Title: A Novel Application of Convolutional Neural Networks to Detect Vitamin A Deficiency and Combat Childhood Blindness

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Advisors:

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Abstract:

Vitamin A deficiency (VAD) is a serious health issue in developing countries and is the leading cause of preventable childhood blindness. The World Health Organization (WHO) estimates that 250,000 to 500,000 children go blind from VAD each year, half of them dying within 12 months of losing their sight. While vitamin A supplementation programs have significantly reduced the prevalence of VAD, there are still countries where the detection and tracking of VAD is sorely lacking. Conversely, mobile phone ownership and the use of mobile health apps in developing countries is growing rapidly. We propose a cost-effective and widely accessible method of counteracting VAD in the form of a free mobile application that detects Bitot's spots, a specific manifestation of VAD, using the phone's camera. The app will prompt users to take a photo of their eye (or their child's eye), and then analyze the image using a Convolutional Neural Network (CNN) to determine whether the image has Bitot's spots. The app will inform users of the results, list possible treatment options, and share basic information about VAD as well as

vitamin A supplementation. The app will provide health workers and affected populations with a powerful tool to identify and track VAD.

Idea/The Problem:

Vitamin A deficiency is a widespread problem in developing countries, affecting an estimated 250 million preschool children globally (World Health Organization: Micronutrient deficiencies, n.d.). VAD impairs people's immune systems, increasing their risk of acquiring fatal infections. If left untreated, VAD can cause xerophthalmia, a progressive eye disease that leads to blindness. Despite the staggering casualties caused by VAD, no existing solution has eliminated the condition.

Idea/Current Work:

Universal vitamin A supplementation (VAS) is currently the leading method of combating VAD. VAS has significantly reduced the incidence of VAD in countries that have implemented programs, but the problem is far from solved. A dismal 54% of people in West Africa have received VAS, leaving more than 165 million of its inhabitants untreated (UNICEF, Vitamin A supplementation interactive dashboard, 2016). A scarcity of trained medical professionals in developing countries makes VAS harder to implement. Many people living in developing countries do not have direct contact with a trained health worker and thus may not be provided with VAS. Most do not know to seek VAS either because they are not aware of VAD or do not know how to treat it. If VAS is to succeed, people living in developing countries must learn more about VAD.

There are few existing mobile apps aimed at spreading awareness about vitamin deficiency. We found just one — the *Vitamin Deficiency Finder* (VDF) — that briefly touches on VAD. The VDF app questions users about symptoms associated with vitamin deficiencies and then informs them which deficiencies they are likely to have. It makes dietary recommendations to address these deficiencies. Our app goes deeper by analyzing an individual’s eye for the appearance of Bitot’s spots, reducing interpretation error and providing more accurate and helpful information.

Idea/The Solution:

Our solution will better enable users to detect and treat VAD. We will make a software application downloadable on Android phones that will detect Bitot’s spots. The app will inform the user about the symptoms of VAD and then prompt her to take a photo of her eye or — since children are particularly vulnerable to VAD — her child’s eye. Our algorithm will classify the photo as having or not having Bitot’s spots using a trained CNN. If it classifies the eye as one with Bitot’s spots it will inform the user that she may have an eye disease caused by vitamin A deficiency. The app will provide information about vitamin A supplements to treat this disease and suggest that the user consult a local healthcare worker, hospital or clinic. To keep our solution manageable within a six-month time frame, we will initially deploy the app in just one country—most likely Ethiopia based on our connections to organizations and researchers targeting VAD there.

Our solution draws inspiration from recent AI projects that have used machine learning to facilitate the detection of other eye diseases. For example, a team in China developed a Web application called CC-Cruiser to diagnose congenital cataracts. That team used data sets of 410 eyes with cataracts and 478 healthy eyes to train and test their CNN and achieved a 90% classification accuracy (Scudellari, 2017). It is thus reasonable to conclude that we can train and test our CNN using a similar number or slightly less images. The detection of eye cataracts is a similar task to the detection of Bitot’s spots since both appear on the surface of the eye and are clearly visible to the naked eye.

Plan/Approach:

We will develop our product in five stages: 1. We will compile our data sets of eye images (Bitot's spots and healthy/control); 2. We will create the CNN on a computing service (backend), training and testing it with our eye images; 3. We will build the basic features of the app to enable users to learn about VAD and take a photo of their eye (frontend); 4. We will connect the app frontend with the app backend via an Application Program Interface (API). 5. We will continuously test the app and work to improve its performance.

