Age Estimation of Adolescents and Adults Using the Dimensions of the Eye and Pupil in "Selfie" Photographs

KariAnna Baber, BA, BS
Research Advisors: Dr. Terry Fenger (MUFSC), Joshua Brunty (MUIS&T),
Cpl. Robert Boggs (WVSP), Ian Levstein (MUFSC)
Summer 2014 Internship with Marshall University Forensic Science Center
West Virginia State Police Digital Forensics Unit

Abstract

The goal of this project is to demonstrate the effectiveness of investigating digital images and correlating an age with the photographed individual. This becomes most relevant for individuals in the teenage age range, who often appear older in age due to the use of make-up, posing, and filter technologies commonly used to take a picture of oneself -- otherwise known as a "selfie." By analyzing features of the face, particularly the eye and pupil regions, the subject has less ability to hinder age estimation based solely on physical appearance. Institution Review Board (IRB) approval was obtained in order to use human subjects. The target age group of participants was between 11-19 years old, however participants not within the age range were accepted. Because there are many variables that influence the functionality of the pupils, such as mood, eye problems, medications, and lighting, images were taken under controlled conditions which include using the same room and lighting. Each subject was given an ID number for the project, and asked a simple list of questions detailing his/her mood, medications, and eye problem history as well as his/her age, birthday and other demographic information. A series of pictures were taken of the individual with a Nikon® D3100 digital camera and Apple® iPad® iOS Version 7.1.1, along with a short video of around the participant's face. The images were downloaded onto a computer for analysis using Photoshop®. Each image was calibrated so that the pupillary diameter, area, and interpupillary distance could be determined and compared using formulas given in MacLachlan & Howland, 2002. Using the known age of each participant and the age from the formulas, the effectiveness of age estimation can be determined.

Literature Research

In the forensic analysis of digital images and age, there are two possible avenues that can potentially determine a correlation. First, there is age synthesis, which involves the process of changing the appearance of the face to mimic the natural aging process (Fu, Guo, Huang, 2010). An example of this process is using a child image and synthesizing the face to appear older. This can be seen on missing children posters. Second, there is age estimation, which involves assigning an exact age or age group to the subject featured in an image. This is a soft biometric technique in that it does not aim to identify an individual, but provides supportive, descriptive information about an individual (Fu, Guo, Huang, 2010). While the perceived age and appearance age can be easily altered, it would be beneficial to be able to determine an estimated age that would place a subject in a minor or non-minor grouping. This is the target process that has potential to be applicable to forensic digital examiners in crimes involving minors.

Age estimation has been found to be most difficult with younger subjects for a variety of reasons (Zeng, et al., 2012). First of all, the image factors such as resolution, quality, and lighting increase the difficulty in an age estimation exercise. A possible way to circumvent these issues is converting the image into gray scale. Second, images of younger individuals are more difficult to assign a perceived age, especially when factoring ethnicity and gender features. Conversely, children were easier to age estimate than adults because of the growth stages of different features in the face.

Certain features of the face have been used for soft biometric age estimations. The ears, nose, mouth width, and facial form are some physical features that continue to change with

age. In a study done by Guyomarc'h & Stephen in 2012, features of the ears were measured and it was determined that this method and feature was minimally accurate in for several reasons. Most strikingly is the subjectivity involved in finding the significant feature positions for measurement and the lack of reference data. Another study conducted by El Dib & Onsi (2011) used multiple eye wrinkle and forehead feature points for age estimation. The process involved cropping an image in different shapes depending on the number of feature points and active shape models, Gabor functions, support vector machines (SVM), and support vector regression (SVR). The mean absolute error (MAE) is around 3 years using these algorithms. However, this study is not representative of minors because of the databases used for analysis (El Dib & Onsi, 2011).

Other computer generated algorithms, along with SVM and SVR, include partial least squares methods (PLM) (Guo & Mu, 2011). This method produced a MAE around 4.5 years, while a linear SVM produced an MAE of 5 years when used on a particular database. Furthermore, using another database, the MAE produced from different algorithms where within 0.45 years of each other. More databases and algorithms along with the use of biologically inspired features have been examined which reduce the MAE to as low as 2.61 years for females and 2.58 for males in different combinations (Guo et al., 2009).

