

A low cost 3D laser-line scanner for facial acquisition

Arnold Bijman, s1483382, student Bachelor Electrical Engineering

Abstract—Biometric recognition can provide a high level of security, while offering convenience to the user. One way to perform biometric recognition is to perform facial recognition. Using 3D information in facial recognition can improve the performance of facial recognition over conventional 2D facial recognition. To perform 3D facial recognition, a 3D reconstruction of the face has to be available. Because most commercially available 3D scanning solutions that have a sufficient accuracy for performing facial recognition are often expensive, it was decided to make an open-source 3D laser-line scanner that can be used for facial acquisition.

In this work, the theory behind the workings of a laser-line scanner will be discussed. Then the setup of the scanner system that is used will be introduced and several aspects of the system will be discussed. To improve the accuracy of the scanning system, an automatic calibration procedure is designed. To process the captured data and construct a 3D point cloud, a software back-end that performs laser-line detection in the captures images, and computes the corresponding points in space needs to be build. The different aspects of the software back-end will be discussed and explained.

After the software back-end has been discussed, the scanning system is characterized and the accuracy is tested. Then some recommendations are given to improve the accuracy and robustness of the system.

Index Terms—3D scanner, laser-line detection, sub-pixel

I. INTRODUCTION

Biometric recognition can help to provide a high level of security while offering convenience to the user. Biometrics promise us access metrics that cannot be stolen and are hard to copy compared to a conventional password. One of the promising ways to provide security is facial recognition. Facial recognition, that often relies on 2D data, can be tricked to circumvent the security. The performance of 2D facial recognition is often hampered differences in pose, lighting or expressions [1]. It has been found that facial recognition using 3D data can be made more secure and harder to trick than 2D facial recognition methods [3]. In order to perform 3D facial recognition, a 3D scan of a persons face has to be obtained. Commercially available 3D scanners are often either expensive or they have a low resolution.

Therefore, it was decided to build an open source 3D face scanner. A sufficient accuracy is needed to perform 3D recognition, since it relies on the geometry of the face [1]. The targeted accuracy is 0.5 mm. For this set-up to be a viable alternative to commercially available 3D scanners, the system must be relatively cheap.

The technique chosen for this 3d face scanner is laser-line scanning. This choice is made because a laser-line scanner can be made relatively cheaply, compared to most other techniques, since no specialist hardware is needed. This technique can also be made accurate enough for our purpose. A more extensive discussion of scanning techniques and the choice for laser-line scanning can be found in the work of T. Post [4].

This project has been taken on by several other people in the past. These are T. Post [4], C. Karaliolios [5], A. Douma [6] and R.Plompen [2]. Over the course of these projects, the system set-up has evolved. For this project, the physical set-up of the system is left as last build by R. Plompen. The contribution of the author to this project consists of building the software that performs the calibration of the system properties and the software for performing a scan. The goal of this part of the project is to get the system into a state where a scan can be performed. Also, the accuracy of the system will be evaluated.

In this paper the set-up of the system will be discusses, as well as the theory behind the workings of the scanner. Then the calibration procedure for both the intrinsic and extrinsic properties of the camera will be discussed. After that, several aspects of the processing of a scan will be discussed and explained. Some tests will be presented after that, and finally, a discussion will be given.

II. THEORY

A. Basic principle laser-line scanner

A 3d laser line scanner uses at least one laser line and a camera to reconstruct points in space. These points can be uniquely determined using triangulation. The laser-line projector projects a laser line onto the scanned object. This laser line can be either horizontally or vertically projected. The camera then captures a picture

of the illuminated object. The laser-line projector has to be at an angle with respect to this camera. Due to the geometry of the scanned object, the laser line will deform. The location of points on the laser line in the captured image is then determined. Using this information and the angle of the laser-line projector with respect to the camera, the points in space corresponding to the points on the laser line in the image can be determined using triangulation. To scan an entire object, the laser-line projector will have to sweep the entire object, and this has to be captured by the camera. The distance between the laser line position in subsequent pictures will dictate the resolution in the direction of the laser-line projector movement.

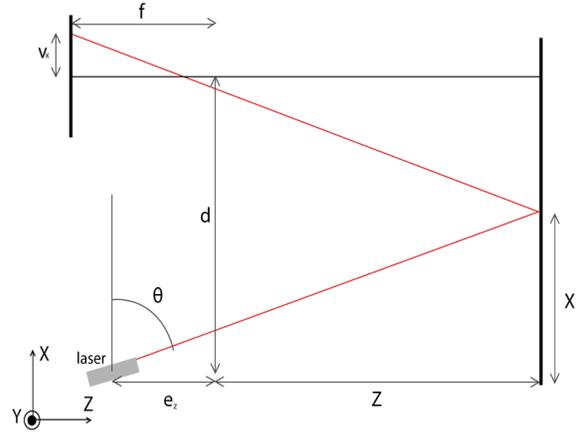


Fig. 1: schematic side view scanner

B. Reconstruction

Using the captured pictures of the projection of the laser line onto the scanned object and the physical positions and orientations of the camera and the laser-line projector and the camera properties, the points in space can be calculated. Figure 1 and 2 give a schematic overview of the system when performing a scan. Knowing theta, e_z , d and the camera properties, the x , y and z coordinates can be uniquely determined.

