2} \quad (4.5)$$

Here y contains the length from point to point, $x[n]$ is the signal of one row, limited from the first minimum point to the last minimum point calculated using equation 4.4. This is done for each row and corresponds to half of the circumference of the neck, this can be seen in the result section.

4.2 3D point cloud

In this section, a method of constructing the point cloud will be explained using two different angles with reference to the human body. After that, measurements can be conducted on the point cloud. The flow of this method can be seen in the flowchart shown in figure 4.3.

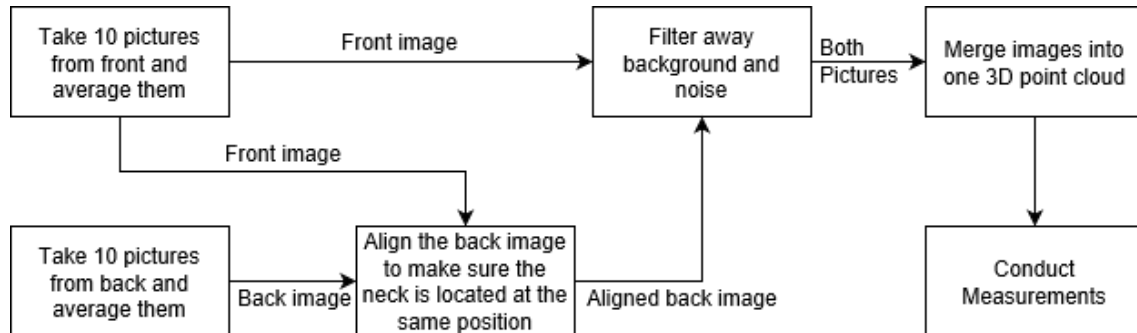


Figure 4.3: Flowchart of the method using images from two angles

4.2.1 Position of the patient

For the first image the patient is facing the camera directly, and the second image the patient is rotated 180 degrees. The patient has to be located in both situations (front and back) at exactly the same position except rotated 180 degrees. This was done by using a rotating platform and rotate the platform by 180 degrees with the patient standing on the platform. The platform is located one meter away from the camera similar to the one angle point cloud. The method is the same as in the one angle point cloud (figure 4.2) except for a rotating platform.

4.2.2 Combining

The next step is taking the pictures, this can be realized using the Image Acquisition Toolbox from MATLAB (2019). Instead of taking one picture from one of the angles, multiple will be taken from one of the angles. The number of pictures taken is 10, with the frame rate of the Kinect of 30 Hz this will take one-third of a second. These 10 pictures will be combined into one by taking the average of each pixel. This will cause some noisy points at the edges of the person, but these will be filtered out. Combining the images is done both on the front and the back images.

4.2.3 Matching

After combining images two images are the results, the front, and the back. These images contain the patient and the background, the background has to be removed. We know that the patient is located one meter away from the camera, which will make the filtering the background out a lot more simple. Assuming that the patient's head and neck are not larger than one meter in diameter, everything that has a depth value of larger than 1.5 meters and smaller than 0.5 meters can become zeros. For the matching part, it is better if these numbers are zero since the normalized correlation coefficient will give a better result. The back image will be shifted over the front image to find where they have the highest correlation. The back image is shifted according to where the highest correlation is.

4.2.4 Filtering

In the matching part, the background has already been replaced by zeros, but in order to transform the image into a point cloud, these have to be removed. This can simply be done by detecting which are zero and deleting them. This already results in a decent point cloud of the patient from one angle, but there is still noise from merging the multiple images and from mea-

surement error. This can be filtered by detecting and removing outliers, an outlier is detected by first calculating the standard deviation from the mean of the average distance to neighbors of all the points, second is analyze if its value is above a specified threshold. The neighbors are the k-nearest points where k can be varied. In MATLAB (2019) this can be realized by using the function `pcdenoise()`, which applies this to a point cloud object. These two parameters, number of neighbors and threshold, can be adjusted until all the noise has been removed. We have to make sure that the filter did not remove points that are necessary for doing the measurement. Now the same has to be done for the back image to create a point cloud of the back.