In the field of ophthalmology and optometry, studies and work have been done focusing on using the pupil of an eye. Two important studies in particular, have found a relationship between the pupil measurements and age. In 2009, Lavezzo, Schellini, Padovani, and Hirai conducted a study using preschool aged children and focused on the differences in the pupil with gaze types. An attentive gaze is considered initial and focused, while a spontaneous gaze is

considered comfortable and exploring the environment. After taking a digital image of the child and controlling the illumination, the image was inverted to take measurement. It was found that the diameter of the pupil differs in spontaneous and attentive gazes, but that the right pupil and the left pupil could be considered equal and within the error range of the mean.

Another study included the tracking of children from 1 month old to 19 years of age (MacLachlam & Howland, 2002). Each year, the individual's eyes were photographed using a fiber optic light guide in a camera lens and flash gun at two different illumination settings. One image at ambient light, 300 lux, and another in dimmed lightening, 15.9 lux. The images were analyzed by measuring pupillary diameter, area, and interpupillary distance. It was found that all three of these measurements have the potential to correspond with age, however the results of children in the 12-19 year old range has a decreased amount of data due to subjects leaving the study. From this study, equations were that correlate each measurement with an age as well as consider gender and the change of illumination in different photographs. Furthermore, an additional measurement could be potentially useful in the field of forensics. Considering the ratio of the cornea to the pupil diameter, may allow for a decreased MAE in age estimation in forensics, although it is used in ophthalmology for surgical planning (Cakmak, et al., 2012).

Considering the pupil for soft biometrics may be new, but using another feature of the eye is known. Hard biometric techniques, which aim to identify an individual, have aimed to use the iris as a means of identification and security (Fu, Guo, Huang, 2010). The iris is the colored part of the eye, which is converted from a round, donut image to a rectangle (Poonguzhali & Ezhilarasan, 2012). The features within the iris are transformed into a pattern using

normalization, sharpening, and Gabor functions. This final information image is then read in a way that matches the pattern to a known database image with corresponding information, similar to a bar code, in order to identify.

Using the iris biometerics is not without its problems, particularly when considering how the pupil works (Hollingsworth et al., 2009). Pupil dilation is affected by many factors such as drug usage, mood, light exposure, and health problems such as cataracts (Lavezzo et al., 2009). When the pupil increases, less of the iris is exposed and when the pupil in constricted, more of the iris is exposed. One of the easiest variables to control is lighting. It then becomes important to normalize the iris pattern when the pupils are at the most extreme degrees of dilation. Complicating the procedure more, the resolution of the image or scanner needs to be able to detect pattern well enough to procure a match from the database (Hollingsworth et al., 2009).

Introduction

Today, in these modern times, the dependence people have on digital devices has increased and is still increasing. From digital cameras to smart phones to tablets, there is a constant opportunity for nearly anyone and everyone to be connected to the internet in order to find information, store information, post about daily routines to social media, and purchase merchandise, not to mention the ever growing downloadable apps that are featured to assist a user in a particular task. Keeping in contact across long distances is easier, deals are easier to find, and massive amounts of information can be obtained and stored in reachable locations and are available anytime, anywhere.

While this makes many daily activities and communication simpler, a new wave of criminal behavior has emerged with unique digital evidence to be analyzed. In particular, digital

images have the potential to be found anywhere from the data in suspect cell phones to personal computer hard drives. These images can be stored and shared with others on the cloud, through social media sites, e-mail, applications, and multimedia messages (MMS). Increasing in popularity is the trend of taking selfies. A selfie is defined by the Oxford dictionary as "a photograph that one has taken of oneself, typically one taken with a smartphone or webcam and shared via social media." Taking a selfie can occur anywhere, anytime, and shared with others, keeping a constant, open line of communication. People take selfies when they are mad, sad, happy, doing something crazy, wearing something stylish, or even to show boredom. This trend has even grown to include taking large group selfies known "usies." One of the more recent and well known examples of this was the picture taken by Ellen DeGeneres during the 2014 Academy Awards. In fact, this usie image was so popular that it crashed the social media site Twitter.com. A feature common selfies which cannot be consciously controlled is the pupil. Even with the most magnificent make-up job or silliest facial expression, the pupil is going to respond in an unconscious way. Pupil size can be altered by numerous factors such as drug usage, mood, light exposure, and health problems such as cataracts (Cakmak, et al., 2012).

