OptiCare: A Mobile Application Diagnosing Ocular Diseases through Novel Point of Care Methods Utilizing Machine Learning Technology

Grant Proposal

Isha Nagireddy

Massachusetts Academy of Math and Science at WPI

Worcester MA, 01605

Author Note

Thank you to Dr. Feng Tian and Eva Wang, Ray Jiang, Keyuan Ren, and Douglas Jiang from the Feng Tian Lab at Harvard Medical School/Beth-Israel Deaconess Medical Center and Dr. Andrés Colubri from UMass Chan Medical School for your continued support, suggestions, and feedback throughout the creation of OptiCare.

Abstract

2.2 billion people suffer from vision loss, and of these cases, at least 1 billion could have been prevented if access to eye care was available. In specific two of the largest eye diseases are glaucoma, the buildup of intraocular pressure in the eye, and cataracts, the cloudiness of the eye's lens. Cataracts cause 65.2 million cases of vision loss, yet 68% of cases remain undiagnosed and glaucoma makes up 80 million cases of vision loss, with 50% of cases going undiagnosed. Due to a lack of diagnosis, both diseases are not caught early in most individuals and cause vision loss. To combat vision loss, OptiCare aims to create novel assistive technology (AT) and a complimentary mobile application to provide cheap, accurate, and accessible diagnostic methods for point-of-care use. First, AT to measure intraocular pressure, and produce fundus images will be created and tested to achieve optimal performance in the diagnosis of glaucoma and cataracts. Then, machine learning (ML) and mathematical models will be created to analyze the results of the different diagnostic tools. Finally, these models will be implemented into an app. Data analysis mainly focused on the performance of the ML models: the cataracts model achieved an accuracy of 87% and the glaucoma model achieved an accuracy of 81% for the left eye and 83% for the right eye. The future steps of OptiCare include fine-tuning larger language models to improve the accuracy of diagnosis and improving the comfortability of the AT created.

Keywords: glaucoma, cataracts, machine learning, assistive technology, diagnostics

OptiCare: A Mobile Application Diagnosing Ocular Diseases through Novel Point of Care Methods Utilizing Machine Learning Technology

Over 2.2 billion people worldwide suffer from vision problems, and at least 1 billion of these individuals' impairments could have been prevented with the proper care (*Vision Impairment and Blindness*, n.d.). The main barriers to ophthalmology include economic inequities, limited transportation options, and a lack of eye-care providers in rural areas (Ervin et al., 2022). Two major eye diseases that are common causes of blindness or severe vision loss that remain undiagnosed are cataracts and glaucoma. With around 68% of cataract cases going undiagnosed (Chua et al., 2017) and over 50% of glaucoma cases (CDC, 2021), the inaccessibility of eye care is a leading cause of preventable vision loss and blindness due to the lack of cheap, accurate, and accessible eye care. OptiCare aims to solve the problem of preventable vision loss problem and improve accessibility to reliable diagnostic tools for the potential detection of glaucoma and cataracts.

Cataracts: The #1 Most Common Cause of Blindness

Over 65.2 million people suffer from cataracts worldwide, and this ocular disease is the leading cause of blindness. ⅓ of all cases of blindness are due to cataracts. Cataracts are an ocular disease that occurs when an individual's eye's natural lens becomes cloudy over time. Treating cataracts early can help prevent severe vision loss. Therefore, an early diagnosis is needed to improve an individual's quality of life. Yet, an early diagnosis is easier said than done. There are no early symptoms of cataracts, which makes catching this disease in its early stages difficult. To catch cataracts early, testing for cataracts should be done at least once every year (*Cataracts*, n.d.). Cataracts can be diagnosed through numerous strategies, including simply observing the patient's eye up close. Overall, the diagnosing of cataracts has immense potential to be implemented in a point-of-care system, with the use of cheap but accurate instruments, and will be used for this project.

