SaveVisions - Product Requirements Document

About the team

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Company: Alcon

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Introduction

What is the problem?

Last year, the Centers for Disease Control and Prevention (CDC) released a group of shocking statistics about common eye disorders. In the United States, there are approximately 12 million people who are at the age of 40 and over have vision problems and about 6.8% of teenagers under 18 years old have diagnosed vision impairments. Therefore, vision disability has become one of the most prevalent disabling conditions. Under this situation, reliable and professional eye surgeries are necessary so as to protect the patients' eye health.

Due to the small size of the eye area, eye surgery requires extreme precision. However, not all eye surgeons perform well during the surgery. According to the statistics, approximately 4 million cataract surgeries are performed each year in the U.S. with 1% of patients experiencing complications after surgeries. As a result, a

reliable scoring system should be designed to help the surgeons reflect on their past surgical performances so that they are able to improve technique in subsequent surgeries.

How is the problem addressed today?

A successful surgical performance of an anterior capsulotomy determines the optimal consequences of a cataract surgery. Anterior capsulotomy is regarded as ideal if it is round, well-centered as well as in an appropriate size. This largely depends on the techniques of surgeons. At present, some scoring systems already exist for assessing technical skills (TS) and non-technical skills (NTS) performed by the surgeons in ophthalmic surgery. There are nineteen scoring systems available for TS which can be applied to the steps of phacoemulsification as well as paediatric cataract surgery, such as the "International Council of Ophthalmology's Ophthalmology Surgical Competency Assessment Rubrics" (ICO-OSCAR) which is for phacoemulsification, and five scoring systems applied to score NTS which is used in cataract surgery and ophthalmic surgery. Nevertheless, none of the scoring systems can satisfy all the reliability and validity standards. Therefore, further research is needed in the future to verify the uniformity and reliability of all scoring systems in the category of ophthalmic surgery.

Objective, Implementation, and Assumptions

What is our objective and who will benefit from it?

Our objective is to develop a tool to score eye surgeons' and novices' performances during cataract surgeries, mainly focusing on the crucial step of the surgery: the capsulorhexis. This application is designed specifically to help eye surgeons and novices to evaluate how well they have performed in the surgeries and to be able to learn and improve by keeping track of their records and observing how

well other eye surgeons perform during the capsulorhexis process. In the end, it can serve as a tool to help surgeons perfect their surgical performance as much as they can such that there can be less people suffering from complications due to poorly performed capsulorhexis in cataract surgeries.

What are the core components of our solution?

Eye Detection

The eye detection algorithm will use the reflection of the surgical light as a reference to the center of the eye to detect the patient's eye during cataract surgery. Although the reflected light is not always exactly in the center, it is sufficient to provide an approximation location of the eye in the video, and utilizing this reflection, the algorithm will crop the video frames such that the eye is the main object in them. After cropping the frames, this algorithm will interact with the rhexis edge and approximation detection algorithms to compute the relevant parameters.

Rhexis Approximation Detection

As the rhexis that is formed may not be a circle and/or is not clear enough to be detected as a circle, this detection algorithm will detect the visible edges of the rhexis and trace out an approximated circle based on these edges. The estimated rhexis will be used to compute the following parameters of the capsulorhexis process: centration, diameter, and roundness. After tracing out an approximated circle around the rhexis, the algorithm will find the center pixel coordinate of the rhexis, which will be used to compare with the center of the iris to evaluate the capsulorhexis centration and to compute the diameter in pixel value. The surgical tool detection algorithm will pass to this algorithm the pixel to actual length of the tool that is in the same frame as the rhexis, then dividing the diameter pixel of the circle by the ratio, the actual diameter of the rhexis will be calculated. The roundness of the rhexis is determined by

the edges of the actual rhexis and the approximation: the errors will be calculated from taking the absolute differences of the actual rhexis and the perfect circle formed for the approximation.

Surgical Tool Detection

The surgical tool detection algorithm will be used to detect the tip of the tools during the capsulorhexis process of the cataract surgery. Once a tool is detected, its pixel measurement along with its real measurement will be computed into a ratio. This tool identification will then be used as a reference object to calculate the diameter of the rhexis using the ratio described above and this value is then passed to the rhexis approximation detection algorithm. In addition, it is also interacted with the capsulorhexis process time calculation algorithm to detect the start and end of the process.

Capsulorhexis Process Time Calculation

The duration of the capsulorhexis process will take the detection of the blade for the initial incision on the eye as the starting point and the last appearance of the suction tool removing the broken capsule of the lens as the ending point for the time duration calculation.