Using figures 1 and 2, the relations between the parameters x , y and z and the parameters found in figures 1 and 2 can be found.

From figure 1 the following relations can be found:

$$\cot(\theta) = \frac{X}{Z - e_z} \quad (1)$$

$$\frac{d - X}{Z} = \frac{-v_x}{f} \quad (2)$$

From figure 2 the following relation can be found:

$$\frac{Y}{Z} = \frac{-v_y}{f} \quad (3)$$

By rewriting and substituting (1), (2) and (3) the expressions for x , y and z can be found.

$$X = \frac{f \cdot d + e_z \cdot v_x}{v_x + f \cdot \cot(\theta)} \cdot \cot(\theta) \quad (4)$$

$$Y = \frac{v_y \cdot (d - e_z \cdot \cot(\theta))}{v_x + f \cdot \cot(\theta)} \quad (5)$$

$$Z = \frac{f \cdot d - f \cdot e_z \cdot \cot(\theta)}{v_x + f \cdot \cot(\theta)} \quad (6)$$

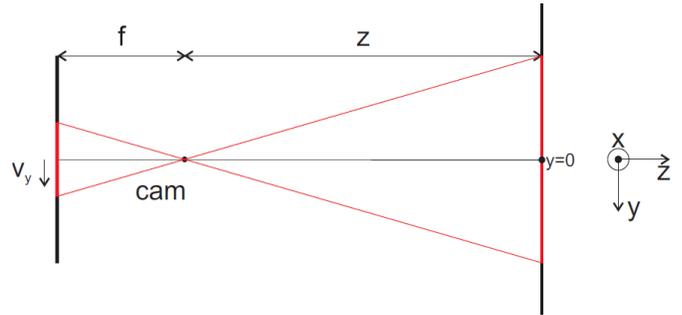


Fig. 2: schematic top view scanner [4]

III. SCANNER SETUP

The system set-up consists of a Raspberry Pi 2¹, a 5MP Raspberry Pi compatible camera board², a geared stepper motor³ and a stepper motor controller⁴. A python script running on the raspberry pi handles the brightness of the laser-line projectors, the rotation of the stepper motor and the capturing and storing of the images. A photo of the system setup can be seen in figure 3

The used camera, uses an Omnivision OV5647 sensor⁵. This sensor has a maximum output resolution of 2592 x 1944 pixels, with a pixel size of 1.4 um. The current system set-up does not use the full resolution, instead the resolution used is 1440 x 1080. This resolution image is

¹<https://www.raspberrypi.org/products/raspberry-pi-2-model-b/>

²<http://www.sainsmart.com/sainsmart-wide-angle-fish-eye-camera-lenses-for-raspberry-pi-arduino.html>

³<http://www.mclennan.co.uk/datasheets/14625451673453689415.pdf>

⁴<http://www.ti.com/tool/drv8846evm>

⁵<http://www.ovt.com/uploads/parts/OV5647.pdf>

obtained by capturing a picture using maximum sensor area and then scaling it back to the desired resolution. The used camera module has a field of view of 33.7 by 22.8 degrees. At a distance of 50 cm, this results in a captured area of 30 by 23 cm.

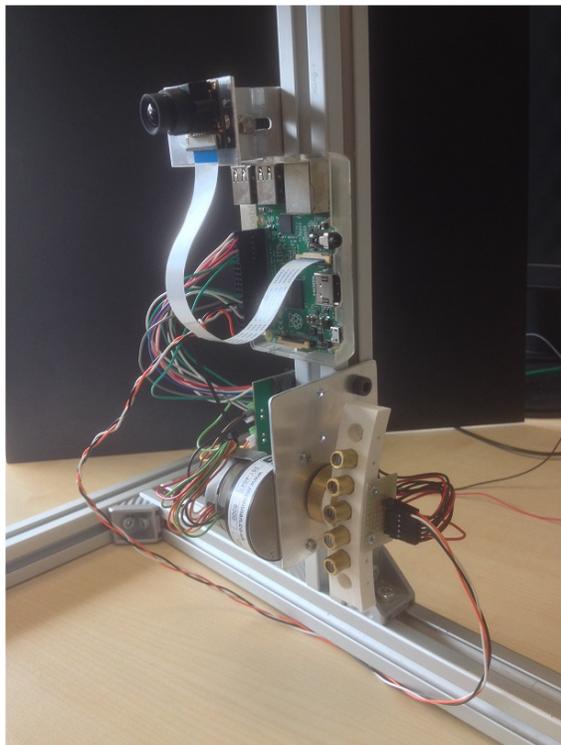


Fig. 3: photo of the scanner, taken from [2]

A. Multiple laser-line projectors

To speed up the process of scanning a face, five instead of one laser-line projectors are used. Figure 4 shows a schematic overview of the five laser-line projectors, mounted on the stepper motor.

