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TOWARDS THE DESIGN OF A MOBILE CATARACT SCREENING SMARPHONE APP

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Zu Quan Ik[a], Sian Lun Lau[a*], Jan Bond Chan[b]

[a]Department of Computing and Information Systems, Faculty of Science and Technology, Sunway University, Bandar Sunway, Malaysia
[b]Department of Ophthalmology, School of Medical Sciences, Universiti Sains Malaysia, Kelantan, Malaysia

*Corresponding author
sianlunl@sunway.edu.my

Abstract

The cataract is the leading cause of blindness and affecting nearly 22 million Americans aged 40 and older. Cataract screening is a process usually carries out by an ophthalmologist using specialize equipment. The hurdles that we are facing today to screen for cataract include the availability of medical practitioner and proper equipment, especially in the rural area. Other problems include the cost and time involved to do eye examination from the medical practitioner. In this paper, we aim to research on an alternate cataract screening solution using a flash-enabled smartphone without any external attachments. The solution should be made usable by general public. The research is divided into three different phases. The first phase aims to understand how medical practitioner performs cataract screening using red reflex and attempts to replicate it using mobile application. The second phase involves collecting data to obtain the appropriate parameters that allow replication of red reflex using mobile application. The third phase of this research intends to replicate the Ophthalmologist diagnosis using Artificial intelligent built into the mobile application. This paper presents the work performed and the obtained outcome from the first and second phases.

Keywords: Cataract detection; medical screening mobile application

1.0 INTRODUCTION

A cataract is the clouding of the lens in the eye, which may lead to blurred vision, discolored vision, impaired night vision/glare or double vision and in severe cases blindness [1]. Cataract is the leading cause of blindness according to the latest assessment by the World Health Organization (WHO). It is responsible for 51% of world blindness, which represents about 20 million people (2010) [2]. Studies have also shown that cataract increases chances of automobile crashes [3] and also accidental injuries sustained to the elderly [4]. The most common cause of cataract is ageing, affecting nearly 22 million Americans aged 40 and older. By the age of 80, more than half of all Americans have cataract [5]. Other than treating cataract problem, the best way to deal with cataract is to have regular screening to detect the symptoms early. Early treatment may help to save one's eyesight.

Figure 1 A child with right eye normal red reflex and, left eye poor red reflex with cataract. (Image taken from [On-line] http://www.cehjournal.org/article/how-to-test-for-the-red-reflex-in-a-child/, last accessed on 14th August 2015)

There are multiple ways to screen for cataract such as using slit lamp examination, red reflex, and light scattering methods [6][7]. In this paper, we focus on the red reflex method. In this method, patients are placed in a dimly lit or dark room, and then in some cases, eye dilating drops are used on the patient to dilate the patient's pupil. The medical examiner, usually an ophthalmologist, will place the ophthalmoscope 30cm / 1 foot away from the eye's retina and observe the reddish-orange reflection (red reflex) of light. The red reflex from ophthalmoscope determines the severity of the cataract as shown in Figure 1. The red reflex occurs because the transmission of light from an ophthalmoscope through all the normally transparent parts of a subject's eye, this light reflects off the ocular fundus at the back of the eyeball and out through the pupil, and is in the eye of the examiner via ophthalmoscope. Any factor that impedes or blocks this optical pathway will result in an abnormality of the red reflex [8].

There are several challenges for regular screening. Firstly, screenings are carried out by medical practitioners, and their availability will be a factor. Secondly, proper types of equipment are needed for the screening, and they are not cheap. Thirdly, the costs and time involved to do eye examination from medical practitioner are also possible factors why some are doing the screening as regular as possible. These challenges are even more difficult when it comes to screening for people from the rural area. Screening for cataract patients should be done at early stages as the doctor may need time to prepare for the patient's surgery and also patients may need time to prepare psychologically. In the case that cataract is discovered in more severe stages, it may be more difficult to perform the cataract surgery as it may lead to major complications during the surgery. The surgery will take a longer time to perform and the medical cost incurred may be higher. The recovery period after surgery is also longer in compare to the earlier stages.

We propose to develop a solution using mobile technology that solves the above challenges. The idea is to use a smartphone with an appropriate app as an alternative screening tool. This tool should be designed for the use by general public. In other words, almost anyone should be able to operate the app and perform cataract screening without the help from a medical practitioner. This paper presents the idea and a first generation prototype to demonstrate the feasibility of the idea. The proposal does not intend to replace the professional screening procedure. The app should serve as a non-medical self-screening service, so that with early detection, the patient can then seek professional screening to confirm and hence able to take precaution steps by having early treatment.