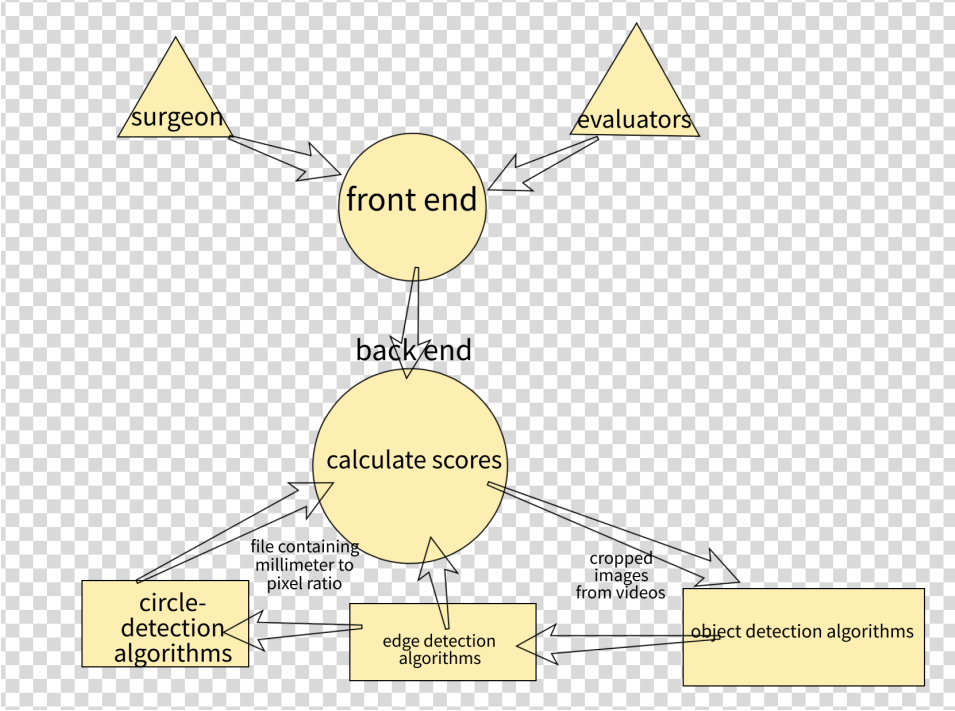
Capsulorhexis Performance Score Algorithm

This scoring algorithm will produce a score according to the parameters measured from the capsulorhexis process using the components described above. The score will be calculated based on the variance from the average parameters acquired from past procedures.

What are the necessary assumptions to be made?

1. The technology is assumed to be able to correctly capture the patient's eye, and nothing will obstruct the camera during the process.
2. The same or similar tools will be used during the capsulorhexis process.
3. Nothing goes wrong with the procedure upon the rhexis being produced.
4. Eye surgeons use similar steps of the capsulorhexis process as they perform the surgery.

System Architecture Overview



Since our program is designated to evaluate the performance of surgeons. Our front end will be a UI where users are able to input surgery videos and get scores. And in the back end, scores are calculated mainly using three algorithms. Firstly the object detection algorithms will detect tools of fixed length and output the cropped images from videos. Then the edge detection algorithm will measure the pixel length of tools and output a file containing millimeter to pixel ratio. And lastly the circle-detection algorithm will measure the pixel lengths of pupil and limbus in surgery. The main back-end algorithm will combine all these data and calculate scores of four parameters.

User Stories

User Story #1: As an eye surgeon, I can use the training algorithm model to determine the diameter of the rhexis. [est. time: 80 hours]

GithubLink: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/1

- **Scenario 1**: Rhexis is visible
    - Given the surgeon has removed the capsule of the lens(opaque part), the rhexis is produced and the algorithm accurately calculates the diameter of the rhexis.
- **Scenario 2**: Rhexis is not visible (capsulorhexis procedure has not been completed)
    - Given that there is no rhexis formed in the eye, the algorithm outputs a null value.

User Story #2: As an eye surgeon, I can use the training algorithm model to evaluate the roundness of the rhexis. [est. time: 80 hours]

GithubLink: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/2

- **Scenario 1**: Rhexis can be detected
    - Given the surgeon has removed the capsule of the lens(opaque part), the rhexis is produced, the model can detect it, and the model accurately calculates the roundness of the rhexis.
- **Scenario 2**: Rhexis cannot be detected
    - Given that the rhexis cannot be detected by the model, roundness cannot be determined. The algorithm will output a null value.

User Story #3: As an eye surgeon, I can use the training algorithm model to check how centralized the rhexis is compared to the centre of the iris. [est. time: 80 hours]

Github Link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/3

- **Scenario 1**: Rhexis is well-centered
    - Identify the centers of both the iris and the rhexis, circle them on the video.
    - Compare the position of the two center coordinates and measure the distance. The smaller the distance between the two points, the better it is centered.
- **Scenario 2**: Rhexis is not well-centered
    - Identify the centers of both the iris and the rhexis, circle them on the video.
    - Compare the position of the two center coordinates and measure the distance. The further the distance between the two points, the worse it is centered.
- **Scenario 3**: Rhexis cannot be detected
    - Given that the rhexis and/or iris cannot be detected by the model, centration cannot be determined. The algorithm will output a null value.

User Story #4: As an eye surgeon, I can use the training algorithm model to check the duration of time I spent during the capsulorhexis process. [est. time: 80 hours]

Github Link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/4

- **Scenario 1**: Both the start and the end of the capsulorhexis step are detected
    - Calculate the time difference between the start and end time.
- **Scenario 2**: The start of the capsulorhexis step is not detected

    - The algorithm will output a null value.
- **Scenario 3**: The end of the capsulorhexis step is not detected
    - The algorithm will output a null value.

User Story #5: As a surgeon, I can keep track of how many grasps it took me to use the forcep to remove the capsule of the lens during capsulorhexis. [est. time: 100 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/5

- **Scenario 1**: The eye surgeon is experienced, and one or two grasps are detected.
    - The eye surgeon will receive a perfect score for this parameter.
- **Scenario 2**: The eye surgeon is experienced, but four or more grasps are detected.
    - Usually novices take four or five grasps, so the eye surgeon's score for this parameter will be lowered corresponding to how many extra grasps he/she took.
- **Scenario 3**: The eye surgeon is a novice, but one or two grasps are detected.
    - The eye surgeon will receive bonus points on top of the perfect score for this parameter as he/she performs at an experienced level.
- **Scenario 4**: The eye surgeon is a novice, and four or more grasps are detected.
    - The eye surgeon will receive half of the perfect score for this parameter if four or five grasps were detected.
    - The score will be deducted from half of the perfect score corresponding to how many extra grasps it took the eye surgeon to remove the capsule of the lens.