Because of the way the 5 laser lines are set up, the d and e_z from the calculations are no longer purely defined by its physical place. The laser-line projectors are placed with an angle difference of 4 degrees, in a circle pattern. The circle from this pattern has a designed radius of 0.17. When the laser lines move in the process of scanning, d and e_z change. This has to be corrected for. These parameters can be calculated from the location of the turning points versus the camera. $e_{z,step}$ and d_{step} are known by the physical layout of the scanner. e_z and d can be calculated using formula (7) and (8) respectively [2].

$$e_z = e_{z,step} + \sin(\theta) \cdot r \quad (7)$$

$$d = d_{step} + \cos(\theta) \cdot r \quad (8)$$

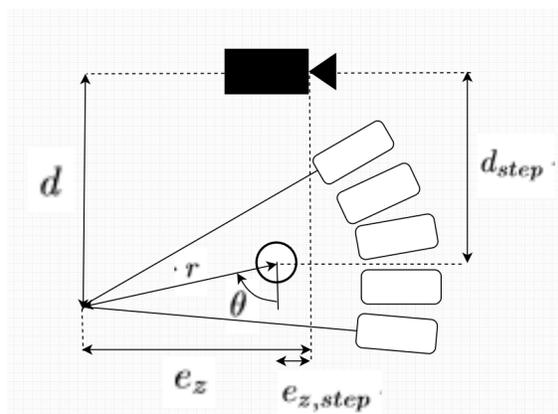


Fig. 4: schematic view multiple laser-line projectors, taken from [2]

IV. CALIBRATION

A. Intrinsic calibration

Cameras often show distortion in the captured images, with calibration this can be corrected for. Distortion in the images will negatively influence the accuracy of the scanner. To reduce the distortion in the captured images, the images need undistorting. To undistort the images, the camera matrix containing the distortion parameters needs to be obtained. To obtain this camera matrix, the camera needs to undergo intrinsic calibration. After a calibration procedure is performed, the distortion in the captured images can be corrected for. The calibration is performed using the OpenCV [8]] camera calibration routines. These calibration routines are based on a method proposed by Zhang [7]. Using multiple images (at least 3) which contain a chequered board in different poses with respect to the camera, the radial and tangential distortion coefficients are calculated, as well as the scaled versions of the focal lengths and the optical centre of the image. Images that are captured during the scanning procedure can be undistorted using the OpenCV library in combination with the camera matrix containing the aforementioned distortion parameters.

B. Extrinsic calibration

Before conducting the first scan, the starting angles of the laser lines with respect to the camera position has to be known. For this, a calibration procedure is needed. T. Post [4] has observed that when a scan is made of a flat surface, the resulting reconstruction is not flat. Instead of the reconstruction being flat, like the scanned surface, the

reconstruction shows a wave pattern in the Z direction. With a calibration routine, this can be corrected for.

The calibration procedure is based on what is described in [2]. A flat surface is put in parallel with the camera lens. On this flat surface, a chequered pattern is placed. First a picture of this surface is taken with the laser-line projectors turned off. Then the camera will perform a scan of the flat surface, meaning it will turn on the laser-line projectors, take a picture, then change the angle of the laser-line projectors and take a picture again. This is done until the whole surface is swept. The number of steps taken by the stepper motor depends on the vertical resolution needed. The images will have to be undistorted using the parameters found in the intrinsic calibration.

1) *Initial angles:* Before a scan can be performed, the starting angles of the laser-line projectors has to be known. For this it is needed to know what the distance Z between the lens of the camera and the flat surface is. This can be calculated using properties of the camera and the chequered board. Using the width of a chessboard vertex in pixels Y_{px} , the known physical size of the vertex Y_{cp} , the focal length f in mm, the width of the image sensor W_{sp} in mm and the image width in pixels W_{px} , Z can be calculated using formula (9) [2].

$$Z = \frac{f \cdot Y_{cp} \cdot W_{px}}{Y_{px} \cdot W_{sp}} \quad (9)$$

Before a scanning procedure can be performed, the starting angles of the laser-line projectors has to be known. Once a calibration is completed, the angle can be determined by looking at how many steps in which direction has been taken since the last calibration.