Glaucoma: The #2 Most Common Cause of Blindness

Glaucoma is another ocular disease that affects around 80 million people worldwide currently. This number is expected to increase to 110 million people by 2040. Glaucoma is caused by a build of intraocular pressure (IOP) in the eye and is the second leading cause of blindness. Glaucoma is 6 to 9 times more common in people of African descent than in other ethnicities and constant testing needs to be done to catch glaucoma early. An early diagnosis of glaucoma can halt and prevent severe vision loss in the future. However, just like cataracts, diagnosing glaucoma in its early stages is a difficult task due to the lack of early symptoms. By the time symptoms of glaucoma start showing up, it is often too late to prevent severe vision loss. To prevent vision loss, frequent eye exams once every 6-12 months should be conducted (MD, 2018). The main tools used to diagnose glaucoma are a fundus camera and a tonometer. A fundus camera can take a picture of an individual's retina, optic nerve head, macula, retinal blood vessels, choroid, and vitreous (*Glaucoma | National Eye Institute*, n.d.). The cost of a fundus camera can range from $9,000-$34,000, but point-of-care alternatives have also been created. As stated in the paper, "Do it yourself smartphone fundus camera – DIYretCAM" a fundus imager can be created using a mobile phone, 20D lens, and PVC pipe (Raju et al., 2016). However, the at-home fundus cameras have one fatal flaw: the lack of dilation in the eye. The dilation of an eye is when the black center of an individual's eye is larger than normal. To dilate eyes, dilation drops can be taken. However, it is important to note that dilation drops can only be administered by a professional. Dilation drops are not available over the counter, and therefore cannot be used in a point-of-care situation. With a lack of eye dilation when taking fundus images, the accuracy and clarity of the images decrease drastically. As seen in the previous study "Undilated versus dilated monoscopic smartphone-based fundus photography for optic nerve head evaluation", only 74% of the tested eyes were possible for smartphone-based fundus imagery when undilated, versus the 98% of eyes that were possible for fundus images after dilation. As a result, it can be inferred that smartphone fundus photography alone is not a viable solution for a complete diagnosis of glaucoma in a point-of-care system (Wintergerst et al., 2018). In addition, mobile tonometry has not been very successful in the past either. A tonometer is an instrument used to measure the pressure in an individual's eye and average prices for a handheld tonometer are $3,000. The previous study "Smartphone Tonometer Effective in Measuring IOP" tried improving the accessibility and decreasing the price of tonometers by creating a point-of-care version, however, it unfortunately performed poorly. The corresponding machine-learning algorithm only successfully processed 56.8% of the inputs (*Smartphone Tonometer Effective in Measuring Iop*, 2020). As a result, there are no accurate and cheap tonometer tools in a point-of-care setting and an improved piece of novel technology must be created for this project.

Novel Technology for the Measuring of Intraocular Pressure

While mobile tonometry uses a traditional applanator and the model remains inaccurate, a more novel approach to measuring IOP is evolving and can be implemented in a point-of-care setting. This is the idea of using sound waves to measure IOP. As stated in the paper, "Testing the Viability of Measuring Intraocular Pressure Using Soundwaves from a Smartphone", there is a relationship between internal pressure and the acoustic the decibels returned in a reflection wave. To explain this idea in more detail, when sound waves are emitted at a specific angle and hit the eye, a portion of the sound waves are absorbed, and the remaining portion of the sound waves are reflected off the eye at the same angle they were reflected on. This paper proves the relationship between pressure and the reflection waves and describes using the measurement of sound waves as a potential route for future work. By utilizing the relationship between pressure and sound waves through the integration of a mobile phone, novel instruments can be created to measure intraocular pressure accurately and cost-effectively in a point-of-care setting (Soanes et al., 2021).