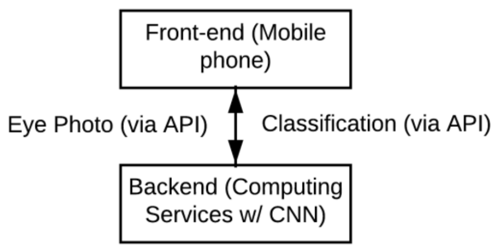

Figure 1: Connection between Front-End and Back-End of the App

Stage 1: We will collect data sets with both non-Bitot's eye images and eyes with Bitot's spots so that we can train our algorithm to properly distinguish between the two. The non-Bitot's images will come from Kaggle's Eye Gaze data set. We have identified a few probable sources for Bitot's images, including a study conducted in Ethiopia that will likely have hundreds of images of Bitot's (Demissie, Ali, Mekonen, Haider, & Umeta, 2010), enough to build our data set. We have reached out to the PI of that study, Dr. Tsegaye Demissie from the Ethiopian Health and Nutrition Research Institute. We have also reached out to an ophthalmology residency training program at St. Paul's Hospital Millennium Medical Center in Addis Ababa that is a partnership with the Kellogg Eye Center for International Ophthalmology.

Stage 2: We will use PyTorch, an open-source ML library in Python to create our CNN. Our training set will consist of the certified images of Bitot's spots shuffled with non-Bitot's eye images. We will train the CNN to classify whether a sample image is an instance of non-Bitot's or Bitot's spots. As we design the network, we will make modifications to the number of layers, our activation function, and the degree of image pooling after testing. We will split the shuffled eye images into training and testing data using k-fold cross validation and will train the algorithm with the former images. A single convolutional layer will consist of convolution, followed by max pooling and Relu activation. The CNN will likely consist of a couple of convolutional layers followed by linear layers.

Stages 3 and 4: We will build an elementary Android application using Android Studio. The app will display brief text and accompanying images describing the symptoms (Bitot's spots and a few other symptoms), causes, and risks of VAD. Next, we will display a button and a call to action to take a close-up photo of one of the user's eyes. We will implement the Viola-Jones eye detection algorithm using OpenCV, a package supporting PyTorch and similar deep learning frameworks, to determine whether an eye appears in the image. If the algorithm does not identify an eye, it will prompt the user to retake the photo. Once the app identifies an eye, it will crop it out of the image and display it to the user. The cropped image will be sent via API to our CNN on the backend. The CNN will analyze the image and send the results back to the app frontend. The app displays the user's results and lists treatment options if the user has Bitot's spots.

Stage 5: Testing will happen throughout the production process. The testing categories are spelled out in the Goals section below.

Plan/Resources:

- Dataset of eyes with Bitot's spots and a non-Bitot's control dataset
- Android Studio 3.2.1 (Windows Download)
- Python packages for PyTorch and OpenCV
- Computing Service (Google Cloud, AWS Lambda, tbd.)

- Nokia 3310 3G or another Android phone for testing purposes
- Digital media specialist to produce video
- Resident ophthalmologist to verify Bitot's spots

Android Studio, PyTorch, and OpenCV are all free, and we have a Nokia 3310 3G. We are confident that we will get computing services for free or at a discounted rate due to our status as high school students as well as this being a public service project. We will find a resident ophthalmologist through the residency training program at St. Paul's Hospital Millennium Medical Center.

Plan/Goals:

Milestone 1—Define/Design: Write a design document detailing the features and functionality of the app.

Milestone 2—Collect and Confirm Images to Train our CNN: Collect at least 350 Bitot's eye images and 350 non-Bitot's eye images. Ophthalmology residents will confirm Bitot's images.

Milestone 3—Building, training, and testing the Convolutional Neural Network: A) Write working code; B) Train and test the CNN for accuracy, sensitivity, and specificity; C) Work to achieve at least 80% classification accuracy.

Milestone 4—App Development: A) The app opens when clicked (no runtime error); B) Button appears and when clicked it accesses the user's camera; C) The app prompts the user to retake the photo if an eye does not appear; D) The app accepts a photo with a clearly visible eye; E) Using the OpenCV eye detection algorithm, the app returns the cropped photo of the eye.

Milestone 5—Integration of App with Computing Service: A) Photos taken with the app are transported via API to CNN backend; B) Once evaluated, the classification results of the CNN are sent back to the user's mobile phone; C) Updates to the CNN do not affect functionality of the app; D) The app displays the correct diagnosis.

Milestone 6—Testing & Quality Assurance: In addition to the QA/testing done throughout the development process, we will ask our resident ophthalmologist partners in Ethiopia to test the app on at least five people with suspected Bitot's spots and at least 10 normal subjects. Our goal is that the resident ophthalmologists will report a classification accuracy of 80% or greater while using the app.

Milestone 7—Release Candidate/Soft Launch: A) Complete short video about the app and the process of building it; B) Publish app on Google Play;

Responsibilities: Zach will document the process through each step. Zach will be responsible for collecting and confirming the Bitot's and non-Bitot's images. Zach will also be responsible for writing the code for the CNN. Zev will test and improve the performance of the CNN. Zev will be responsible for developing the frontend of the app. Zev will also be responsible for integrating the CNN with the frontend via an API. We will work together to create the promotional video and publish the app on Google Play. We have a history of collaborating: We have been working together for 4 months on the project and have worked together on the school's robotics programming team for 2 years.