User Story #6: As an eye surgeon, I can find historical data about my past surgeries in order to learn about how well I previously performed capsulorhexis. [est. time: 40 hours]

Github Link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/6

- **Scenario 1:** The eye surgeon has available scores and data about past surgeries.
    - The records for the eye surgeon's past surgeries are listed with the most up-to-date one on the top, and the oldest one on the bottom.
    - For each of the surgeries, eye surgeons can click on a surgery and see his/her score regarding the performance.
- **Scenario 2:** The eye surgeon has never performed any surgeries in the past or has no available data.
    - The message "No available records" will be displayed.
    - The eye surgeon will have the option to upload his/her surgery video(s) to the application, which will store the data and evaluate the surgeon's performance.

User Story #7: As a technician/manager, I can find historical data to check the overall capsulorhexis performances of the surgeons and obtain a trend line of how they perform overtime. [est. time: 40 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/7

- **Scenario 1**: History record successfully loads.
    - Given that the history record is available and is loaded, the algorithm generates a graph and displays it.
- **Scenario 2**: History record is unavailable.

    - An error message will be shown, and an option to reload data will be available.
    - After three attempts of loading data, a message saying "No history record is available, please upload new/existing data" will be popped up.

User Story #8: As a medical student, I can learn the Williams scalpel by the algorithm along with the video. [est. time: 20 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/8

- **Scenario 1**: Potential Williams scalpel detected
    - Place where potential Williams scalpel is located will be squared and label with "Williams scalpel"
- **Scenario 2**: Williams scalpel not detected
    - Warning message will pop up saying: "No Williams scalpels detected for the surgery"
    - This false could also influence the rhexis detection model to output the accurate approximation of the diameter of the rhexis

User Story #9: As a medical student, I can learn the marks of the position Williams scalpel cut into the pupil by the algorithm along with the video. [est. time: 40 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/15

- **Scenario 1**: Potential Williams scalpel detected and intersect is detected
    - Intersection cut will be marked and labeled by the algorithm
- **Scenario 2**: Potential Williams scalpel detected but intersect is not detected
    - Warning message will pop up saying: "No intersection is detected with the Williams scalpels detected for the surgery"

- **Scenario 3**: Williams scalpel is not detected
    - Warning message will pop up saying: "No Williams scalpels detected for the surgery"

User Story #10: As a medical student, I can learn the surgical forceps by the algorithm along with the video. [est. time: 20 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/16

- **Scenario 1**: Potential surgical forceps detected
    - Place where potential surgical forceps is located will be squared and label with "surgical forceps"
- **Scenario 2**: Surgical forceps not detected
    - Warning message will pop up saying: "No surgical forceps detected for the surgery"

User Story #11: As a medical student, I can learn the marks of the position surgical forceps interact with the pupil by the algorithm along with the video. [est. time: 40 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/17

- **Scenario 1**: Potential surgical forceps detected and potential intersected area is detected
    - Intersected area will be marked and labeled by the algorithm
- **Scenario 2**: Potential surgical forceps detected but potential intersected area is not detected
    - Warning message will pop up saying: "No intersection is detected with the surgical forceps detected for the surgery"

- **Scenario 3**: Potential surgical forceps is not detected
    - Warning message will pop up saying: "No surgical forceps detected for the surgery"

User Story #12: As a medical student, I can learn the phaco handpiece by the algorithm along with the video. [est. time: 20 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/18

- **Scenario 1**: Phaco handpiece detected
    - Place where potential phaco handpiece is located will be squared and label with "surgical sucker"
- **Scenario 2**: Phaco handpiece not detected
    - Warning message will pop up saying: "No phaco handpiece detected for the surgery"

User Story #13: As a medical student, I can learn the marks of the position phaco handpiece interacts with the pupil by the algorithm along with the video.[est. time: 40 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/19

- **Scenario 1**: Potential phaco handpiece detected and potential intersected area is detected
    - Intersected area will be marked and labeled by the algorithm
- **Scenario 2**: Potential phaco handpiece detected but potential intersected area is not detected
    - Warning message will pop up saying: "No intersection is detected with the phaco handpiece detected for the surgery"

- **Scenario 3**: Potential phaco handpiece is not detected
    - Warning message will pop up saying: "No surgical sucker detected for the surgery"

User Story #14: As an eye surgeon, I can use the algorithm to obtain the scores for each parameter of the capsulorhexis process in the cataract surgery. [est. time: 80 hours]

Github Link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/20

- **Scenario 1**: All parameters of the capsulorhexis have been obtained from the algorithm.
    - Each parameter is evaluated based on the average or previous record.
    - The capsulorhexis parameters are shown below the score, each compared to the average parameter values that were collected from past surgeries.
- **Scenario 2**: Some parameters of the capsulorhexis have been obtained from the algorithm.
    - Only the scores of the parameters that are detected are displayed.