As smartphones become almost ubiquitous in most urban places since the past years, cataract self-screening with a smartphone may help to remove the barriers like screening cost and travel/time inconvenience for patients who may have a cataract. As cataract occurrence increases with age [5], frequent self-screening can help to detect cataract early to reduce preventable blindness.

The structure of this paper is as follows: Section 2 elaborates the methodology applied and the proposal of the envisioned screening mobile application. In Section 3, the experiment setup, implementation, initial results and a discussion on current related work as well as the potential of future smartphone-based medical screening solutions are presented. The paper is concluded in Section 6.

2.0 METHODOLOGY

The screening to detect possible cataract symptoms using the red reflex method may produce results as depicted in Figure 2. If the outcome is similar to result "A" in Figure 2, it is an indication that the subject's eyes are normal and has no sign of any cataract problem. If the results are as shown in B or C of the same Figure, they are all indication of a detection of cataract, ranging from mild to severe accordingly. If a smartphone can create a similar effect of an ophthalmoscope in the red reflex method, it can then be an attractive alternative to allow self-cataract screening applications. A smartphone has a camera, which can be used to capture the picture of a patient's pupils. The red eye effect, usually observed in photography using a camera flash, will be similar to the effect needed to analyze the characteristics of the captured pupils. The goal of this work is to explore, how the app can achieve the above steps and enable the obtaining of results similar to the possible ophthalmoscope diagnosis (see Figure 2).

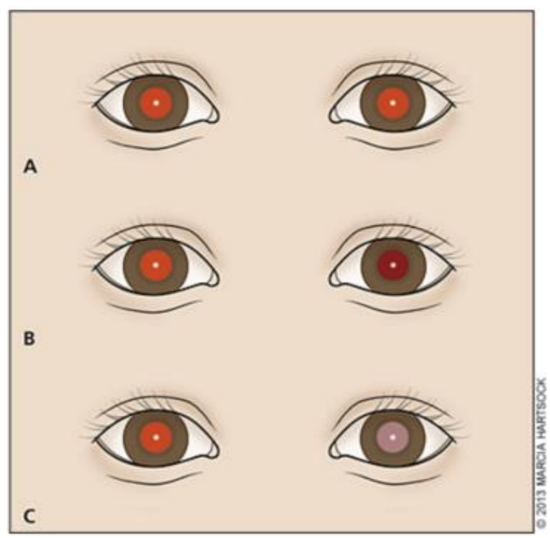

Figure 2 Ophthalmoscope diagnosis - A is normal, B is mild cataract and C is severe cataract. (Image taken from [Online] http://www.aafp.org/afp/2013/0815/p241.html, last accessed on 30th June 2015)

The methodology of this research is divided into three main phases (as shown in Figure 3). They are elaborated as follows:

2.1 Phase 1 - Replication Phase

In Phase 1, the research revolves around how to replicate red reflex generated by ophthalmoscope using a mobile camera and its flash. The red reflex we are looking to create out from the mobile app is the same as red-eye effects from camera flash as seen in Figure 4. There are a lot of studies focusing on techniques that remove red-eye effects. However, to the best of our knowledge, not many investigations can be found that aims to create the red eye effect. Therefore, the main challenge in this phase is to create a mobile application that can recreate red-eye effects. From our analysis, there are six variables that will allow us to achieve the recreation of the red eye effect (as shown in Figure 5). These variables are elaborated as follows:

a) The patient's pupil needs to be dilated in order for maximum amount of light to enter and exit. This effect will help to create the red reflex.
   Challenge: *How do we dilate the patient's pupil without medication?*
b) Like the conventional ophthalmoscope, a certain distance is required to create the red reflex.
   Challenge: *How do we determine the best distance between the mobile camera and the eye?*
c) Similar to variable number 2, a certain range of angle is required to capture the desired red reflex.
   Challenge: *How do we determine the best angle between the eye and mobile camera?*
d) Conventional ophthalmoscope requires dim lighted room to be able to use. In other words, we need to identify a certain range of surrounding light intensity of the selected environment.
   Challenge: *Will the envisioned app have the same requirement on surrounding light intensity? If yes, how do we determine the best room lighting in term of luminosity?*
e) We propose to use the camera flash to create the red reflex.
   Challenge: *How intense should the camera flash in order to get a red reflex response? Can we use LCD screen along with the mobile front camera to create red reflex? Or we have to use proper camera flash?*
f) Another variable is the control of the timing when to capture the red reflex once the cameras flash is fired. When the flash is fired, the eye pupil will start shrinking. It will create a problem if immediate capturing of the pupils cannot be achieved immediately.
   Challenge: *How do we determine the best timing to capture the red reflex using a smartphone's camera, and if the flash is used, once the flash is fired?*