Diagnostic Methods Based on Physical Testing

After all physical tests (fundus images, slit lamp tests, and intraocular pressure measurements) are taken, they are then analyzed for diagnosis. While diagnosis is usually done with the assistance of an ophthalmologist, autonomous diagnosis has made giant leaps in the world of healthcare in recent years. Autonomous diagnostics can be done through the aid of machine learning technology. Machine learning is a branch of artificial intelligence that uses data and algorithms to imitate the learning process (*What Is Machine Learning and How Does It Work?*, n.d.). Starting with cataracts, the slit lamp test is used to observe the opacity of the lens. If the lens is showing signs of opacity, then this may indicate early signs of cataracts. With this relationship in mind, a machine-learning algorithm can be developed to detect and diagnose cataracts using slit lamp images taken from a user's phone. Moving on to glaucoma, another machine-learning model can be created to diagnose glaucoma based on fundus images. Glaucoma can be seen in fundus images when cupping is present. Cupping is the idea of an increased cup-to-disc vertical ratio. However, as mentioned before, smartphone fundus images taken on non-dilated eyes do not provide enough data for an accurate diagnosis of glaucoma. Therefore, in addition to taking fundus images, IOP can also be measured periodically using the novel sound waves incorporated in the assistive tool created as a part of this project and recorded over time in a local digital database to monitor potential increases in IOP. After these models and algorithms are created, they will be implemented in a mobile application to increase accessibility. When published on the App Store, OptiCare will be available to 1.46 billion active Apple users worldwide (Shewale, 2024).

Necessary Resources and Knowledge Required for Diagnostic Models

Specific software and machine learning theory are necessary to create machine learning models and a mobile application. One popular are Neural Networks. Neural Networks are a form of machine learning, in specific deep learning, that works like the human brain: there are numerous neurons that relate to one another to perform tasks, create algorithms, and make prediction (What Are Neural Networks?, n.d.). A few popular options include the integrated development environment (IDE) Google Colab and the programming language Python for machine learning models, the IDE XCode for mobile app development, the programming language Swift for mobile app development, and the user database Core Data.

Section II: Specific Aims

This proposal's objective is to develop a mobile application and complimentary assistive technology to aid in the accurate, cheap, and accessible diagnosis of cataracts and glaucoma.

The long-term goal is to prevent hundreds of millions of people from going blind through early intervention with the help of OptiCare's diagnostic system. The engineering goal of this project is to create a mobile application that can catch cases of glaucoma and cataracts in early stages through fundus images, and IOP measurements. The rational for this project is the fact that of the 2.2 billion people currently suffering with vision loss problems, 1 billion of these cases could have been prevented with access to eye care. The work proposed here has the potential to prevent these cases of vision loss by increasing of accessibility of eye care for two of the largest eye diseases in the world: glaucoma and cataracts.

Specific Aim 1: Test, modify, and create assistive technology to aid in the diagnosis of glaucoma and cataracts.

Specific Aim 2: Develop machine learning and mathematical models that read data from the assistive technology and diagnose cataracts and glaucoma. Implement the best performing models into a mobile application.

The expected outcome of this work is a set of assistive technology used to fundus images and monitor IOP and a mobile application for the early diagnosis of cataracts and glaucoma.

Section III: Project Goals and Methodology

Relevance/Significance

Glaucoma and cataracts are the two most common ocular diseases in the world. With hundreds of millions of people suffering from severe vision loss and even blindness due to these diseases, it is imperative that accurate, cheap, and accessible tools for diagnosis are available to halt these diseases early on and prevent avoidable vision loss.

Innovation

Current diagnostic tools, while on the right track, are currently lacking for eye diseases. Assistive technology such as fundus imager are only truly accurate when the patient's eyes are dilated. Without dilation, a treatment that cannot be found over the counter and is therefore inaccessible, fundus images are often impossible to take. In addition to this, machine learning diagnostic models for glaucoma and cataracts are often inaccessible due to the knowledge required to run the code and understand the output. Accurate machine learning models incorporated into mobile applications for the diagnosis for both glaucoma and cataracts are lacking.