However, these images may not be as ordinary as a picture of one's dog or from the night of a best friend's wedding. Digital images have become prevalent in criminal behaviors such as the distribution and possession of child pornography, sexting, stalking, harassment, and prostitution and solicitation. Many of the crimes listed are of concern because of the involvement of minors as well as the frequency at which these types of cases are being seen by forensic digital analysts. While it may be common to utilize the terms "child" and "minor" interchangeably in lay conversation, legally they can have different implications depending on

state statues. The terms generally differ in the age associated with maturity. According to one legal dictionary, a child is anyone under the age of 14 while a minor is under the age of 18 (http://legal-dictionary.thefreedictionary.com/child). In the state of West Virginia, however, a child is anyone under the age of 18 years old, which is the same as the definition of a minor (http://www.legis.state.wv.us/wvcode). This becomes an important fact to consider when determining what kind of crime was committed, if one was at all.

Typically, when thinking of the crimes listed previously and thinking of children, the image of a kindergartener, someone around 5 years old, comes to mind. But, there is an age group of children that can frequently appear much older than they actually are adolescents. With the use of make-up, posing, lighting, outfits, etc. adolescents can alter their perceived and appearance age while masking their actual age in images taken on digital devices. Then, these pictures may end up on social media sites, be sent as an MMS to a friend, or used in matters of child exploitation. In evidentiary images, making a determination which describes the subject as a minor or minor is difficult and problematic based on physical appearance. So, the question becomes whether age can be determined from a digital image using pupil and eye measurements that cannot be consciously controlled and is there an appropriate methodology to determine age from a digital image?

Institutional Review Board (IRB) Approval

Although previous studies have used existing databases to retrieve and analyze for age estimation purposes, it was believed that having the ability to control as much of the environment in which the pictures would be taken would be most beneficial. This entails using actual adolescents as participants to photograph. Because children are a protected population

and the personal, face-to-face interaction became necessary, IRB approval needed to be granted.

In a meeting with Bruce Day at the Office of Research Integrity at Marshall University, it was required to apply for an expedited review of a social research project. Social research projects differ from medical research projects in that there is a lack of medicine trials, and typically the risk-benefit components of participation are minimal. An expedited review was chosen because of the absence of risk and benefit to participants. In other words, by participating in this project, a participant would not be at any risk or gain any prize or reward.

With that, the privacy and confidentially of the participant and their information is important. This project design only records a participant name on permission and consent forms which are stored in a random, unparticular order. The worksheet designed to assist in the picture taking process assigns a participant number to the individual allowing the confidentially of the participant to be protected. The participant numbers were given in order of data collection to correspond to the order of the images taken, but do not match the order of the consent forms. The privacy of the participants was considered and a protocol to house the images on one, password protected computer which is located in a keyed access room at Marshall University Forensic Science Program. The stored images would be labeled by participant number and age. Again, the order of the images and participant number are not matched with the names on the consent forms.

Parental permission, child assent, and informed consent forms were developed using a standard template provided by Bruce Day. Along with those forms, an advertisement to recruit participants through personal connections, an abstract, and a protocol were also created and

submitted for approval by the board. Upon approval, the life of the project would be one year. After this year all forms and images will be kept with Dr. Terry Fenger for 3 years for audit purposes. Should the project continue in the future, an extension could be requested in 1 year increments. If there is no extension, then all of the images cannot be used in future work and are essentially "out of play."

Furthermore, it was necessary to submit a CV/resume of all the people on research team and obtain the CITI certification required by IRB. This includes KariAnna Baber, Josh Brunty, and Dr. Terry Fenger. After submission, it took about a week for the approval to come through.

Methods and Materials

The approved advertisement was passed to personal connections and spread through e-mail. The targeted age groups of participants are those 11-19 years old. This age range was chosen based on the drop-off of data that reference studies showed. Also because this group is active in social media, taking selfies, and has the potential to appear more mature in age. This range goes up to 19 years old in a hope to find a distinguishable difference between the age estimation of minors and non minors which is less specific than estimating a yearly age of each individual. Dates and times for participation were on the advertisements, but appoints outside of those times were also possible.

In order to see the if ability to efficiently age estimate a minor and non-minor using pupil measurements, the studies by Lavezzo et al. (2009), MacLachlan & Howard (2002), and Watson & Yellott. (2012), have been used as models for design. The room in which the pictures were taken was monitored with a Dr. Meter ® lux meter to find the lux value before any

pictures are taken of an individual. These measurements were taken by holding the detector towards the camera at the position of the participant's eyes. Once lux is recorded and used for the remainder of the pictures. This is assuming that the lights do not change and that the sunlight able to enter the room remains consistent. Using a Nikon® D3100 digital camera, two reference images of an individual are taken, one at an attentive gaze and the other at a spontaneous gaze, at 1.5 meters (59.06 inches) from the viewfinder to the pupil. The set-ip can be seen in Figure 1.