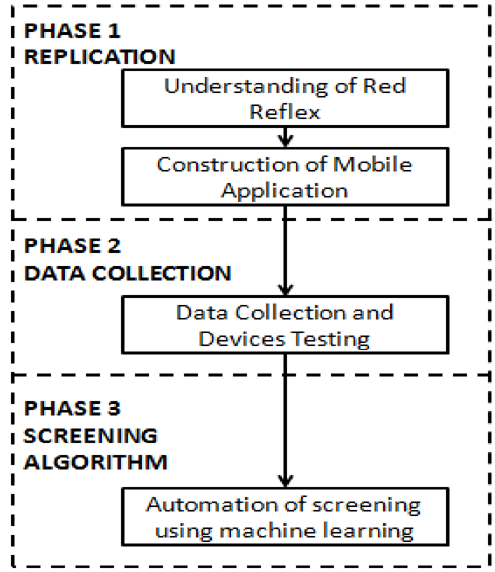

Figure 3 Project flow chart

Figure 4 Red-eye effect in photography with flash. (Image taken from [Online] https://commons.wikimedia.org/wiki/File:BoldRedEye.JPG, last accessed on 30th June 2015)

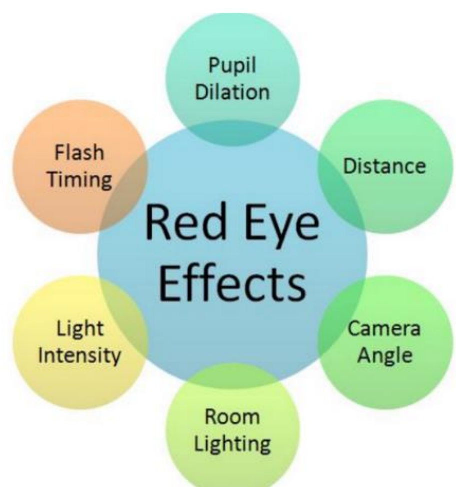

Figure 5 Replication challenges

2.2 Phase 2 – Data Collection

The output of Phase 1 will provide the variables needed to replicate the red reflex using a smartphone's camera. The outcome enables us to develop a mobile app that can generate and capture red-reflex. In Phase 2, the mobile app will be tested with different subjects by an ophthalmologist to collect possibly a large number of images from real volunteer patients, with and without cataract, to form a dataset. This dataset will be accompanied with the diagnose based on the ophthalmologist's expertise and also proper medical grade equipment. In the case of a detected cataract, the severity of the cataract should be recorded.

With this dataset, we can then verify how successful the app is in achieving the goal of capturing the desired red reflex from potential cataract patients. An informed consent will be taken from the patients for the data collection process. Other variables, such as age and gender, will also be included, in case we need further information to understand any situation where any of these variables could have affected the creation of red reflex using the mobile app. The mobile app will also be implemented in different phone models to check how each phone's configurations affect the red reflex. At this phase, the output of the mobile application should not be used as diagnosis reasoning. The main goal of this phase is to create a dataset with different patients and phone models.

2.3 Phase 3: Screening Algorithm

In the third phase, we will employ suitable machine learning techniques to evaluate the most appropriate algorithm that may enable the automatic classification of cataract detection. Based on the dataset produced in Phase 2, selected algorithms will be applied and evaluated in order to identify the most suitable algorithms to be integrated into the envisioned mobile app. The best algorithm should provide not only the ability to detect possible cataract for a user with real cataract risk, but also provide the ability to recognize the cataract severity.

Finally, second round of the data collection will be carried out with the help from an ophthalmologist with volunteer patients. The mobile app, with reliable red reflex recreation and automatic cataract as well as severity detection functions, will be tested. This will allow us to verify the accuracy of cataract detection and confirm the success of our ideas as well as the screening app.

Currently, we have completed and achieved Phase 1 and part of Phase 2. The outcome is a prototype app that serves as proof of concept. The data collection in Phase 2 as well as Phase 3 have yet to be started. In the next section, the prototype app will be presented.