4.2.5 Merging

Now there are two point cloud, one from the front and one from the back, and these have to be merged. The merging is done with the following steps:

- Equalize the means of both the point clouds, this can be realized by subtracting the difference in mean of the point clouds from the back point cloud. The reason for doing this is that there is no way for us to know what the exact center is of the patient. A reference point is necessary to merge the point clouds, and also a link between the point cloud and the reference should be know. The mean as a reference for the point clouds is very stable since it removes most variations.
- Rotate the back point cloud 180 degrees, this can be realized using a transformation matrix that rotates around the y-axis, which is the vertical axis. The matrix to rotate around the y-axis can be seen below:

$$R_y(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \quad (4.6)$$

where theta is the angle, which is 180 degree in this case. Because of the rotation around the y axis the depth values are negative. A simple absolute of the depth values will fix this.

- Combine the two point clouds, the means are the same for both point clouds which means they are overlapping. To fix this a fixed distance between the two point clouds are created. This distance is a parameter that can be set at the beginning of the code and alters the resulting volume quite a lot (because you are changing the spacing between the two point clouds). This is not a problem as long as it is a constant distance for all future measurements of the patient.

This procedure results in a nicely formed point cloud from two angles, this can be seen in the result section.

4.2.6 Neck volume

After creating a 3D point cloud the volume can be measured. This is done by scanning from top to bottom over the vertical axis and collecting all the areas of each slice. The area of each slice can be measured using the following formula:

$$A = \frac{1}{2} \sum_{n=0}^{N-2} (x_n + x_{n+1})(y_n - y_{n+1}) \quad (4.7)$$

Then the complete volume can be calculate as follows:

$$V = \sum_{n=0}^N A_n \Delta y \quad (4.8)$$

where A_n is the area of each slice, and Δy the height of each slice. But the complete volume is not what we need, only the volume of the neck is required. That is why a start point and an endpoint is required. How this is done is explained in the results section, and so is the results of this method.

5 Results

In this chapter results of the two methods will be illustrated. First, the method of using one image to measure half of the circumference of the neck. Second, the method of using two different angles and merging the images into one to calculate the volume of the neck.

5.1 One angle point cloud

The results of the first method of using one image from one angle will be demonstrated here.

5.1.1 Reference depth image

As mentioned before, the depth image focused on the neck will be used as a reference for locating the center of the neck in future check-up sessions. The reference image can be seen in figure 5.1.

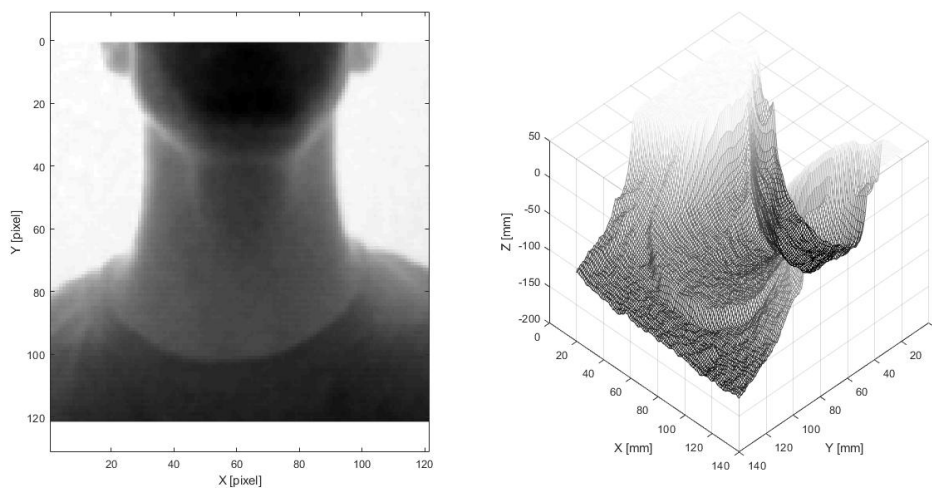


Figure 5.1: The reference neck used for finding center of the neck, left is the 2D version and right is a mesh of the same depth image in 3D

5.1.2 Measurement points for circumference

The points that will be used to measure half the circumference of the neck can be seen in figure 5.2.