Figure 1: Method set-up with digital camera

During these photographs, a crime scene ruler is to be placed in the plane of the pupil to provide measurement references. Participants wearing glasses were asked to remove glasses for a second set of images, with the same gazes, in case the glasses caused analytical differences. After the reference images, an Apple® iPad® version 7.1.1 was used to take a selfie image and a short, 10 second video of the participant moving the iPad® around the face and looking into the camera. The video aims to record different angles of the participant's eyes for pupil measurements and comparisons using Adobe® Photoshop® Cs5 Extended version 12.1

x32. The set-up can be visualized in Figure 2.

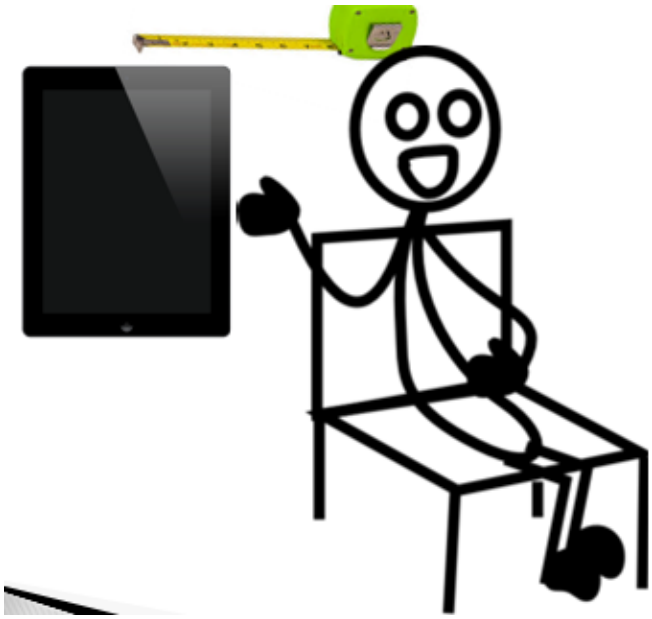

Figure 2: Method set-up with iPad

A worksheet was developed to assist during the data gathering process. On the worksheet, demographic information like ethnicity, birthday, and actual age were all recorded. In addition, the date, eye problems, whether medication was taken previously, mood, and whether the required consent and permission forms were signed and collected. Then, the number of images taken with the camera and the tablet were recorded, as was the lux value determined by the lux meter. The arm length at which the participant held the tablet to take the selfie was recorded, whether or not a video was taken, and the camera settings used to take the reference images.

Once images were taken, they were uploaded to a single computer in the MISDE lab at Marshall University Forensic Science Center (MUFSC). Images on an SD card were transferred using a write-blocking SC card reader. The images and videos from the iPad® were transferred using a USB-connector. All the images were placed in a folder titled BaberResearch, followed by

subfolders depicting the device in which the images came. The images were named by the participant number. The gaze type was also included in the naming scheme so the two were not confused.

Results

A request for advice was sent to several ophthalmologists associated with Marshall University School of Medicine. Dr. Charles Francis was one of the professionals who responded and a meeting to ask questions and share the idea of the project was set up. During this meeting, Dr. Francis pointed out several areas of concern and answered many questions.

First, he pointed out the drop out of individuals included in the MacLachlan & Howard article (2002). To correct for this, he suggested obtaining a minimum 50 participants of each age in the targeted age range, or a statistically significant number of each area in order to be able to apply the age estimation to an entire population. Another issue he brought up was the difficulty associated with controlling the pupil dilation. He said mood, drugs, and near or far sightedness would affect the pupil so those factors should be considered. A suggestion of analysis was also made stating that it may be beneficial to find the ratio of the pupil to the cornea. He said that the cornea average 11 mm, and at first glance, at an attentive gaze, the pupil should be bigger than a glance that has been on-going, a spontaneous gaze. These were fantastic suggestions because they correlated well with the literature research that was previously done. It was also discussed that the pupil is to be a circle, not an irregular shape, and that it would be a circle no matter the angle it may be seen from. Now, this is a healthy, ordinary pupil, assuming no usual medical conditions exist.

During the conversation, Dr. Francis mentioned the different materials he has that may

be potentially useful in the project, such as pupil rulers and infrared pupilometers. However, it was difficult to keep in constant communication with each other during the summer, but it is respected that his schedule during the summer was incredibly busy.