Methodology

1. Test, modify, and develop assistive technology.
    a. Test and modify the oDocs fundus imager to fit for the latest iPhone model.
    b. Create an assistive tool to measure IOP using sound waves.
2. Create machine learning and mathematical models to diagnose glaucoma and cataracts.
3. Create a mobile application implementing the highest performing models (based on acuray) from Step 2.

Specific Aim #1: The objective is to test, modify, and develop assistive technology to take fundus images, and measure IOP.

Justification and Feasibility. As seen in Figure 1, the accuracy of current diagnostic tools, to take fundus images, are inaccurate due to the lack of dilation in the eye. Since dilation drops are not available over the counter, taking quality fundus images without dilation and the use of a smartphone camera is difficult and even impossible in certain situations. To learn more about how quality of images and ranking in general was determined by the study "The Quality and Visual Components of Taking Fundus Images in Dilated vs Non-Dilated Eyes", information is

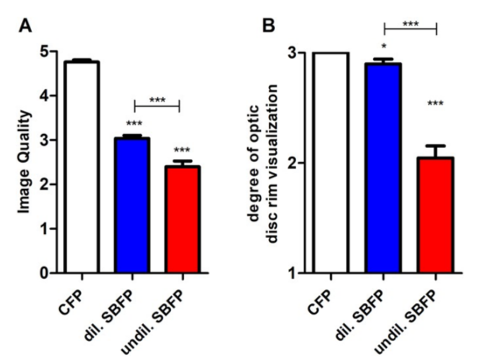


Figure 1: The Quality and Visual Components of Taking Fundus Images in Dilated vs Non-Dilated Eyes. *This graph was taken from the study "Undilated versus dilated monoscopic smartphone-based fundus photography for optic nerve head evaluation". The undilated eye images (undil. SBFP) were poorer than dilated eye images (dil. SBFP).*

available in Appendix 1 and Appendix 2. A tool that provides accurate insight into glaucoma diagnosis in a point of care setting is not available yet. This project will tackle this issue by creating a novel device that measures sound waves to monitor an increase in IOP, and therefore, can help diagnose glaucoma. In addition to this, this project will also slightly modify, and test fundus imagers produced by oDocs if needed.

Summary of Preliminary Data. A preliminary 3D CAD model was designed to measure IOP using sound waves as seen in Figure 2. One arm will hold a small speaker emitting the sound waves and the other arm will hold a small microphone to measure the decibels emitted by the reflection wave. Using the decibels returned in the reflection wave, the reflection coefficient, which is directly proportional to internal pressure can be calculated. For the exact formula please see Appendix 3.

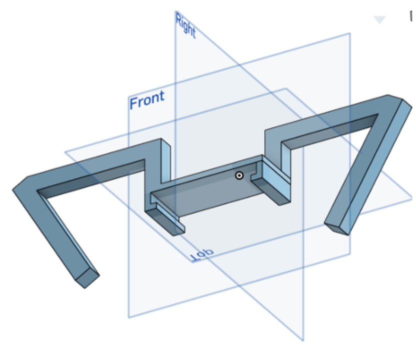


Figure 2: Preliminary Design for the 3D CAD Model to Measure IOP. *This model is the first of many to come to create a device that uses sound waves to measure IOP for the diagnosis of glaucoma.*

Expected Outcomes. The outcome of this aim is to test, modify, and develop revolutionary assistive technology to aide in the diagnosis of glaucoma and cataracts.

Potential Pitfalls and Alternative Strategies. One potential pitfall with the use of soundwaves to measure IOP is that the exact mathematical relationship between IOP and sound waves remains unknown. As a result, specific IOP levels cannot be determined. However, as an alternate strategy, solely the change in internal pressure, and therefore the change in IOP can be measured to detect for an increase in pressure of the eye.

Specific Aim #2: The objective is to develop machine learning and mathematical models based on input of the assistive technology to diagnose glaucoma and cataracts.