3.0 RESULTS AND DISCUSSIONS

3.1 Experiment Setup for Phase 1 and 2

Our current prototype app is built on Android OS and running on a Xiaomi Mi3 smartphone with a 13-megapixel camera and a Dual LED Flash. The mobile application requires two persons to operate, the application user and the patient. To confirm the methodology and identify the correct parameters how the app can achieve similar results as compared to an ophthalmoscope, the following steps have been applied:

1. The application user stands directly in front of and facing the patient. He should stand at a distance of three feet or an adult arm length away from the patient.
2. The application user then places the smartphone on the eye level of the patient and ensures no light sources are present.
3. The mobile application is then used to capture red reflex from the patient. Figure 6 shows the prototype screen where the application user aims the camera on the patient's face and press capture.
   Image captured will then be cropped to just showing the eyes only. The application users will then fill in the patient's generic data including gender, age group and eye colors for data collections. In Figure 7 shows the screen where it has the image of the cropped eyes along with data collection forms.

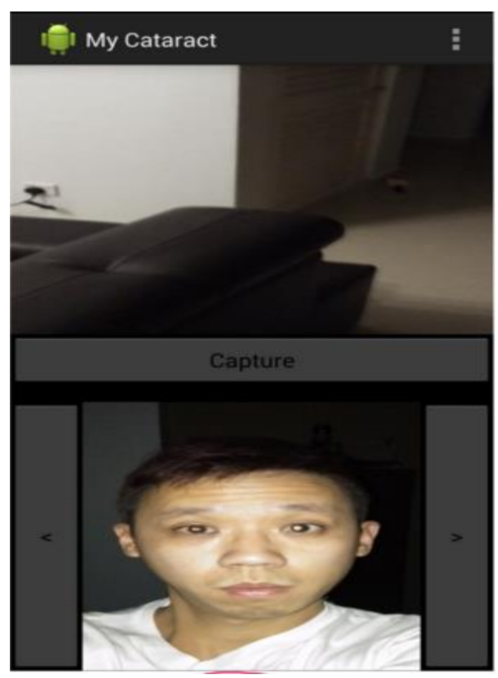

Figure 6 Capturing red reflex using prototype mobile application

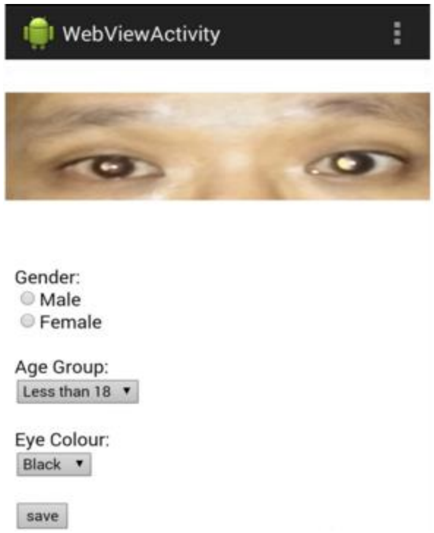

Figure 7 Data collection prototype screen

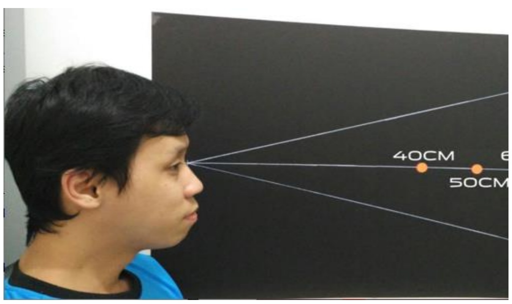

Figure 8 Distance test

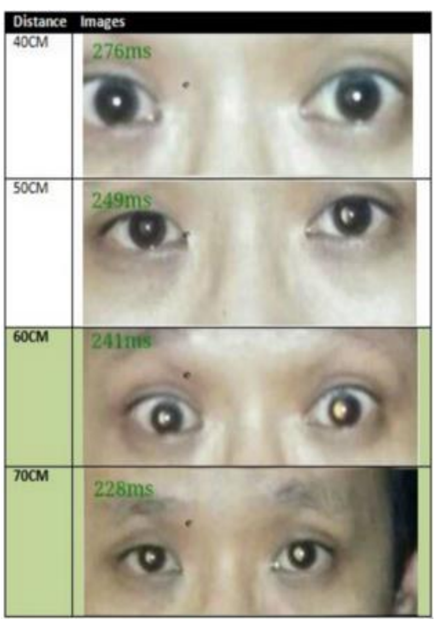

Figure 9 Distance test result

3.2 Initial Result

The initial results obtained from the above experiments are summarised as follow:

Clarity – At the moment, the test is performed on a normal person's eye, by using that as baseline, we can evaluate the clarity of a red reflex based on the diameter and the brightness of the red reflex. As seen on Figure 9, the brightness and diameter of the red reflex are almost non-presence in 40-50cm, therefore defined as unclear red reflex. Unlike 60-70cm, which have a bigger red reflex diameter and bright glow from the eye.