As a volunteer at CONTACT Rape Crisis Center, employees were contacted in person and by e-mail to assist in finding participants. In particular, Kerri Thomas, Liz Deal, Adriane Beasley, and Donnel Horn, all reached out to personal friends and family member to find participants with-in the age group. The organization was, and continues to be, completely supportive of the project and still attempting to recruit interested participants. Messages were sent to faculty and staff in MUFSC to recruit, as were several middle and high schools.

After recruitment, only 10 participants showed up to participate. Of the nine participants, there were 8 females, 2 males, 5 African-Americans, and 5 Caucasians. More information can be found in Table 1 and 2. Table 1 demonstrates the ages of the participants. The ages were not collected evenly and are at the lowest and highest ages in the targeted range. Most of the participants wore glasses, which can be seen in Table 2. The mood of the participants was mostly content, while a few described themselves as happy or calm, which is displayed in Figure 1. Five of the 9 participants were not on any medications which can be seen in Figure 2. The ones that reported they were had previously taken allergy medications, and anti-depressants.

Table 1: Participant Age(years)								
11	12	13	14	15	16	17	18	19
3	1	0	1	0	0	0	3	2

Table 2: Participant Eye Problems			
Glasses	Contacts	Cataracts	None
6	0	0	4

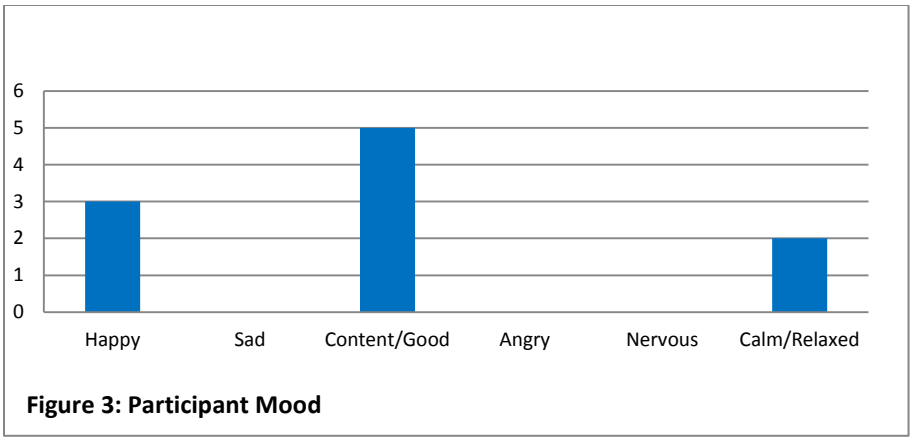

Figure 3: Participant Mood

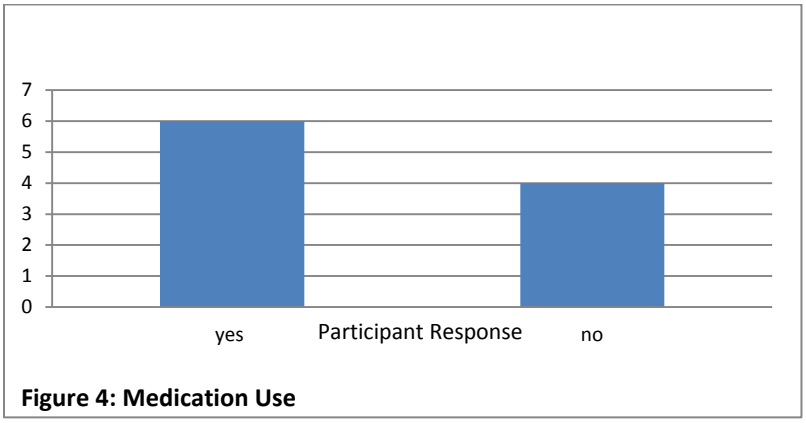

Figure 4: Medication Use

Discussion & Future Work

The turn out of the participants was not what was hoped for by the end of the internship. After doing research, obtaining IRB approval, and waiting for participants to show up, there was no time to really delve into much analysis over the summer. The lack of participants may have been due to the fact that few people were in town and able to come to MUSFC for participants because of summer break, or a lack of transportation. In one instance in particular, emails sent to schools were spammed and a message went out to all teachers in the district that no response should be sent to inquire more information or show interest. It is not really sure if the avenue of communication was inappropriate, or if the wrong people were emailed, but that was a very discouraging point. Many appointments were set over the phone

and through email with various people, but more often than not, people did not show up.