Justification and Feasibility. Autonomous diagnosis of glaucoma and cataracts allows individuals to test from the comfort of their own home and still obtain accurate results and data on ocular diseases. As to the best of our knowledge, there are no mobile applications that allows for the accurate and reliable diagnosis of both glaucoma and cataracts. Machine learning models will be created using classic Support Vector Machines (SVM) and Neural Networks. One potential form of neural networks that may be used are Vision Transformers given normal neural networks performs poorly. In addition to this, a mathematical model will be created to analyze the increase of IOP measurements.

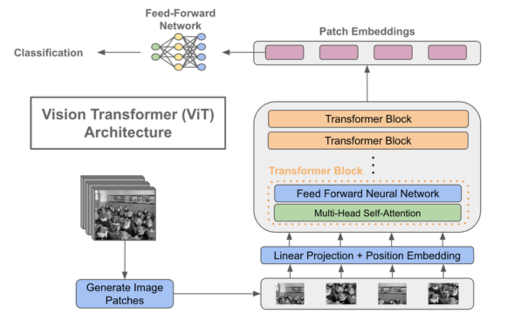
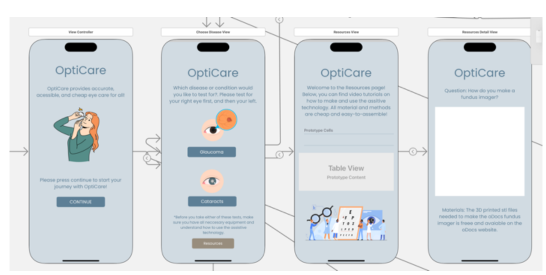


Figure 3: Vision transformers Architecture: *As stated in the article "Using Transformers for Computer Vision" the architecture of Vision Transformers are complex with numerous types of blocks and algorithms.*

Summary of Preliminary Data. As preliminary data, a SVM model for cataract eye images was created. As seen in Figure 4, the model performed well with an accuracy of 93% on the training set and 87% on the validation set. Higher model accuracies will be achievable due to the different between accuracy in the validation and training set: there might be slight overfitting, when the data takes too much into consideration. In the future, the parameters can be changed to further

```
16/16 [==============================] - 0s 5ms/step
              precision    recall  f1-score   support

           0       0.92      0.95      0.93       243
           1       0.95      0.91      0.93       246

    accuracy                           0.93       489
   macro avg       0.93      0.93      0.93       489
weighted avg       0.93      0.93      0.93       489

4/4 [==============================] - 0s 5ms/step
              precision    recall  f1-score   support

           0       0.87      0.87      0.87        61
           1       0.87      0.87      0.87        60

    accuracy                           0.87       121
   macro avg       0.87      0.87      0.87       121
weighted avg       0.87      0.87      0.87       121
```

Figure 4: Developing a SVM Model. This model was created for the diagnosis of cataracts using slit lamp images. This model performed well with an accuracy of 87% on the validation set.



prevent overfitting. After all the models are created, the models that perform the best for each task (diagnosing cataracts and diagnosing glaucoma) will be implemented into a final mobile application. The preliminary design for this mobile application can be seen in Figure 5.

Figure 5: Preliminary Design of the Mobile Application*. This design will be built upon and encompass the diagnostic testing interface in the future.*

Expected Outcomes. The outcome of this aim is to develop 2 machine learning models and a simple mathematical to diagnose glaucoma and cataracts based on images, and monitor IOP pressure respectively. The best performing models in terms of acuray would be implemented into a final mobile application.

Potential Pitfalls and Alternative Strategies. One potential pitfall is the poor accuracy for the glaucoma model that takes in fundus images generated with the smartphone camera as input. Due to the poor quality, the model performance may be too low for implementation (<70%). One alternate strategy if this occurs is to use fundus images taken from large machinery as input. Since the image quality will be better, model accuracy will potentially increase.