User Story #15: As an eye surgeon, I can use the algorithm to obtain an overall score for the capsulorhexis process of the cataract surgery in order to evaluate my performance. [est. time: 100 hours]

Github Link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/13

- **Scenario 1**: All parameters of the capsulorhexis have been obtained from the algorithm.
    - Algorithm defines a weight for each error of the parameters and calculates the score. The eye surgeon's score is displayed.

    - The capsulorhexis parameters are shown below the score, each compared to the average parameter values that were collected from past surgeries.
- **Scenario 2**: Only some of the parameters were obtained from the algorithm.
    - Algorithm defines a weight for each error of the available parameters and calculates the score. The eye surgeon's score and a message indicating that the undetected parameters were not considered for the evaluation are displayed.

User Story #16: As a medical student, I can see scores for each parameter of previous surgery videos that are performed by the surgeons and learn from it. [est. time: 30 hours]

Github Link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/21

- **Scenario 1**: All parameters of the capsulorhexis have been obtained from the algorithm.
    - Each parameter is evaluated based on the average or previous record.
    - The capsulorhexis parameters are shown below the score, each compared to the average parameter values that were collected from past surgeries.
- **Scenario 2**: Some parameters of the capsulorhexis have been obtained from the algorithm.
    - Only the scores of the parameters that are detected are displayed.

User Story #17: As a medical student, I can see the overall score of previous surgery videos that are performed by the surgeons and learn from it. [est. time: 30 hours]

Github Link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/22

- **Scenario 1**: All parameters of the capsulorhexis have been obtained from the algorithm.
    - Algorithm defines a weight for each error of the parameters and calculates the score. The eye surgeon's score is displayed.
    - The capsulorhexis parameters are shown below the score, each compared to the average parameter values that were collected from past surgeries.
- **Scenario 2**: Only some of the parameters were obtained from the algorithm.
    - Algorithm defines a weight for each error of the available parameters and calculates the score. The eye surgeon's score and a message indicating that the undetected parameters were not considered for the evaluation are displayed.

User Story #18: As a technician/manager, I can find each score for the parameters in the capsulorhexis process of the historical cataract surgery. [est. time: 50 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/9

- **Scenario 1**: All parameters of the capsulorhexis have been obtained from the algorithm.
    - Each parameter is evaluated based on the average or previous record.
    - The capsulorhexis parameters are shown below the score, each compared to the average parameter values that were collected from past surgeries.
- **Scenario 2**: Some parameters of the capsulorhexis have been obtained from the algorithm.
    - Only the scores of the parameters that are detected are displayed.

User Story #19: As a technician/manager, I can find the overall score for the surgical performance in the capsulorhexis process of the historical cataract surgery. [est. time: 50 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/9

- **Scenario 1**: All parameters of the capsulorhexis have been obtained from the algorithm.
    - Algorithm defines a weight for each error of the parameters and calculates the score. The eye surgeon's score is displayed.
    - The capsulorhexis parameters are shown below the score, each compared to the average parameter values that were collected from past surgeries.
- **Scenario 2**: Only some of the parameters were obtained from the algorithm.
    - Algorithm defines a weight for each error of the available parameters and calculates the score. The eye surgeon's score and a message indicating that the undetected parameters were not considered for the evaluation are displayed.

User Story #20: As an eye surgeon, I can observe the rhexis with its edges clearly traced out as I perform the grasps with the forcep to form a circular path. [est. time: 150 hours]

Github link: https://github.com/PandaTeamCapstone21/alcon_capstone/issues/23

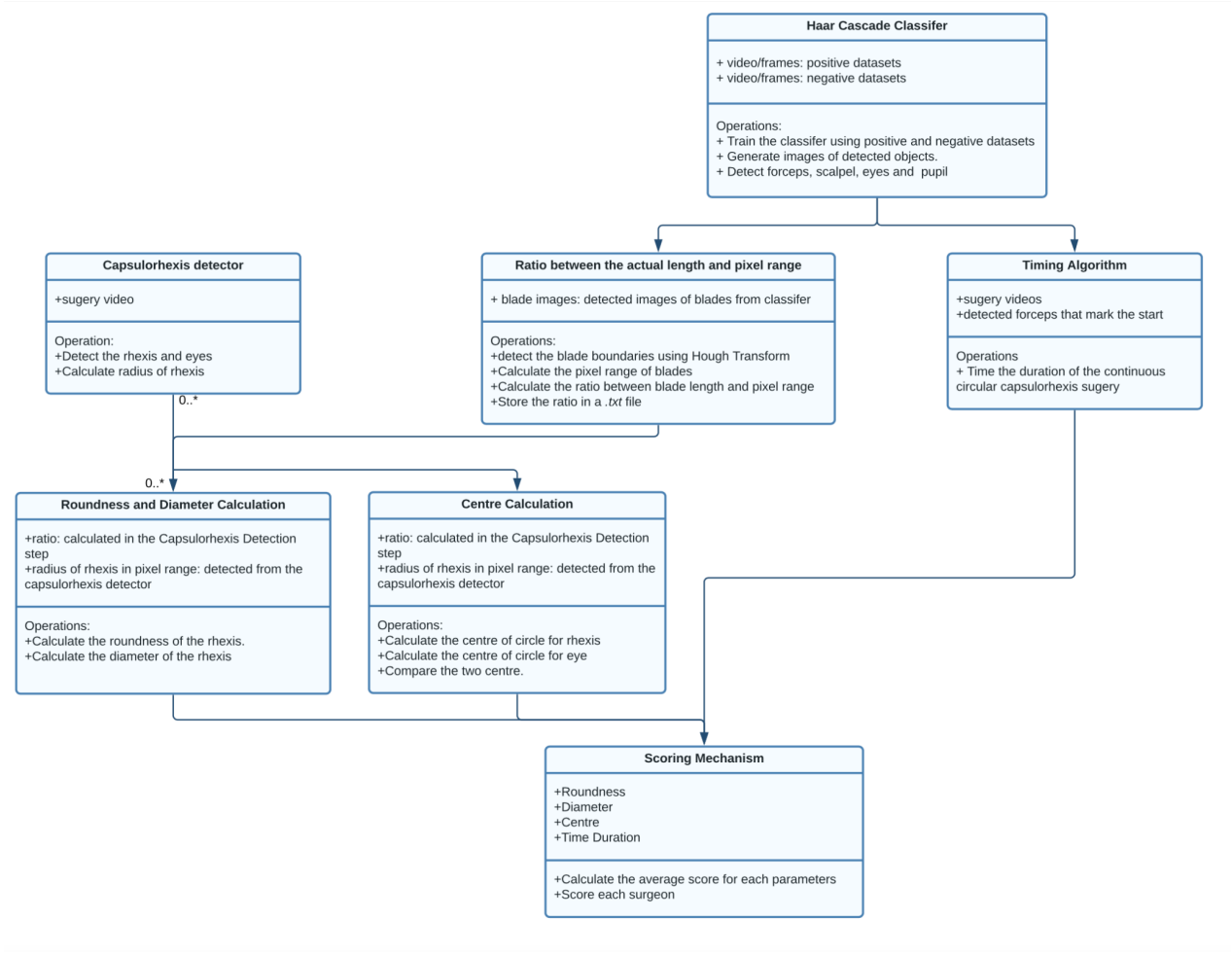
- **Scenario 1**: Forcep tip not detected.
    - Without the forcep tip being detected, no circular path can be detected. The algorithm returns nothing and shows an error message: "no available rhexis."