The middle laser line has to be determined first, since the angle of this laser line determines the e_z and d for all laser-line projectors. Finding this angle with the corresponding e_z and d is done iteratively. By iteratively increasing or decreasing the angle theta, and calculating e_z and d using formulas 7 and 8 and filling in the variables into (6), the angle for which Z is equal to the Z determined using formula (9) is the starting angle of this laser line.

Because the mechanical structure holding the laser-line projectors is not perfect, the angles of the other laser-line projectors cannot be assumed to be 4 and 8 degrees more or less than the angle of the middle laser-line projector. Because of this imperfection in the mechanical structure, the radius r that determines the value of d and e_z cannot be assumed to be exactly 0.17 meters.

To find the starting angles of the laser-line projectors and their radius r , two points with Z_1 and Z_2 are needed for each of the laser-line projectors. Since the angle of

the middle laser-line projector is not affected by the value of r , the middle laser-line is used to compute the angle difference $\Delta\theta$ between the two points.

$$Z_1 = \frac{f \cdot d_1 - f \cdot e_{z_1} \cdot \cot(\theta_1)}{v_{x_1} + f \cdot \cot(\theta_1)} \quad (10)$$

$$Z_2 = \frac{f \cdot d_2 - f \cdot e_{z_2} \cdot \cot(\theta_2)}{v_{x_2} + f \cdot \cot(\theta_2)} \quad (11)$$

By filling in the expressions for d and e_z from formula (7) and (8), where θ becomes γ , and rewriting formula (11), the following expression for r can be found:

$$r = \frac{Z_2 \cdot (v_{x_2} + f \cdot \cot(\theta_2)) - f \cdot d_{step} + f \cdot e_{z,step} \cdot \cot(\theta_2)}{f \cdot \cos(\gamma_2) - f \cdot \sin(\gamma_2) \cdot \cot(\theta_2)} \quad (12)$$

To find the correct radius r and the angle θ , θ_1 is increased or decreased until Z_1 is within a margin of the Z determined using formula (9). Z_1 is computed using formula (10), where d_1 and e_{z_1} are computed using formula (7) and (8). d_1 and e_{z_1} are computed using r , which is computed using (12), where $\theta_2 = \theta_1 - \Delta\theta$. This process has to be repeated for all laser-line projectors, except for the middle laser-line projector.

2) *Wave pattern:* The wave like pattern is due to a fluctuation in rotational speed. Figure 5 shows difference in angle of the laser line projectors between two consecutive captured pictures. Here the fluctuation in the angle difference between two subsequently captured images can be observed. This fluctuation in the angle difference causes the wave pattern in the scan of a flat surface.

To correct for the wave pattern observed, the angle differences between consecutive images has to be known. Since this angle difference will be equal for each of the laser-line projectors, only the middle laser-line projector angle has to be found. Using the same iterative process as described above, the angle can be found in each of the captured images. The angle difference can then be calculated and saved for use in a scan.

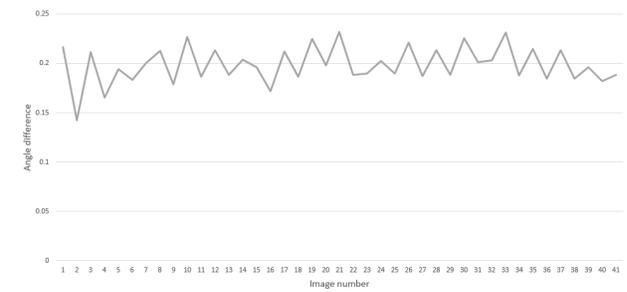


Fig. 5: Angle difference between two images

3) *Parallel surface*: The calibration procedure uses a surface parallel to the camera to determine the angles of the laser-line projectors and the angle differences between consecutive images. In practice however, it is very hard to make sure this surface is exactly parallel to the camera lens. To increase the robustness, repeatability and accuracy of the calibration procedure, the pose of the flat surface can be estimated and corrected for.

In the current implementation, the pose is estimated for vertical rotation. To further the accuracy of the distance measurement, the pose should be estimated for both vertical and horizontal rotation.

V. SCANNING PROCEDURE

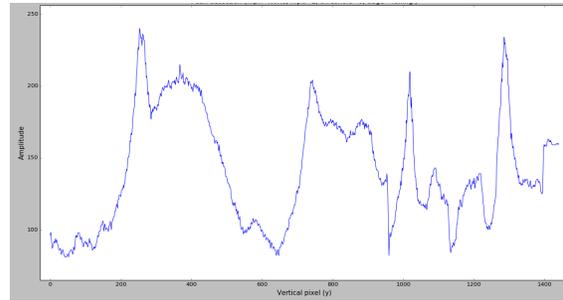
A. Angle synchronisation

In order to make an accurate reconstruction of the scanned object, the angle of the laser-line projectors has to be known accurately for each of the captured images. To this end, the amount of steps taken between each of the captured images is saved into a text file and read out at time of reconstruction. The laser scanner will capture an image, move the laser-line projectors, save the steps taken in a text file and repeat this until the scan is completed. It would be faster to move the laser-line projectors and capture the images simultaneously, however, this makes the synchronisation more difficult. Because of hardware limitations, it was chosen to not perform these tasks simultaneously [2].