Section IV: Resources/Equipment

For this project, assistive technology designs were utilized and modified from the oDocs Fundus Imager open-source 3D model files. To print this material, a 3D printer is also required.In addition to this, the software program OnShape is required to develop the 3D CAD models. The programming part of this project, a MacBook Pro, and numerous online tutorials will be utilized. Specific software used includes the integrated development environments XCode and Google Colab, and the programming languages Python and Swift.

Section V: Ethical Considerations

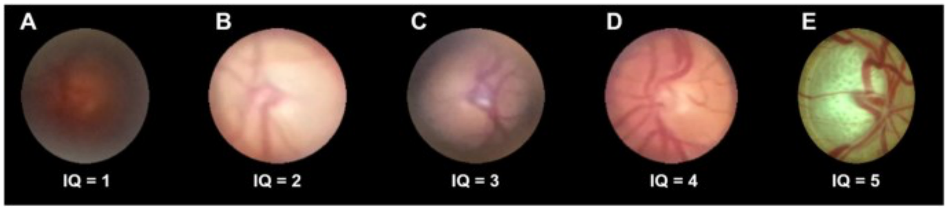
Since the development of this project takes place mostly using computer software and programs, there are no ethical considerations in terms of the building process. However, there are ethical consideration to consider for the application of this project. No machine-learning models can truly achieve an accuracy of 100%, and this should heavily be taken into consideration especially for diagnostic models as described in this project. It is compulsory that OptiCare does not replace the advice and suggestions of a medical professional. OptiCare is simply a tool for early intervention and is meant to be used as a way for individuals to see if they show signs of glaucoma or cataracts. OptiCare is used to strengthen a diagnosis made by professionals and does not, on its own, provide a final diagnosis.

Section VI: Timeline

1. September – November: Complete preliminary research and establish a thorough knowledge of background research.
2. December – January: Complete aim #1: test, modify, and create assistive technology to aid in the capturing of fundus images, and IOP measurements.
3. February – Develop the machine learning and mathematical models to diagnosis glaucoma and cataracts based on data from the assistive technology and implement into a mobile application.

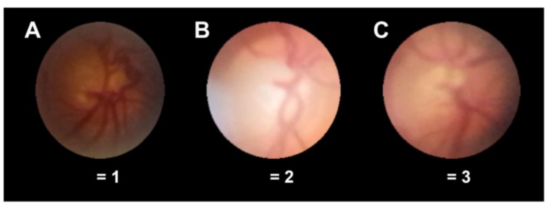
Section VII: Appendix

Appendix 1: Image Quality Grading



Appendix 1: Image quality grading was done by the paper "Undilated versus dilated monoscopic smartphone-based fundus photography for optic nerve head evaluation". There were five main levels, with the 5th level being images of the highest quality and the 1st level being images of the lowest quality;

Appendix 2: Optic Disc Rim Visualization Grading



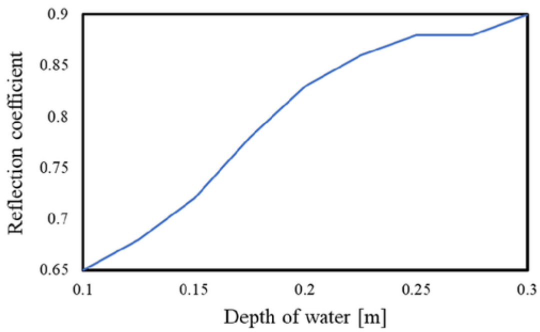
Appendix 2: Optic dis rim visualization was graded based on the following three levels in the paper "Undilated versus dilated monoscopic smartphone-based fundus photography for optic nerve head evaluation". Level 3 is the best, while level 1 is the worst in terms of visualization.

Appendix 3: Formula for Finding the Reflection Coefficient

$$R_C = \left(\frac{A_R}{A_I}\right)^{-1} = \frac{A_I}{A_R}$$

Appendix 3: Rc represents the reflection coefficient, Ar represents the reflection wave, and Ai represents the incident wave first emitted from the speaker.