- **Scenario 2**: Forcep tip detected.
    - Once the forcep tip is detected as it is inserted into the eyes, the surgical tool detection algorithm will trace out the positions that the tip goes through and output the edges of the rhexis.

Sequential Model

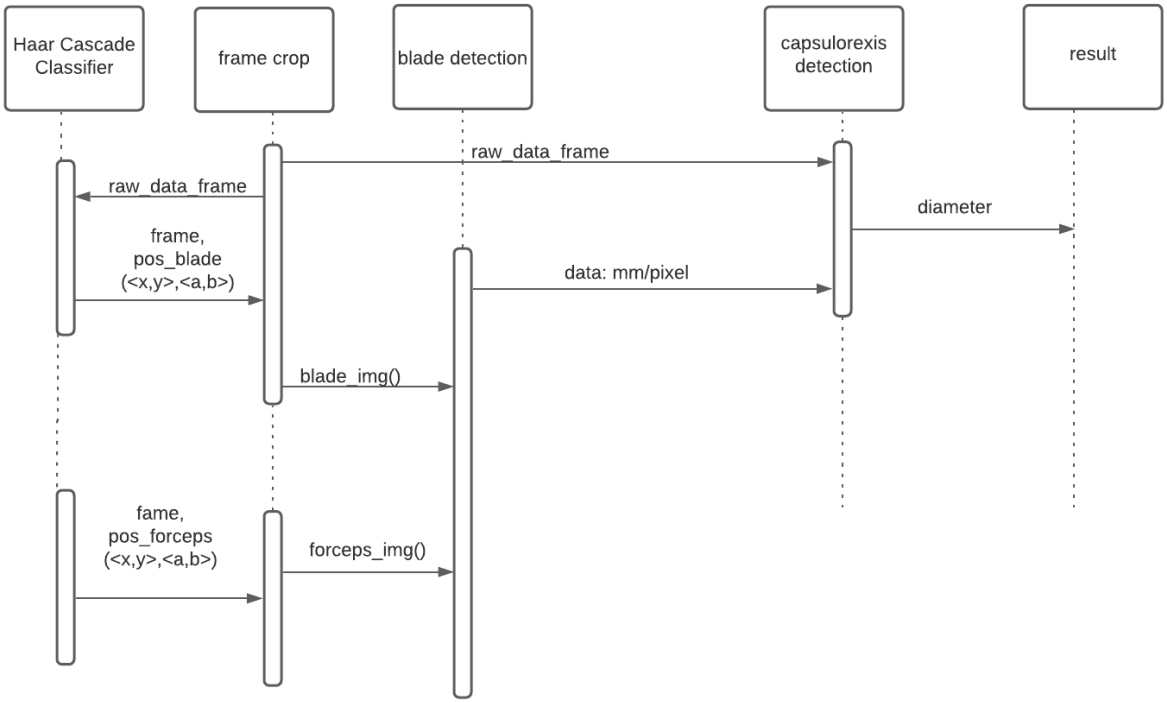
1. The first step is to label the positive and negative training datasets. The positive training datasets are the objects that we hope to detect and the negative datasets include objects that shouldn't be detected. In our case here, the positive datasets may include pupil, forceps, and the scalpel. The negative examples may be the capillary vessels, etc.
2. Train our Haar Cascade classifier based on positive and negative datasets. The objects included in the positive datasets shall be recognized by the detector. Our detector will also take a snapshot of the detected object and save it in a local file for future use.
3. The snapshot of the image will be taken as input to another function that detects the edge of the scalpel. The function will then measure the pixel range of the scalpel. Given that we already know the actual length of the scalpel, we can calculate the ratio between the pixel range and the actual length of the scalpel and store that ratio in the text file for future use.
4. Input the ratio to another machine learning algorithm to calculate the roundness of the rhexis on the pupil.
5. Using the roundness and other parameters to score the surgeon's performance.