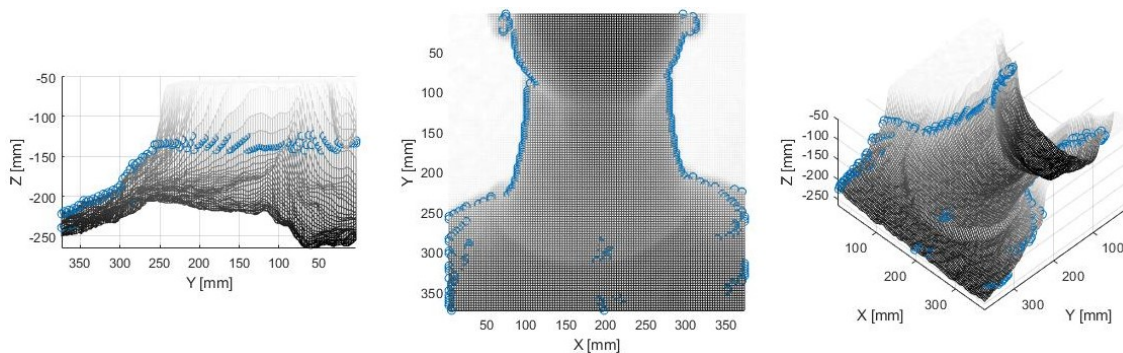


Figure 5.2: The points that are used to measure half the circumference of the neck from different angles

It can be seen that the points align all around the same depth. They do not exactly align because there are no points closer to the average depth. It can be improved by using linear interpolation between the points larger and smaller than the average depth. This will result in points all exactly at the same depth. This was not yet implemented due to the change of focus to the 3D point cloud. It can also be seen that after $y \approx 80$ the neck has ended. This value can also be found by inspecting the derivative since after $y \approx 80$ the peaks will have a smaller value. So by determining when the peaks of the derivative cross a certain threshold, this point can be found. For the resulting circumference, this point is used as the endpoint.

5.1.3 Resulting circumference

After this the half the circumference has been calculated from point to point shown in figure 5.2. This was done using equation 4.5 and the result can be seen in figure 5.3.

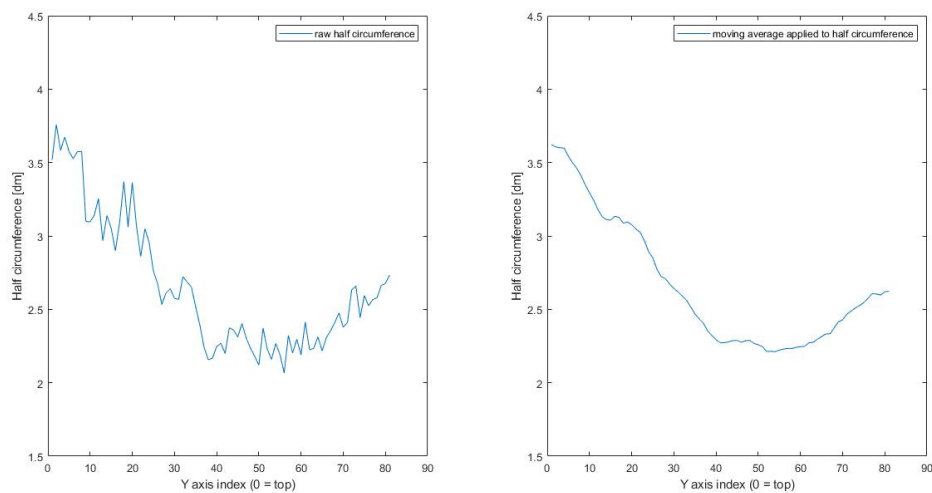


Figure 5.3: The raw circumference (left) and a moving average applied to the raw circumference (right)

It can be seen that the raw data still contains a lot of noise. But after applying a moving average over the signal the noise has been mostly removed. The noise in the raw circumference is due to the fact that all the measurement points are not exactly at the same depth. This can be improved by using linear interpolation between two points, where the first point is smaller than the average depth value and the second larger. The right image of figure 5.3 can be used to store as reference for the next session. By overlapping this reference and the next session's result anomalies can be detected. This has not been done in this thesis since the focus changed to obtain the volume of the neck using a full 3D point cloud.