Appendix 4: The Direct Relationship Between the Reflection Coefficient and Internal Pressure



Appendix 4: This relationship was established in the paper "Testing the viability of measuring intraocular pressure using soundwaves from a smartphone". The depth of water represents the internal pressure in a fake eye model.

Section VI: References

Cataracts. (n.d.). SEE International. Retrieved January 12, 2024, from https://www.seeintl.org/cataracts/

CDC. (2021, January 22). *Current glaucoma programs*. Centers for Disease Control and Prevention. https://www.cdc.gov/visionhealth/research/projects/ongoing/glaucoma.htm

Chua, J., Lim, B., Fenwick, E. K., Gan, A. T. L., Tan, A. G., Lamoureux, E., Mitchell, P., Wang, J. J., Wong, T. Y., & Cheng, C.-Y. (2017). Prevalence, risk factors, and impact of undiagnosed visually significant cataract: The singapore epidemiology of eye diseases study. *PLoS ONE*, *12*(1), e0170804. https://doi.org/10.1371/journal.pone.0170804

Ervin, A.-M., Solomon, S. D., & Shoge, R. Y. (2022). Access to eye care in the united states: Evidence-informed decision-making is key to improving access for underserved populations. *Ophthalmology*, *129*(10), 1079–1080. https://doi.org/10.1016/j.ophtha.2022.07.011

Glaucoma | national eye institute. (n.d.). Retrieved January 12, 2024, from https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/glaucoma#

Jan Bond Chan, (mbbs), Hao Chi Ho, (mbbs), Nor Fariza Ngah, (mbbs, & Elias Hussein, (mbbs. (2014). Diy—Smartphone slit-lamp adaptor. *Journal of Mobile Technology in Medicine*, *3*(1), 16–22. https://www.journalmtm.com/2014/diy-smartphone-slit-lamp-adaptor/

MD, R. N. W. (2018, March 23). *Glaucoma worldwide: A growing concern | glaucoma. Org*. https://glaucoma.org/glaucoma-worldwide-a-growing-concern/

Papers with code—Vision transformer explained. (n.d.). Retrieved January 12, 2024, from https://paperswithcode.com/method/vision-transformer

Raju, B., Raju, N. S. D., Akkara, J. D., & Pathengay, A. (2016). Do it yourself smartphone fundus camera – DIYretCAM. *Indian Journal of Ophthalmology*, *64*(9), 663–667. https://doi.org/10.4103/0301-4738.194325

Shewale, R. (2024, January 11). *32 iphone user statistics: Sales, usage & revenue(2024)*. https://www.demandsage.com/iphone-user-statistics/

Slit-lamp exam information | mount sinai—New york. (n.d.). Mount Sinai Health System. Retrieved January 12, 2024, from https://www.mountsinai.org/health-library/tests/slit-lamp-exam

Smartphone tonometer effective in measuring iop. (2020, March 1). American Academy of Ophthalmology. https://www.aao.org/eyenet/article/smartphone-tonometer-effective-in-measuring-iop

Soanes, M., Essa, K., & Butt, H. (2021). Testing the viability of measuring intraocular pressure using soundwaves from a smartphone. *Engineering Reports*, *3*(7), e12355. https://doi.org/10.1002/eng2.12355

Vision impairment and blindness. (n.d.). Retrieved January 12, 2024, from https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

What is a support vector machine? | Definition from WhatIs. (n.d.). WhatIs. Retrieved January 12, 2024, from https://www.techtarget.com/whatis/definition/support-vector-machine-SVM

What is machine learning and how does it work? In-depth guide. (n.d.). Enterprise AI. Retrieved January 12, 2024, from https://www.techtarget.com/searchenterpriseai/definition/machine-learning-ML

Wintergerst, M. W. M., Brinkmann, C. K., Holz, F. G., & Finger, R. P. (2018). Undilated versus dilated monoscopic smartphone-based fundus photography for optic nerve head evaluation. *Scientific Reports*, *8*(1), 10228. https://doi.org/10.1038/s41598-018-28585-6