Distance - Ophthalmoscope requires a distance of 30 cm/ 1 foot and at a position direct in front of the eye to check for red reflex. In order to perform the distance check for our application, we attempt to capture various distance where the red reflex response is the strongest.

The test setup includes positioning our test devices 40cm – 70cm away from the patient's eye at 10 cm interval as shown on Figure 8. The experiment starts at the test device minimal focal distance of 40 cm and it ends at 70cm, as the cropped picture of the eyes beyond 70cm is too low resolution in our test device.

Based on our test result shown on Figure 9 at distance lesser than 60 cm, the red reflex tends to be dimmer, and it gets clearer at 60-70cm, the clarity difference between 60-70cm are minimal. Therefore 60-70cm will be used as our guide moving forward in the subsequent test. However, each mobile phone has different processing speed, flash configurations and camera quality. The result above only applies on our test devices.

Vertical Angle - We will be performing testing on the camera vertical angle from the patient's eye to determine whether it will affect the clarity of red reflex. In order to perform the vertical angle experiment, we attempt to capture picture on various vertical angles and analyse the clarity.

Using our distance test result from our previous test, we will be placing the test device 60-70cm away from the patient's eye. The test device is then positioned 15 degrees above and below the patient's eye level. The test starts and ends at 15 degrees to -15 degrees with 15 degrees' interval as shown on Figure 10.

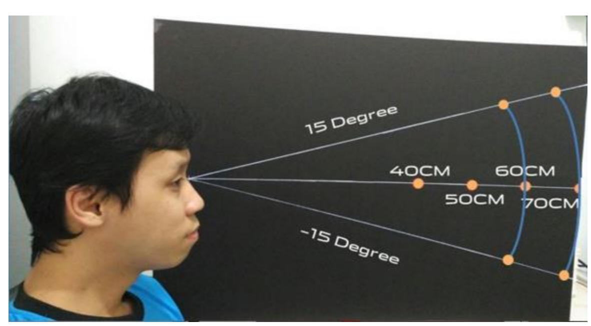

Figure 10 Vertical angle test

Figure 11 vertical angle test result

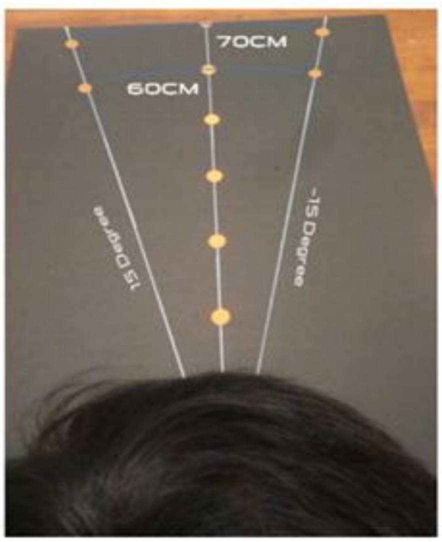

Figure 12 Horizontal angle test

Based on our vertical test result as shown in Figure 11, there are only no differences between 15 to -15 vertical degrees

Horizontal Angle - This experiment is designed to determine whether capturing on different horizontal angles will affect red reflex clarity. In order to perform the horizontal angle's check for our application, we attempt to capture various horizontal angles where the red reflex response is the strongest.

Using our distance and vertical angles test result from our previous test, we will be placing the test device 60-70cm and 0 degree away from the patient's eye. The test device is then positioned 15 degrees beside the patient's eye to determine the best red reflex clarity as shown on Figure 12. The test starts and ends at 15 degrees to -15 degrees with 15 degrees' interval because beyond 15 degrees, we will not be able to have a clear view of the full eyeball.

Based on our horizontal test result as shown in Figure 13, there are no differences between 15 to -15 horizontal degrees.

Environment Lighting - Ophthalmoscope examination is performed in a dimly lit room. This is to ensure a clearer red reflex as well as prevent pupil shrinking due to external light sources. In the mobile application, we need to study whether environment lighting affects the test result. In order to measure environment lighting, lux meter is being used. In this experiment, we are using Light-O-Meter application as shown on Figure 14 on our android test device to measure the environment lighting in Lux.

Figure 13 Horizontal angle test result.