5.2 3D point cloud

Because of the doctor meeting, who preferred to see results based on the total volume of the person, the model to conduct measurements on will be created using two different pictures from different angles. This will create a full 3D point cloud. In this section, it is shown how it is done.

5.2.1 Before and after filtering

First, ten pictures from one angle will be taken and merged together (explained in the design). After ten pictures have been taken and merged together, some noise remains, this is removed by filtering. The filtering includes removing background and removing noise, removing the background is simple so it is not shown here. The filtering of the noise is applied separately on

the front and the back image, in figure 5.4 the filtering result of the front point cloud can be seen.

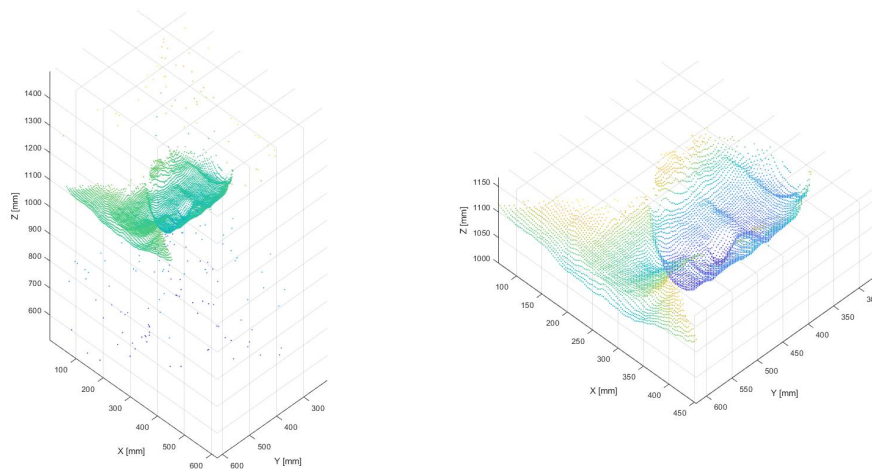


Figure 5.4: Before filter (left) and after filtering (right)

5.2.2 Full 3D point cloud of the patient

The filtering is done and applied to the front and back point cloud. The two images are aligned with each other as explained previously. The next step is merging the two point clouds together to make a full 3D point cloud. This can be seen in figure 5.5

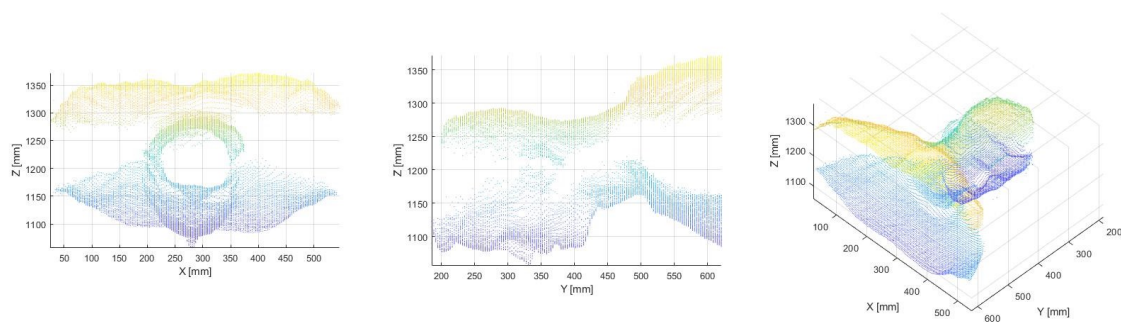


Figure 5.5: A complete 3D point cloud of the patient viewed from three different angles

5.2.3 Area of the neck

From the full 360 point cloud of the patient, the area of each layer from top to bottom can be measured. The result of this can be seen in figure 5.6.