After discussion with advisors, it was decided that working on the project could continue into the semester in hopes of better schedule coordination and finding participants so there was sufficient data to analyze. Over the semester there was an increased effort to find a suitable number of participants for analysis to take place. Once that happens, there are several different problems that need to be addressed.

First, is the metadata of the images, particularly those from the iPad®. The metadata of the camera should provide information about the settings. The camera was set in aperture priority mode, but with the shutter speed setting, ISO value, and f/stop, the luminescence can be calculated. This is opposite of how typical light meters work to tell the camera what settings are best to use in the particular lighting. By using the equation

$$2Ev = \frac{N^2}{t} = \frac{L * S}{C}$$

where Ev= exposure value, N= aperture, t= shutter speed, s= ISO value, and C=12.5 as the calibration constant for a Nikon or Cannon digital camera, the lux, L, can be calculate. The one issue when doing this with images from the iPad® is there is no C value to determine lux. However it may be possible to create a value that would allow the equation to work. Figure 4 is a representation of the raw metadata that was found from the digital images using the Nikon®.

Nikon® Metadata

image	Mode	focal length	35 mm focal length	Expos Bias	shutter speed (T)	f-stop (A)	ISO (S)	Dr. Lux Value	A^2/T	EV=luminescence (lux)	calculated Lux
001_attent	AV	45 mm	67	1.7	1/4	f/5.3	800	162.1	112.36	6.8119847	212.8745225
002_atten	AV	45 mm	67	1.7	1/8	f/5.3	800	292	224.72	7.8119847	244.1245225
003_atten_w	AV	45 mm	67	1.7	1/8	f/5.3	800	240	224.72	7.8119847	244.1245225
003_attent_w/o	AV	45 mm	67	1.7	1/8	f/5.3	800	240	224.72	7.8119847	244.1245225
004_attent	AV	45 mm	67	1.7	1/10	f/5.3	800	262	280.90	8.1339128	254.1847754
005_atten_w/o	AV	45 mm	67	1.7	1/6	f/5.3	800	230	168.54	7.3969472	231.1546006
005_atten_w	AV	45 mm	67	1.7	1/8	f/5.3	800	230	224.72	7.8119847	244.1245225
006_atten_w/o	AV	45 mm	67	1.7	1/8	f/5.3	800	216	224.72	7.8119847	244.1245225
006_attent_w	AV	45 mm	67	1.7	1/8	f/5.3	800	216	224.72	7.8119847	244.1245225
007_atten	AV	45 mm	67	1.7	1/8	f/5.3	800	251	224.72	7.8119847	244.1245225
008_atten_w	AV	45 mm	67	1.7	1/8	f/5.3	800	231	224.72	7.8119847	244.1245225
008_atten_w/o	AV	45 mm	67	1.7	1/6	f/5.3	800	231	168.54	7.3969472	231.1546006
009_atten_w/o	AV	45 mm	67	1.7	1/6	f/5.3	800	213	168.54	7.3969472	231.1546006
009_atten_w/o	AV	45 mm	67	1.7	1/8	f/5.3	800	213	224.72	7.8119847	244.1245225
009_atten_w	AV	45 mm	67	1.7	1/8	f/5.3	800	213	224.72	7.8119847	244.1245225
0014_atten	Manual	1.8 mm	27	1.7	1/8	f/3.5	800	220	98.00	6.6147098	206.7096826

Figure 5: Raw metadata to be analyzed from the Nikon camera. Notice the Dr. Meter lux value compared to the calculated lux value.

Second, the pupils need to be measured in order to determine axial diameter, area, and interpupillary distance. Using the reference images, it is possible to set a measurement scale in Photoshop® using the ruler that is present. Then, the images can be measured in millimeters. With these measurements, an estimated age can be determined using the following equations in which EA= estimated age, where were developed in the study done my MacLachlan and Howland (2002):

$$Axial\ length = 18.822 + 3.79 * EA$$

Figure 6: Demonstration of pupil diameter measurement.

$$Female\ Diameter = 5.40 + 0.285 * EA - 0.0109 * EA^2$$

$$Male\ Diameter = 5.83 + 0.181 * EA - 0.0053 * EA^2$$

Figure 7: Demonstration of interpupillary distance measurement.