Figure 14 A print screen of the Light-O-meter mobile application (Image taken from [Online] https://play.google.com/store/apps/details?id=spaceware.lightmeter&hl=en, last accessed on 11th October 2015)

Figure 15 Environment light test

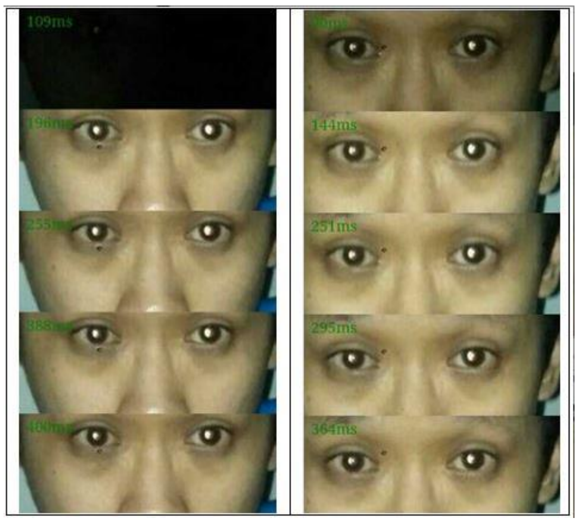

Figure 16 Flash Timing Test, photos are taken consecutive with set timer. However, each shots results in different timing due to delay in mobile phone

Figure 17 Using 2 different test devices with the same mobile application produces different red reflex colour

Lux meter mobile application usually measure the environment lighting via the front camera, thus causing discrepancy between different mobile phone. In future, we plan to use professional lux meter device as measuring tools instead. In Figure 15, the environment lighting test revealed that lower environment lighting creates a clearer red reflex.

Flash Timing - The human pupil will shrink quickly once it is exposed to a strong light source, and the size and clarity of the red reflex is highly dependent on the pupil size. One of the major challenges for this project is the attempt to control the timing of the flash so that the red reflex image can be captured before the pupil shrinks. Both Android and iOS as of current does not support manual overriding of flash timing.

In our initial attempt to overcome this, the torch mode was being switch on and off quickly followed by a swap to normal camera mode to capture the image. However, this has resulted in delayed and inconsistent timing in our test device in capturing the red reflex perfectly. Our subsequent solution therefore was to turn the torch mode on and off during live video preview and the video preview screen was captured as image instead. This however has resulted in a lower resolution picture as compared to using a camera.

Another issue we encountered during this test is that each mobile phone has its own flash position, processing power as well as camera configuration, and the differences will affect the timing required to capture red reflex. As shown on Figure 16, each test is fired continuous at the same time, but mobile phone delay caused the fire rate to differ from each other. Due to the limitation, the mobile application currently allows the user to manually select the best image to use. In future, the application should contain an algorithm inside to automatically determine the best red reflex to be analysed. The algorithm can be based on either the timing or the image colour histogram.

Light Intensity - Although the camera flash is able to replicate red reflex, there were reports of individuals who has experienced pain and dizziness after being exposed to the camera flash in a dark environment. We therefore explored an alternative method using our test device screen as a light source and its front camera to capture red reflex. However, the brightness of the test device screen could not generate red reflex. A more thorough research is thus required to analyse the light luminosity required to generate red reflex, as different smart phone camera uses different flash intensity and technology including Xenon flash, single LED and dual LED flash.

3.3 Work in Progress

In order to fully replicate Ophthalmoscope in mobile application, the following researches are still pending:

1. Due to delay in mobile phone, the application has to resolve to take multiple images after the flash is fired and the user has to manually choose the best picture. An algorithm to automatically pick the best red reflex among the photos is required.
2. As seen on the test images generated, most images have a brighter reflex on the left. This may be due to the flash configuration

of our test devices which is on the left. Future testing on different flash configurations mobile phone.

3. Currently, we are using Lux meter android application for environment lighting experiment, as the application relies on the quality of the mobile phone's camera, future test needs to be performed using professional lux meter device.
4. The mobile application produces different colour and shape of red reflex on our Xiaomi Mi3 test devices against another mobile phone Samsung Note 5 as shown on Figure 17. The picture taken from Samsung Note 5 using our prototype mobile application was not done in a controlled environment, therefore the variable that affects the result is not known. However, it managed to produce one of the best results. Therefore, we can assume that all phones behave differently and requires further and understanding.
5. The current parameters are generated from testing on a single subject using a single test device. These parameters may be adjusted in future once it is performed on more subjects using different devices.

3.4 Future Work

Once we have collected the dataset from different patients and smartphones, we aim to understand how each of these variables affects one another to ensure most categories of patients as well as most smartphones can utilize the application to capture red reflex. Finally, we will employ suitable machine learning techniques to enable the screening automatically. The screening should extend beyond detecting presence of cataract but ability to classified cataract severity accordingly.