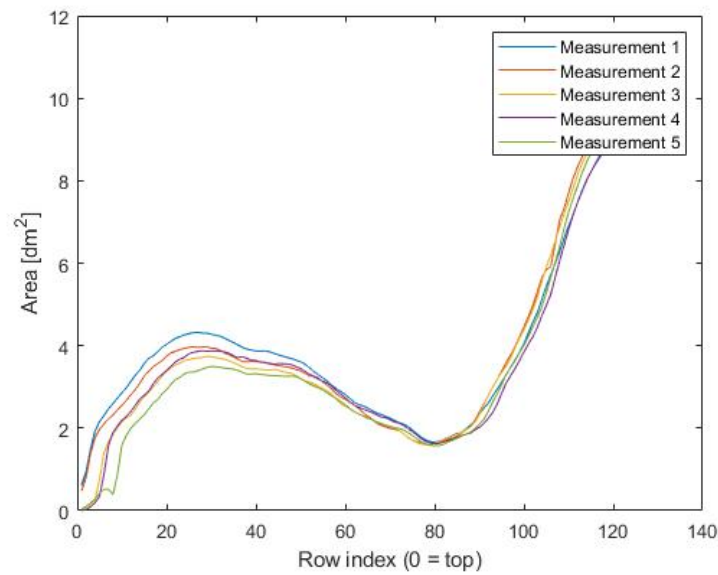


Figure 5.6: Area of the total point cloud of the patient from top to bottom

In the figure, the local minimum corresponds to the neck area since this is the smallest area of the patient when it is evaluated from top to bottom. It can be seen that at this local minimum the area of all measurements are overlapping quite accurately. In order to calculate the volume of the neck only, a starting point and an endpoint are required. This start point and endpoint is based on the local minimum of the neck. Once this point is found a value based on the prominence of the peak will be used to find the start and endpoint, the best way to show this is in figure 5.7

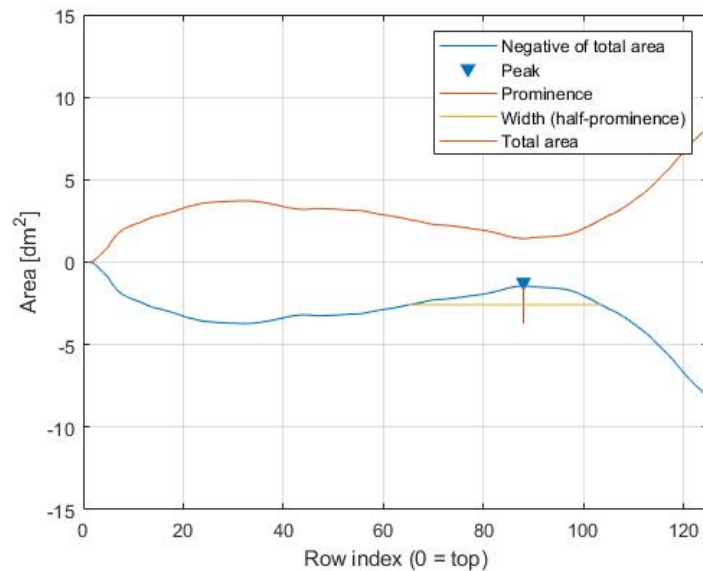


Figure 5.7: Displaying the method of narrowing down the neck area to calculate the volume

This is done for each of the signals in figure 5.6, and this results in figure 5.8.