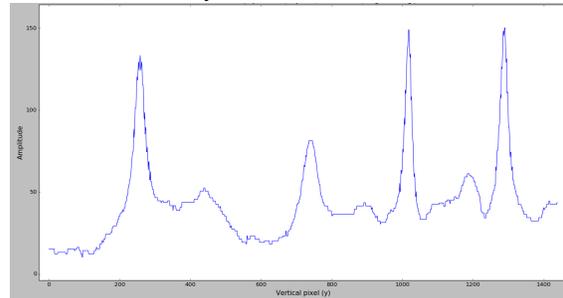
B. Line detection

1) *Pre-processing*: To perform laser line detection, the intensity levels of the pixels are used, and the peaks in these intensity levels are found. Light coming from the environment can cause problems when performing line detection, since this light can cause peaks in the intensity levels, while these peaks are not part of the laser lines. To increase the robustness of the laser line detection, and decrease the effect of light coming from the environment, one can make use of the fact that the red laser lines will be mostly present in the red channel and therefore only process the red channel. This is done by T.Post. Since white light is approximately equally present in each of the channels, white light can still cause peaks in the intensity levels from the red channel. This can lead to the detection of peaks that are not part of a laser line. To filter out the white light, the average of the green and blue channels is subtracted from the red channel. This way the light from the environment can be mostly filtered out. This results in better distinguishable peaks.

Figure 6a shows a plot of the intensity levels in one column in the red channel. 6b shows the same column,



(a) intensity levels column red channel



(b) intensity levels column red channel minus average blue and green channel

Fig. 6: intensity levels column

after the average of the blue and green channels has been subtracted.

2) *Detection*: To find the points from the laser line, the image is processed column by column. To find these points, the peaks belonging to the laser lines in the processed image columns have to be found. There are various ways to do peak detection. The algorithm should be efficient though, since it will have a large impact on the processing time.

The previously used algorithm for the detection of the laser lines was a constant threshold [2]. As the conditions, like lighting, in which the scan is taken is not always equal, a static threshold is not suitable for reliable peak detection. It is observed that the background intensity levels are not always equal throughout the image, therefore is a constant threshold throughout the image not sufficient for reliable peak detection.

To make the peak detection more robust, it was decided to use a running average to compensate for the changing background intensity levels. The running average for each point in the processed column is computed. To perform peak detection, a threshold is set. This threshold value is the running average at each point, to which a static threshold is added. The intensity values in the column are then compared to the threshold and the values that are higher than this threshold are reckoned to belong to a point on one of the laser lines.

3) *Sub-pixel accuracy*: With a targeted resolution in Z of 0.5 mm, physical size of the pixels should be maximum 1.14 μm [2]. The pixels on the used camera sensor however, have a pixel size of 1.4 μm . To be able to reach the target resolution in Z , the locations of the peaks have to be determined with sub-pixel accuracy. To estimate the peak location with sub-pixel accuracy, several methods can be used. One of the ways it can be achieved is by parabola fitting. This technique was also used by C. Karaliolios [5] in a previous version of the scanner. D. Kim, S Lee, H. Kim and S Lee [9] have compared three different methods of performing sub-pixel line detecting, including the parabola fitting method using by C. Karaliolios. It was found that when using more than 3 points to fit the parabola to, the performance of this method degrades. Using only 3 points as a representation of the found peak however, will not give an accurate result, since the shape of the peaks are not always smooth and can have ragged edges. Two other methods were tested, a weighted average and a normalized weighted average method. It was found that the normalized weighted average method performed best, while being less computational complex than the parabola fitting method. The normalized weighted average can be computed with (11), where w_{x+t} denotes the intensity levels of the peak.

$$x_{subpix} = \frac{\sum_{t=-n}^n (w_{x+t} - \min(w))(x+t)}{\sum_{t=-n}^n w_{x+t} - \min(w)} \quad (11)$$

4) *Missed points*: Because of the laser light getting reflected away from the camera on some steeply angled surfaces, the intensity of the laser line can be relatively low at points. At these points however, there is still a peak in the intensity level. To prevent detecting noise as a laser line point, the static part of the threshold cannot be set low enough to detect those peaks.

To detect these points but not detect the noise as a laser line point, information from the columns on either side of the processed column is used. The detected peaks are compared to the detected peaks in the columns on either side. If a peak that is detected in the columns on either side, but not in the column that is processed, part of the column around that peak location in the other column is again compared to a threshold, but then the static threshold is set lower. If a peak is detected with the new threshold, it is added to the detected peaks.