$$Female\ Interpupillary\ Distance = 41.76 + 1.891 * EA - 0.052 * EA^2$$

$$Male\ Interpupillary\ Distance = 43.36 + 1.6631 * EA - 0.034 * EA^2$$

After an estimated age is found, an overall MAE can be determine using this technique using the equation listed below, where A= actual age and EA= estimated age.

$$MAE = \frac{1}{n}\sum_{A=1}^{n} |EA - A|$$

If this technique proves to be useful for reference images, then the images taken from the iPad® need to be analyzed the same way in order to determine the versatility of the

technique. However, the 10 reference images analyzed female and male pupil diameter did not show the same correlation as the referenced studies. This can be seen in Figures 8-11. Figure 8 demonstrates the female pupil diameters obtained whereas the male pupil diameters are in Figure 9. The trend does not match that in referenced studies, which mostly can be resulting from the small amount of participants. Interpupillary distances of females, Figure 10, and males, Figure 11, have the same trend conclusions. Ultimately, more participation is needed.

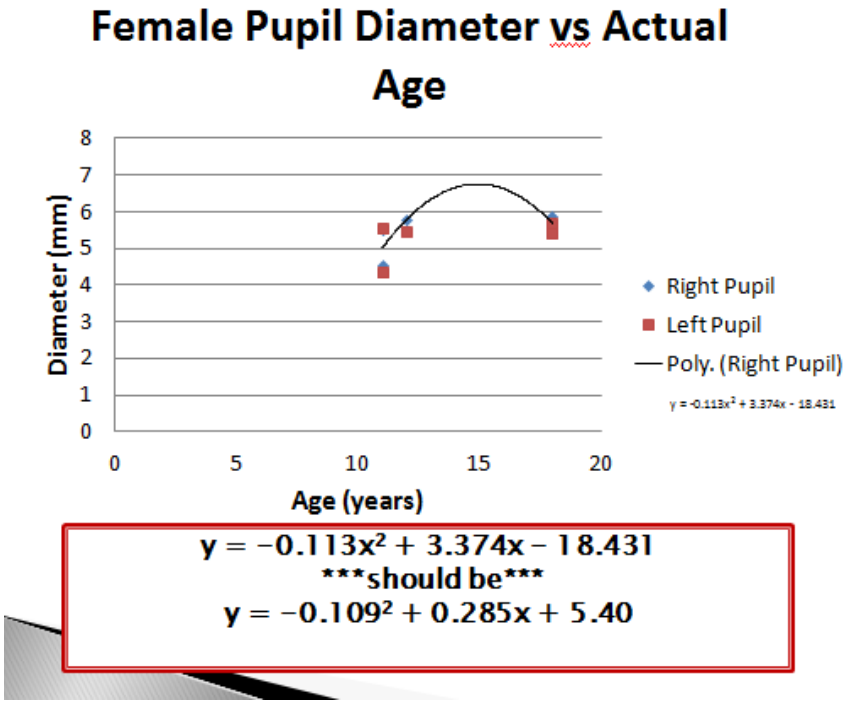

Figure 8: Female Pupil Diameter. The trend does not match that of the reference equation.

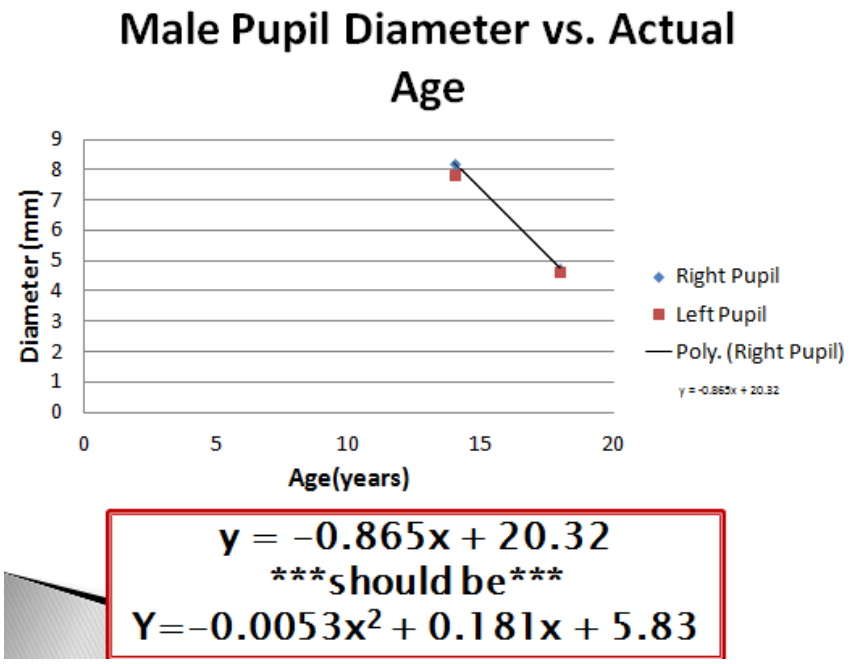

Figure 9: Male pupil diameters. Notice the difference in the equations. Since only 2 males allowed for measurements, the trend is linear, not second order polynomial as it should be.