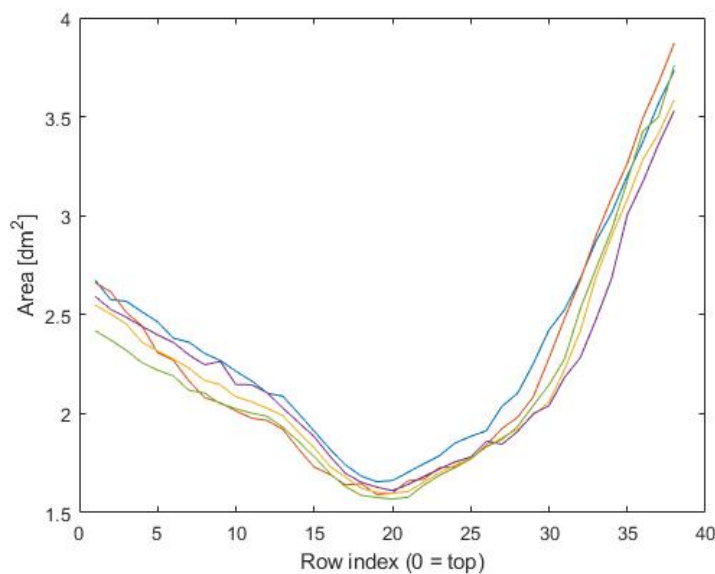


Figure 5.8: Narrowed down neck

This method shifts the areas according to the minimum point and overlaps them. The last step is multiplying each value by Δy and sum these values together. This results in the volume of the neck in dm^3 which is the same as liters.

5.2.4 Accuracy and Precision

Precision can be determined by statistical variability, and accuracy can be determined by measuring how close the result is to the true value. To test these properties of the system the following test and calculations will be conducted:

- 10 measurements will be taken of the patient without anything attached to the neck
- 10 measurements will be taken of the patient with something attached to the neck. The thing that is attached to the neck will be clay, where the volume is measured beforehand.
- The volume will be calculated for all these measurements. After that, the standard variability will be calculated, which will give an indication of the precision.
- The difference in the average volume of the first 10 measurements and the second 10 measurements will give an indication of the accuracy.

The clay that was used has a simple shape that can be attached to the neck. The clay can be seen in figure 5.9.

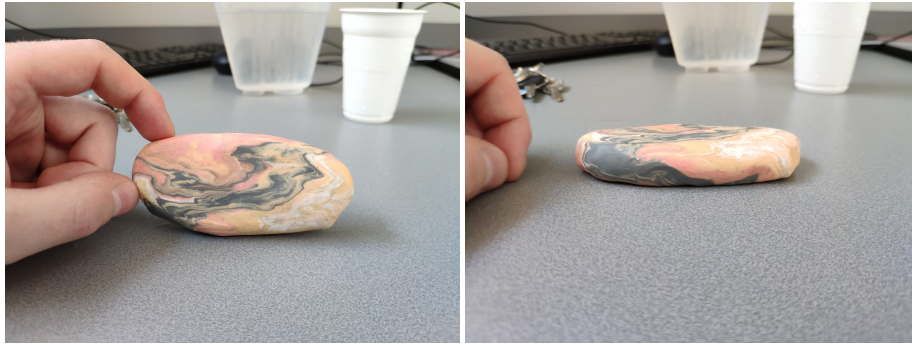


Figure 5.9: The shape of the clay from the top and the side

The method of measuring the volume of the clay is by submerging it into a measuring cup. This can be seen in figure 5.10.

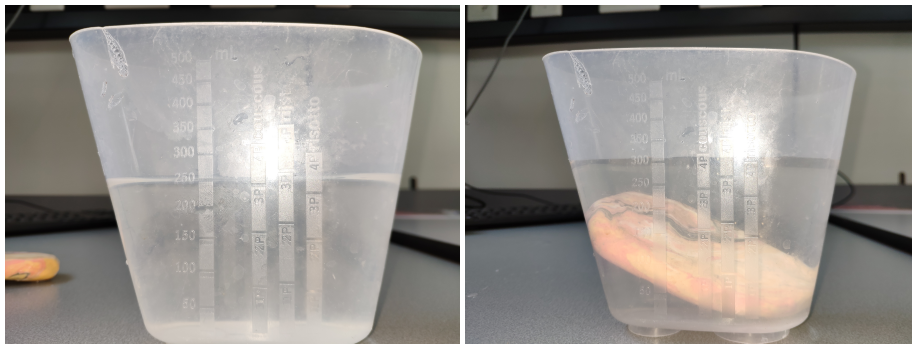


Figure 5.10: The water before submerging (top), the water after submerging (bottom)

With these two images, the difference in the water level is equal to the volume, which is approximately 60 ml.

The result of the method explained at the beginning of this subsection can be seen in table 5.1 below.