UML Class diagram

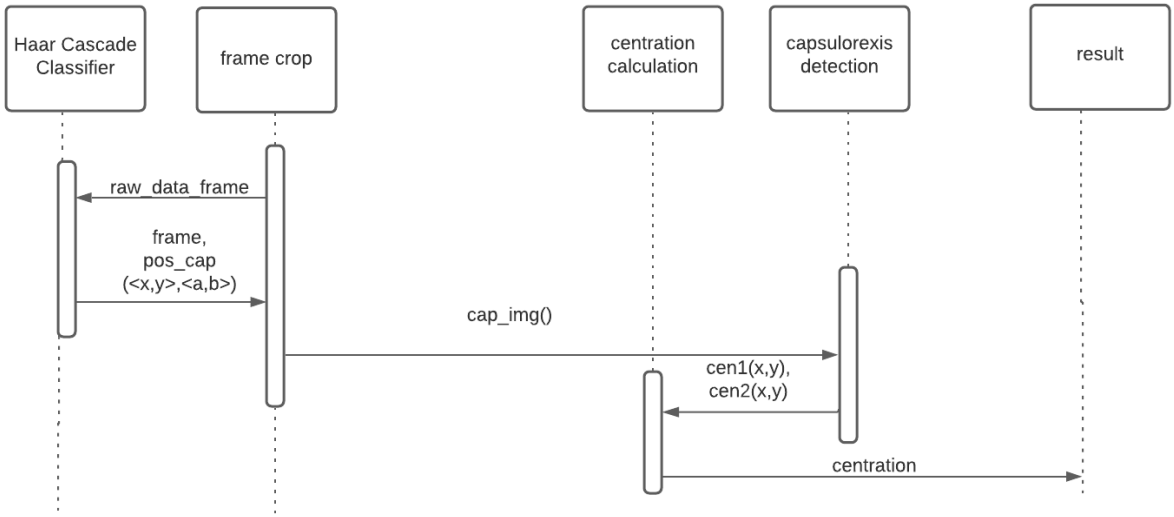


System Models

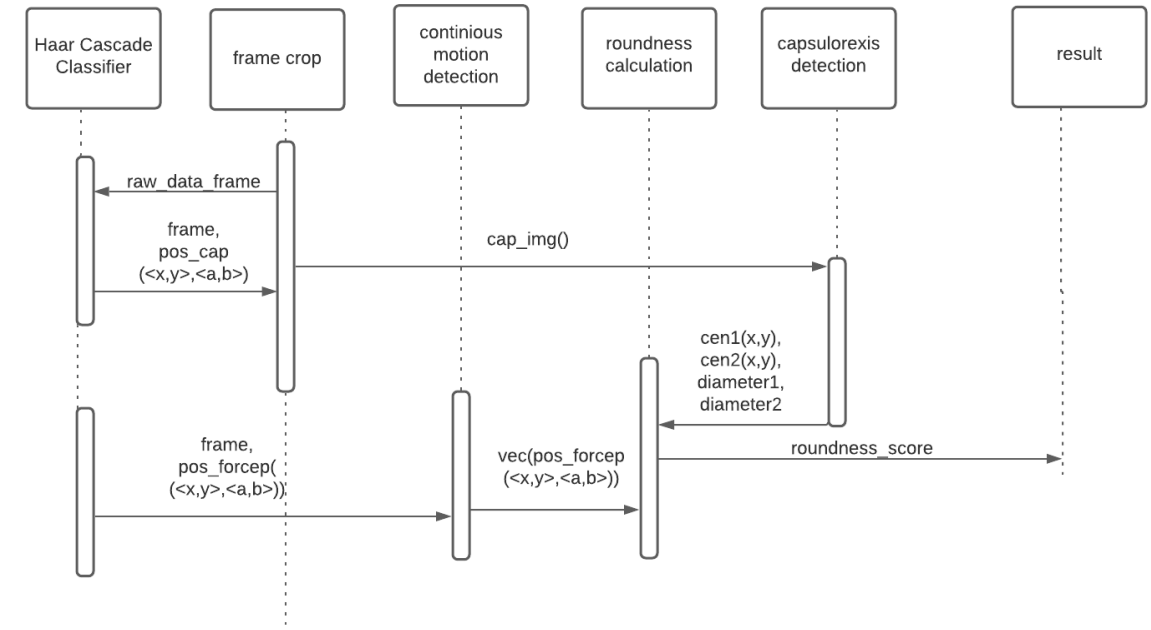
Measure diameter(Sequence Diagram)