VI. RECONSTRUCTION

A. Working principle

Once the laser line points are detected, the 3D point cloud can be computed, using formulas (1) (2) and (3) from the *Theory* section. Because there are five laser-line projectors, the found laser line points have to be associated with the correct laser lines. If the wrong laser line is chosen, the location of the point in 3d space will be calculated incorrectly.

If all five of the laser line points in the column that is processed are detected, the points can be directly associated with each of the laser lines, and therefore the angles of the laser-line projectors. If there are less than five points detected however, there are multiple options to associate a laser line with each point. To know to which laser line the detected points belong to, for each possible combination of detected points and laser lines the distance Z is computed. 7 shows a schematic view of the laser-lines being projected onto the scanned surface, during a scanning operation. Four of the five laser lines get projected onto the scanned surface. If those four laser lines are detected, matching them with the laser line projectors can be done in multiple ways. Table I shows the possible ways to match detected points with the laser-line projectors, in case of four detected laser line points.

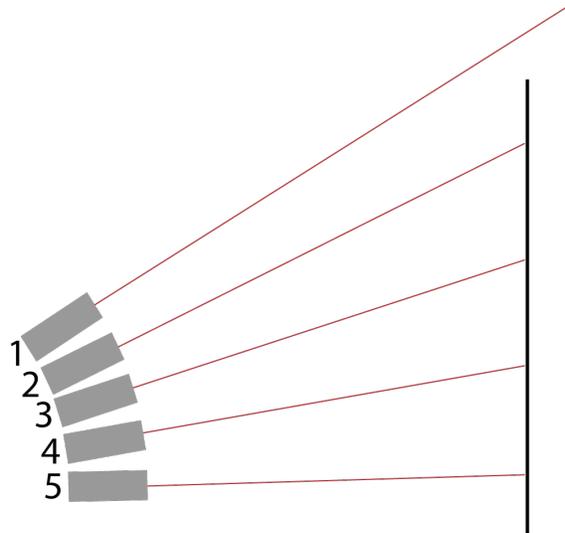


Fig. 7: Laser lines projected onto the scanned surface

TABLE I: Possible peak location and projector matches

	Choice 1	Choice 2	Choice 3	Choice 4	Choice 5
Point 1	1	2	1	1	1
Point 2	2	3	3	2	2
Point 3	3	4	4	4	3
Point 4	4	5	5	5	5

If less than five points are found, then there is often more than 1 combination of laser lines that will give a solution within the working range. Because the face is relatively flat, combinations that give a lot of spread in Z can be considered incorrect. Using the option that gives minimum spread in Z however, can still give incorrect solutions. Therefore, the average Z thus far is computed and the combination of laser line angles with the detected points that gives a solution that is closest to this average Z.

B. Occlusion

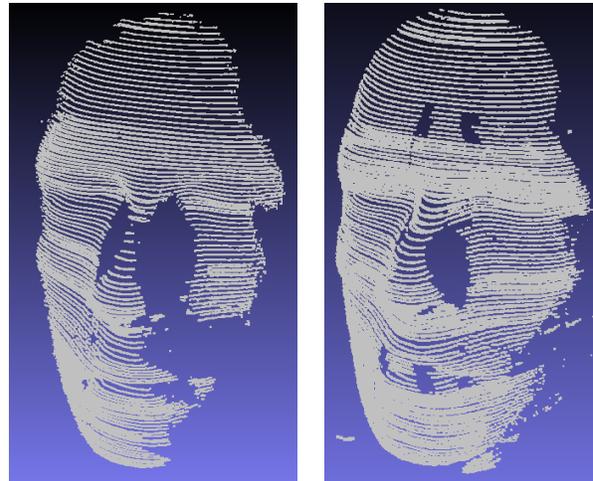
If the detected laser-line points are points from subsequent laser-lines, then not all possible combinations of points and angles have to be computed. Instead of computing every combination possible, only the solutions for subsequent laser-line projector angles have to be computed. Out of these computed distances, the best solution is determined using the above described technique.

Some parts of laser line might not be detected, while others in the same column are. If for the part of the laser line that is not detected there is detected a laser line that is lower and a laser line that is higher than it, then the detected laser line points are not points from subsequent laser lines. This typically happens because of occlusion or when the scanned surface has a large angle with respect to the camera, such that not enough light is reflected back to the camera. If this is the case, the first calculations of looking for subsequent laser-line projector angles will not give a solution with low enough spread in Z. If this is the case, all possible combinations of the detected laser line points and laser-line projector angles have to be considered. Then, out of all these options, the option that has least deviation from the average Z will be chosen.