Measurement nr.	Normal (without clay) [dm^3]	Abnormal (with clay) [dm^3]
1	1.7451	1.8177
2	1.7195	1.7845
3	1.7633	1.9109
4	1.7212	1.7504
5	1.6651	1.7720
6	1.6864	1.7765
7	1.7054	1.7777
8	1.6809	1.7422
9	1.7079	1.7190
10	1.7488	1.7558
SD σ	0.0317	0.0530
Mean μ	1.7143	1.7807

Table 5.1: Table containing the measurements

The complete statistics can be seen in table 5.2 below.

Average Standard Deviation [ml]	42.4
Difference in mean [ml]	66.3
Error [ml]	6.3
Error [%]	10.5

Table 5.2: Statistics of the measurements

In the discussion section, these results will be further discussed.

6 Discussion

The aim of the experiment was to compare two different methods of getting volume information about the neck. One was using a depth image from one point of view, and the second using two depth images from two points of view. The second aim was to see how accurate and precise the method is compared to real life. To do this a piece of clay with known volume was used and attached to the neck. Afterward, the volume of the neck with the clay was measured and compared with a previous measurement without the clay.

From figure 5.3 it can be seen that the raw data from using a single image is very noisy. This noise is due to not using linear interpolation between the points. This method has not been thoroughly tested to evaluate if it can detect a change in the circumference of the neck. From figure 5.8 it can be seen that this method using two images contains a lot less noise compared to the method using a single image.

From table 5.2 it can be seen that the accuracy is slightly off by 10.5 % compared to the real volume. This might be due to some wrong estimations in the system, and also due to the Kinect not seeing everything. The estimation that was made is that each pixel corresponds to a certain amount of millimeters in real life. This was converted using a constant factor estimated beforehand, it is possible that this factor is slightly deviated from what it should be. The second thing is that the clay used was not completely flat, so when a picture was taken by the Kinect it is likely that some of the clay's shape was changed due to shadowing in the depth image. This can only increase the volume of the clay just like what the results show since it shows 6.3 ml larger than it should be.

The precision of the system was determined using the standard deviation. The standard deviation of the system is 42.4 ml, which is 17.6 ml smaller than the real volume of the clay. This is problematic if only one measurement would be taken since it is possible that the doctor will neglect the status of the lymphedema or over-exaggerates the status of the lymphedema. That is why the suggestion is to take multiple measurements for each session and estimate the average. This will give a better indication of the status due to the accuracy of the system.

7 Conclusion and Recommendations

7.1 Conclusion

The current method of using a measuring tape to detect the status of lymphedema in the neck is inconsistent and is prone to human error. The method of using two images from different angles has an error of 10.5 % compared to the real volume when taking multiple measurements. The first research question in the introduction is *'How accurate and precise is this method for detecting a change in volume in the neck area caused by lymphedema?'*. This method is able to detect if the status of the patient is improving or declining since this directly relates to volume increasing/decreasing. There is no real measurable quantity that exists at the moment to determine the status of the neck lymphedema, that is why it is impossible to say when the volume increase/decrease is problematic. The doctor can determine if something is problematic, but hopefully, the change in volume in the neck is a good indicator.

The second research question is *'How many pictures are required from different angles to create a model that can be used for detecting lymphedema?'*. A model created from one angle caused a lot of noise to be on the resulting circumference. However, a model created from two angles caused good results, but can be improved, since the point cloud still contains a lot of points missing at the neck area. A point cloud created from three angles will result in a solid point cloud.

7.2 Recommendations

What should be improved in a future version of this method is a couple of things listed below:

- The setup uses two angles to construct a 3D point cloud. This can be increased to three since it can be seen in figure 5.5 that the point cloud has a gap in the middle which contains no points.
- The constant used to convert pixels into millimeters should be calculated from the image itself. This can be done by getting a reference object in the depth image where the area is known of.
- The method used for finding a feature based on the minimum area of a layer from the neck should be improved. The minimum area of a layer from the neck can shift due to swelling caused by lymphedema. This can cause the problem that a wrong comparison can occur between two check-up sessions. A better method would be by finding a fixed reference point that does not change due to swelling in the neck. For example, the nose or lower lip can be used for this.

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