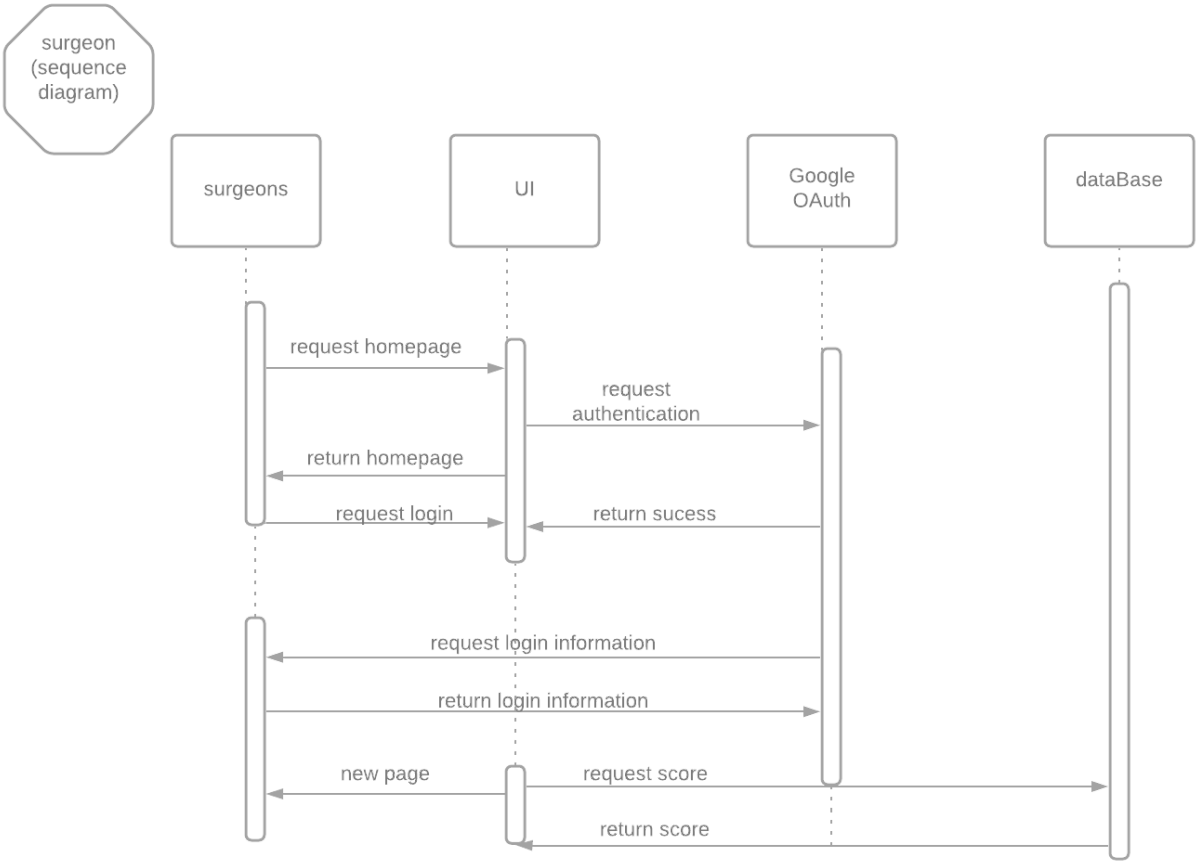


Measure centration(Sequence Diagram)



Measure roundroundness
(Sequence Diagram)