VII. CHARACTERIZATION AND TESTING

A. Line detection

1) *Environment light:* If the light from the environment is bright, the detection of the laser lines can become harder. To test how well the laser line scanner works in a bright environment, a scan of a foam head is made in a bright room. The resulting reconstruction of the scan can be seen in figure 8a. It can be seen that parts of the nose and left cheek are missing. Figure 8b shows a reconstruction of the same foam head, but then the scan is made in a dimmer environment. When comparing the two reconstructions, it is clear that in case of bright conditions when performing a scan, the resulting reconstruction will miss more parts of the face.



(a) Scan in bright light (b) Scan in dim light

Fig. 8: 3D reconstructions

2) *Accuracy:* To test the accuracy, a laser line is projected onto a flat surface, within the working range of the scanner. The laser line points are then located and the laser line is reconstructed. The resulting laser line can be seen in figure 9. A linear approximation is made of the laser line, giving an approximation of the ideal projection of the laser line onto the flat surface. The difference between the approximation and the found laser line is then computed. This resulted in a maximum deviation of 0.972124 pixels. The corresponding deviation in Z is 0.83 mm.

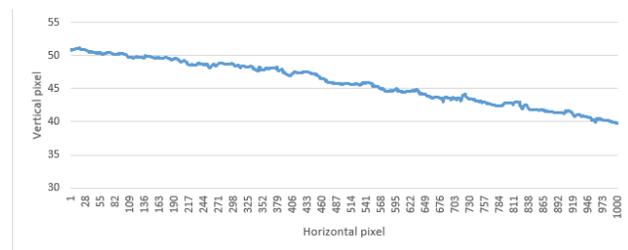


Fig. 9: Laser line

If a laser line is very bright in comparison to the environment, saturation can occur. This saturation will cause the bright red light of the laser line to be captured as white light in the picture. Because the white light will be mostly filtered by subtracting the average of the blue and green channels, these very bright parts of the laser lines will be filtered out as well.

An example of a captured laser line with saturation can be seen in figure 10. As can be seen in the figure, some parts of the laser line appears as almost white. The effect that the filtering of the white light has on

intensity profile of a peak can be seen clearly in figure 11. Figure 11a shows a peak in the intensity levels of the red channel. Figure 11b shows the same peak, but then in the filtered channel. It can be observed that the peak in the filtered channel has side peaks.



Fig. 10: Laser line

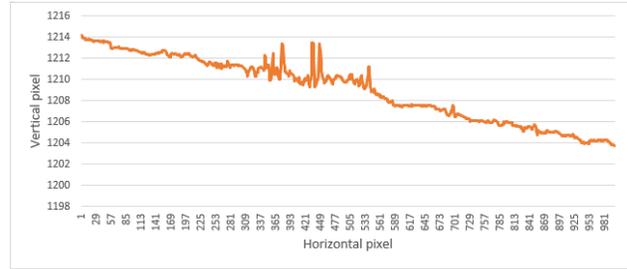
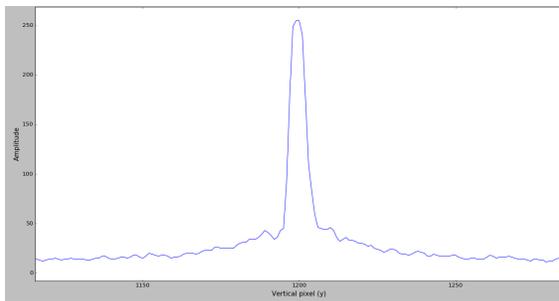
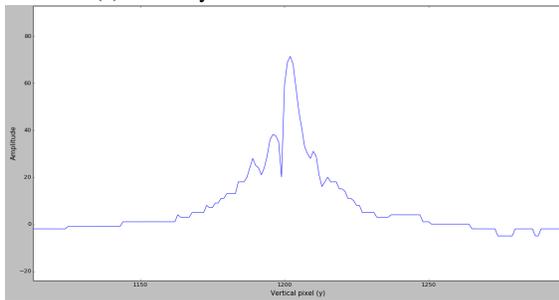


Fig. 12: Laser line when saturation occurs



(a) intensity levels column red channel



(b) intensity levels column red channel minus average blue and green channel

Fig. 11: Peak red and filtered channel

This changing of the intensity profile of the peak will cause the outcome of the sub-pixel computation to be different, since this profile is used for determining the sub-pixel location. The effect of this can be clearly seen in the laser line that is found. Figure 12 shows a laser line that is projected onto a flat surface. To find the deviation from the actual laser line, the laser line is approximated and the found laser line is normalized. The maximum deviation from the laser line normalized is 3.78 pixels. This gives a maximum deviation in Z of 2.95 mm.

B. Reconstruction

Because the algorithm that matches the detected laser line points with the available laser-line projector angles uses the average Z of all the points added thus far, and matches the new points to be as close to the new average as possible, a large relief in the scanned objects can give incorrect reconstructions. This becomes especially apparent when the laser line gets projected onto another object that is captured in the image.