3.5 Discussion: Future of Smartphone-based Medical Screening

With the portability, accessibility, increasing image quality, declining cost and stronger computational power of smartphones, it has open up new opportunities that lead to increased number of research in medical screening. The increased in camera resolution and the advanced optic can be used to capture detailed images required for diagnosis. While the increased processing power of a smartphone, enabled the options to process complicated algorithm, image processing logic and inclusion of artificial intelligent diagnosis into the smartphone.

Medical screening at the moment should not be seen as a replacement for the professional medical diagnosis. Miss-diagnose result from the technology may place the patient into life and death situation, and the ethical of computer generated diagnosis requires further research to determine the responsibility in the situation of miss-diagnose. However, it still can come in handy in rural areas where medical professional and equipment are scarce. Some research also suggested additional attachments to the smartphone where medical professionals can also use it as portable medical devices helping them with diagnosis. This provides great portability for medical professional to move around without the need of bulky equipment. Another area where the smart phone may come in helpful for medical professional is the use of remote monitoring and/or diagnosis of patients using video/image as diagnosis aid.

Figure 18 A photograph of the fundus (Image taken from [Online] https://en.wikipedia.org/wiki/Fundus (eye), last accessed on 30th June 2015)

Currently, the majority of research in the mobile ophthalmological application focuses on diseases affecting the eye's posterior pole. Most of these investigations are intended for diagnostic of diabetic retinopathy [16] [18] using image analysis [17]. There is also research into an attachment to smartphones that works as a lens or an ophthalmoscope and allows the physician to see the patient's fundus [19] [15]. Again, these solutions allow the scanning for diseases like diabetic retinopathy and cataract, where the latter is similar to our research presented in this paper. For the case of [20], the application analyzes the movements of the eyes to detect eye abnormalities. However, these devices are developed and intended for ophthalmologists, general practitioners and emergency physicians. In other words, they are not made for general public.

There are some studies on smartphone medical screening on other areas of specialty. They include ovarian cancer detection [9], screening for water-borne parasites [10], skin tumor screening [11], remote wound assessment [12], rapid screening for refractive error [13]. The closest research related to cataract detection is [14], but it proposed a solution using an external attachment. We argue a solution without any external attachment is a more viable and practical solution. If the solution can be operated and used by non-medical practitioners, it will be seen as more attractive.

The future of smartphone-based medical diagnosis is an interesting and important area of research. It will offer a wide range of solutions. Currently, the main focuses are in the area of remote diagnosis, medical decision support system, and computer aided diagnosis tools for medical professionals and disease screening [17].

With the advantages of smartphones being widely available and portable, medical professionals can utilize it to capture detailed imaging of various diseases for further processing, finding new patterns and discovering new ways to screen for diseases.

For example, the examination of optic fundus, as shown in Figure 18, allows the discovery of various diseases. The photograph of the optic fundus can be captured with an attachment to smartphone [15] [19]. If these images can be processed and analysed, whether locally on the smartphone or remotely on a server, diagnosis and decisions can be made by the user in almost real time. This is also the next stage of the presented research in this paper. The next phases (Phase 2 and 3) will focus on automatic cataract detection using suitable machine learning algorithms.

4.0 CONCLUSION

In conclusion, as cataract is the leading cause of blindness and affecting nearly 22 million Americans aged 40 and older. Multiple studies have also shown that cataract increases chances of automobile crashes and also accidental injuries sustained to the elderly. A self-screening cataract mobile application that can be performed by the general public should help with early detection and reduce accident rate due to cataract. This research aims to provide 2 main key learning. Can flash enabled smart-phone replicate red reflex done using ophthalmoscope? And can ANN be trained to screen the severity of the cataract. The outcome should allow the public with camera flash enabled a smartphone to do a self-screening and also use as a portable screening method in places with limited medical facilities or professional. The research is not meant to replace proper screening procedure done by trained medical practitioner or to provide higher accuracy screening method.

References

[1] N. E. Institute, Facts About Cataract, https://nei.nih.gov/health/cataract/cataract Facts, Last Accessed 30th June 2015.

[2] W. H. Organization, Prevention of Blindness and Visual Impairment, http://www.who.int/blindness/en/, Last Accessed 30th June 2015.