Plan/Risks:

1. *Eye image datasets*: It is possible that the institutions we have contacted will not have the required Bitot's spots images. If so, we will modify our test for VAD to a test for night blindness. We would alter the brightness on the user's phone and ask them to identify the letters displayed on the screen. If, in low light, the user fails to identify the same number of letters as in normal light, we would identify him/her as being at risk for night blindness and provide him/her with a list of treatment options.

2. *Budget*: If our current sources do not have the Bitot's spots images, but are willing to collect them, they may charge us a fee greater than our contingency of $125. We would a) Negotiate with them; b) Seek external funding; c) Test for night blindness instead of Bitot's spots. Additionally, it is possible that we will not have computing services donated (or provided through MIT). In that case, we will find a more affordable alternative.

3. *Classification*: If the classification of Bitot's spots is not as simple as we anticipated, it may require the purchase of advanced ML software outside of our budget, though we hope this software will be available through MIT (groups such as CSAIL, etc.).

Plan/Timeline

Time	**Milestone/Deliverable**	**Documentation**
January 7–21 (2 wks)	Milestone 1: Define/Design	Wireframes/Designs
Jan 14–Feb 11 (4 wks)	Milestone 2: Collect/Confirm Datasets	Report with sample images and ophthalmologists verification.
Feb 11–Mar 25 (6 wks)	Milestone 3: Building, training, and testing the CNN	Show CNN (code and report)
Mar 11–May 23 (6 wks)	Milestone 4: App Development	Show functional app (video)
May 23 - June 3 (2 wks)	Milestone 5: Integration of CNN and App	Report/Video
June 3–17 (2 wks)	Milestone 6: Testing & Quality Assurance	Report, including field testing results and video
June 10 - 24 (2 wks)	Milestone 7: Release Candidate/Soft Launch	Final video (showing all stages and final app)

Plan/Current Progress:

We have been working with a computer vision specialist (Dr. Pooj) and public health faculty at Columbia. After consulting with Dr. Pooj, we have determined the best approach to the binary classification task is the CNN. From her, we have learned a lot about the CNN and the OpenCV eye detection algorithm. We have performed basic image processing techniques on a sample set of Bitot's images using MATLAB and have achieved above 60% classification accuracy on these preliminary tests. We have identified our target country of Ethiopia and have researched Android prevalence there. We have determined that we will use Android Studio to develop the app. We have researched sources for a Bitot's data set and have already contacted several leads.

Plan/Need for Funding:

We are not qualified to classify medical images like Bitot's spots and thus need funding to pay someone to perform this task. We may also need to pay ophthalmologists in Ethiopia to test the app when complete. We have identified someone to help produce and edit a video for $200. We hope that MIT researchers (at CSAIL or other mentors) will help us achieve the 80% classification accuracy by providing us with state-of-the-art ML software as well as guidance.

Projected budget:

Item	Amount	Estimated Cost
Resident ophthalmologists (classifying images)	2	$300 ($150 per person)[1]
Digital media specialist (promotional materials)	1	$200
Resident ophthalmologists (testing the app)	2	$240 ($120 per person)[2]

[1] Estimate based on expected classification rate and average hourly salary for resident ophthalmologists.

[2] Estimate based on resident's salary plus expected time to test each patient plus record results.

Computing Service (i.e. Google Cloud/AWS)	1	$50[3]
Publishing app/Google Play	N/A	$25
Other/Contingency	N/A	$125
Estimated Total*	**N/A**	**$875-1000***

* Given student-driven, public service project, we intend to request donated and/or discounted services. Therefore, the budget above may vary.

Personal:

My name is Zachary Hine and I am a 16-year-old junior at Bronx High School of Science with a passion for math, robotics, and computer science. I am competent in Java, Python, and MatLab, and am currently learning HTML5. I have studied some C and have used TensorFlow. I'm also a programmer for the BxSci Robotics team where most of our coding is done in Java. For this project I'll need to learn Android Studio, and there's always more to learn about ML. Since April 2017, I have been pursuing research at the Columbia University Medical Center with Professor Jiook Cha, where I'm applying ML to neuroimaging data to make more accurate predictions about patients' response to prescription medication. I am knowledgeable in the structure and implementation of Convolutional Neural Networks, having built such networks from scratch in my research with Dr. Cha. I was inspired by my research with Dr. Cha to find a problem that I could work on with ML. Through research, I became interested in how ML could be used to detect ocular manifestations of VAD.

[3] Amazon's AWS Educate initiative allows students to apply for free usage of AWS services. $50 contingency.

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