Figure 13 shows a reconstruction of the authors face. In the top left of the figure, some points can be seen that are not part of the face. These points are part of a wall, behind the scanned face, that was visible in the images. Because the detected points are matched with the available laser-line projector angles to give minimal deviation from the average Z, the points are assigned an angle that gives the points a Z close the average.



Fig. 13: Reconstruction face author

VIII. FURTHER CONSIDERATIONS

A. Calibration

As stated in the *calibration* section, the horizontal rotation that the calibration surface has with respect to the camera is currently not corrected for. This rotation will cause the distance estimation using formula (9) to be inaccurate, since the width of the chessboard vertex in pixels will decrease with an increased angle of rotation. This means that when performing a calibration procedure care has to be taken to put the calibration surface close to parallel to the camera. Even then the calibration surface can be not placed perfectly parallel to the camera. This will cause the calibration to be less accurate. To improve the accuracy of the scanner, the rotation with respect to the camera in both vertical and horizontal direction should be corrected for.

The laser line projectors are assumed to project a laser line that is perfectly horizontal. In practice however, this will not be the case. Using calibration, this can be corrected for as well.

B. Movement

When making a scan of a human's face, movement of the head can give inaccuracies in the resulting reconstruction. For a reliable and accurate reconstruction of human faces, the scanned face needs to be totally still, or a correction procedure for the movement of the head needs to be performed. Another option to reduce the impact of human movement is to perform the scanning procedure more quickly. The bottleneck for the scanning speed in the current set-up is the rotation speed of the stepper motor.

C. Eye safety

Since the scanner is intended to be used for acquiring a 3D reconstruction of faces, the scanner needs to be eye safe. In this part of the project, eye safety is not considered. In further development of the scanner, eye safety will have to be considered. If the brightness of the laser-line projectors needs to be lowered, the scanner will miss more points if the scan is taken in a bright environment.

IX. CONCLUSION

The goal of this project was to build a software backend that would allow the system build by R. Plompen to perform a scan and to evaluate the accuracy of the system. To achieve this goal, first a calibration method needed to be implemented. The calibration method is based on the method proposed by R. Plompen, but it will give a more accurate approximation of the system

parameters. This will allow the system to be more accurate. There are however still improvements to be made in the calibration procedure. The current system will estimate the pose of the flat calibration surface, but only in the vertical orientation. If the flat surface is not perfectly parallel to the camera horizontally, the accuracy of the calibration, and therefore the facial scans, will suffer.

To allow the system to function in various operating environment, a robust laser line detection method had to be constructed. The method relies on filtering out white light out of the red channel to make the laser line detection more reliable. To make the laser line detection more robust still, a running average was computed and added to the threshold. It was found that if the scan is made in a bright environment, the laser line points are not always detected.

To test the accuracy of the scanner, a scan was made of a flat surface and the laser line projection onto this surface was found. It was concluded that the targeted accuracy of 0.5 mm is not achieved. It was also found that the reconstruction method falls short when there is a large differential in the depth of the different objects in the image.

REFERENCES

- [1] I. Kakadiaris, G. Passalis, G. Toderici, N. Murtuza and T. Theoharis. "3D Face Recognition". In Mike Chantler, Bob Fisher and Manuel Trucco, editors, *Proceedings of the British Machine Conference*, pages 89.1-89.10. BMVA Press, September 2006. doi:10.5244/C.20.89.
- [2] R. Plompen. "A low cost open-source 3D scanner for facial acquisition". 2016
- [3] C. Beumier. 3D Face Recognition. In: *Industrial Technology, 2006. ICIT 2006. IEEE International Conference on*. Dec. 2006, pp. 369-374. doi:10.1109/ICIT.2006.372385.
- [4] T. Post. A compact 3D laser scanner for facial acquisition. 2013.
- [5] Chrysostomos E. V. Karaliolios. Low Budget 3d laser-line scanner for facial acquisition. 2015.
- [6] A.T. Douma. A compact 3D laser scanner for facial acquisition - revised. 2015.
- [7] Z. Zhang. A flexible new technique for camera calibration. In: *IEEE Transactions on Pattern Analysis and Machine Intelligence* 22.11 (Nov. 2000), pp. 13301334. ISSN: 0162-8828. doi:10.1109/34.888718.
- [8] *Camera calibration With OpenCV*. OpenCV. Jan. 2017. http://docs.opencv.org/2.4/doc/tutorials/calib3d/camera_calibration/camera_calibration.html
- [9] D.Kim, S. Lee, H. Kim and S. Lee, "Wide-angle laser structured light system calibration with a planar object," *ICCAS 2010*, Gyeonggi-do, 2010, pp. 1879-1882. doi:10.1109/ICCAS.2010.5670184.