[3] A. A. 2010. of Ophthalmology, Cataract Surgery Saves Lives, Dollars by Reducing Auto Crashes, http://www.aao.org/newsroom/news-releases/detail/cataract-surgery-saves-lives-dollars-by-reducing-a, Last Accessed 30th June 2015,

[4] V. Tseng, F. Yu, F. Lum, and A. Coleman. 2012. Risk of Fractures Following Cataract Surgery in Medicare Beneficiaries, JAMA. 308(5): 493–501, [Online]. Available: +http://dx.doi.org/10.1001/jama.2012.9014

[5] A. A. 2011. of Ophthalmology, Eye Health Statistics at A Glance, http://www.aao.org/newsroom/upload/Eye-Health-Statistics-April-2011.pdf, Last Accessed 24th November 2014

[6] I. Litmanovitz and T. Dolfin, 2010. Red Reflex Examination In Neonates: The Need for Early Screening, *Isr Med Assoc J*, 12(5): 301–302,

[7] M. B. Datiles, P. A. Edwards, B. L. Trus, and S. B. Green, 1987. In Vivo Studies on Cataracts Using The Scheimpflug Slit Lamp Camera. *Investigative Ophthalmology & Visual Science*. 28(10): 1707. [Online]. Available: +http://dx.doi.org/

[8] A. A. 2008. of Pediatrics et al., Red Reflex Examination in Neonates, Infants, and Children, *Pediatrics*. 122(6): 1401–1404,

[9] S. Wang, X. Zhao, I. Khimji, R. Akbas, W. Qiu, D. Edwards, D. W. Cramer, B. Ye, and U. Demirci, 2011. Integration of Cell Phone Imaging with Microchip Elisa To Detect Ovarian Cancer He4 Biomarker in Urine at The Point-Of-Care, *Lab on a chip*. 11(20): 3411–3418. [Online]. Available: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3767574/

[10] D. Tseng, O. Mudanyali, C. Oztoprak, S. O. Isikman, I. Sencan, O. Yaglidere, and A. Ozcan, 2010. Lensfree Microscopy on A Cellphone, *Lab Chip*. 10: 1787–1792. [Online]. Available: http://dx.doi.org/10.1039/C003477K

[11] S. Kroemer, J. Frhauf, T. Campbell, C. Massone, G. Schwantzer, H. Soyer, and R. Hofmann-Wellenhof, 2011. Mobile Teledermatology For Skin Tumour Screening: Diagnostic Accuracy of Clinical and Dermoscopic Image Tele-Evaluation using Cellular Phones, *British Journal of Dermatology*. 164(5): 973–979. [Online]. Available: http://dx.doi.org/10.1111/j.1365-2133.2011.10208.x

[12] C.-H. Hsieh, H.-H. Tsai, J.-W. Yin, C.-Y. Chen, J. C.-S. Yang, and S.-F. Jeng. 2004. Teleconsultation with The Mobile Camera-Phone in Digital Soft-Tissue Injury: A Feasibility Study, *Plastic and Re-constructive Surgery*. 114(7): 1776–1782

[13] V. F. Pamplona, A. Mohan, M. M. Oliveira, and R. Raskar, 2010. Netra: Interactive Display for Estimating Refractive Errors and Focal Range, *ACM Trans. Graph*. 29(4): 77:1–77:8, Jul. [Online]. Available: http://doi.acm.org/10.1145/1778765.1778814

[14] V. F. Pamplona, E. B. Passos, J. Zizka, M. M. Oliveira, E. Lawson, E. Clua, and R. Raskar. 2011. Catra: Interactive Measuring and Modeling of Cataracts, *in ACM SIGGRAPH 2011 Papers, ser. SIGGRAPH'11*. New York, NY, USA: ACM. 47:1–47:8. [Online]. Available: http://doi.acm.org/10.1145/1964921.1964942

[15] J. B. Chan, H. C. Ho, N. F. Ngah, and E. Hussein. 2014. DIY - Smartphone Slit-Lamp Adaptor, *Journal of Mobile Technology In Medicine*. 3(1): 16–22,.

[16] A. Bourouis, M. Feham, M.A. Hossain, L. Zhang. 2014. An Intelligent Mobile Based Decision Support System for Retinal Disease Diagnosis *Decision Support Systems. 59:* 341-350

[17] de la Torre-Díez, Isabel, et al. 2015. Decision Support Systems and Applications in Ophthalmology: Literature and Commercial Review Focused on Mobile Apps. *Journal of medical systems* 39(1): 1-10.

[18] Prasanna, Prateek, et al. 2013. Decision Support System for Detection of Diabetic Retinopathy Using Smartphones. *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2013 7th International Conference on*. IEEE

[19] Myung, David, et al. 2014. D Printed Smartphone Indirect Lens Adapter for Rapid, High Quality Retinal Imaging. *Journal of Mobile Technology in Medicine* 3(1): 9-15.

[20] Hu, X-P., L. Dempere-Marco, and G-Z. Yang. 2003. Hot Spot Detection Based On Feature Space Representation of Visual Search in Medical Imaging. *Information Technology Applications in Biomedicine, 2003. 4th International IEEE EMBS Special Topic Conference on*. IEEE