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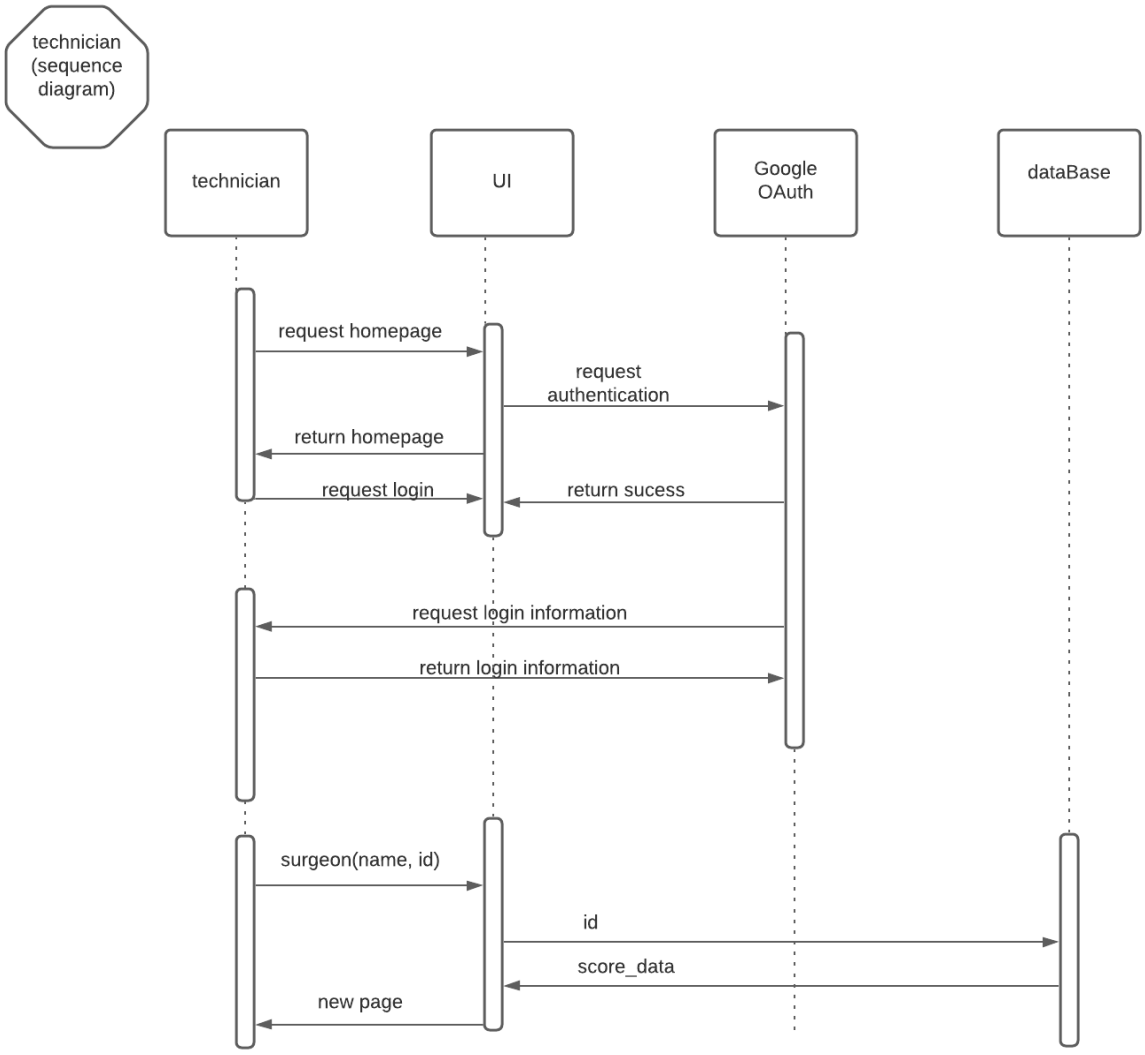
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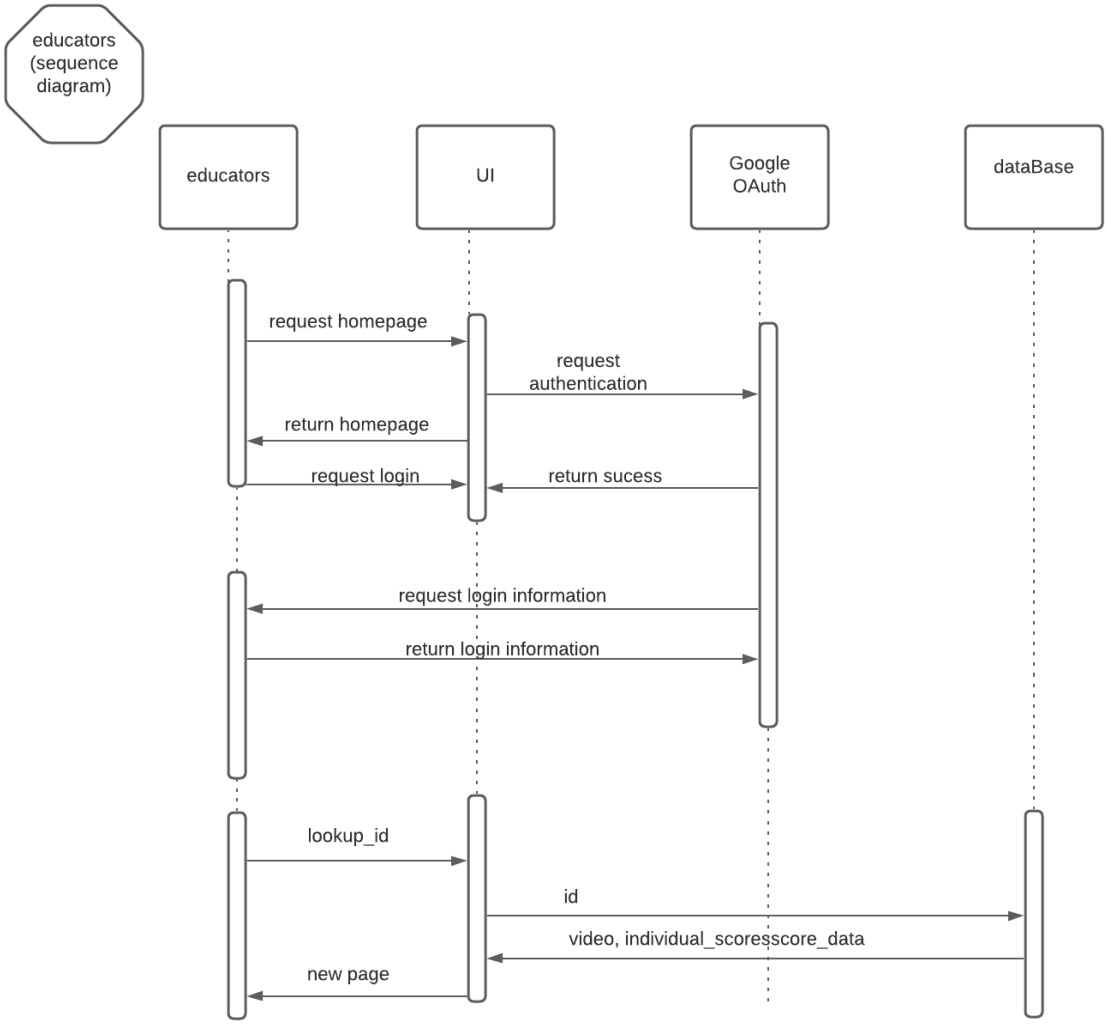
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Technologies Employed

- Open CV (https://opencv.org)
- Matlab (https://www.mathworks.com/products/matlab.html)
- Haar classifier (https://docs.opencv.org/3.4/db/d28/tutorial_cascade_classifier.html)
- Canny Edge Detection (https://docs.opencv.org/3.4/da/d22/tutorial_py_canny.html)
- Hough Transformation (https://learnopencv.com/hough-transform-with-opencv-c-python/)