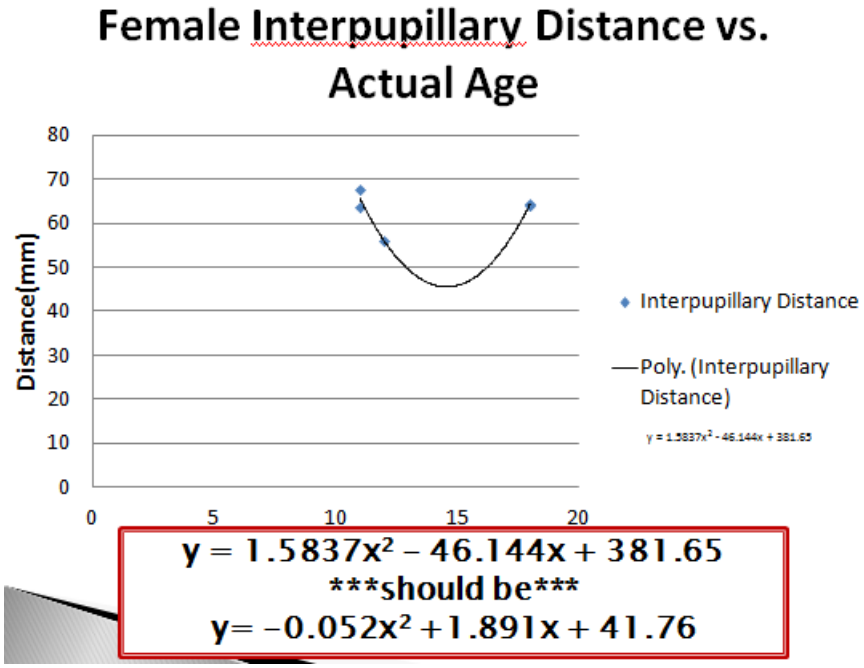

Figure 10: Female interpupillary distance. Still, the trends do not match.

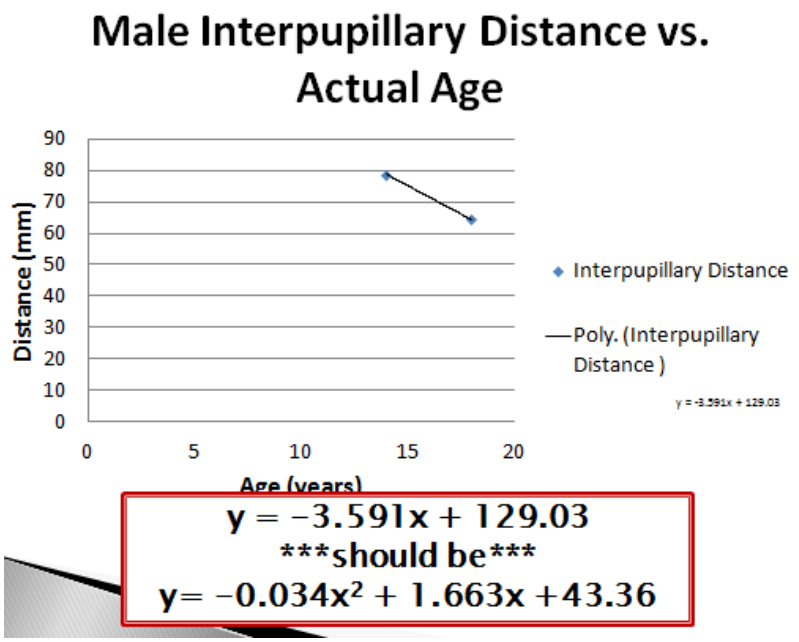

Figure 11: Male interpupillary distance. The trend is linear, which is due to the sample size being 2 individuals.

Acknowledgements

This project could not be possible without the participation of the adolescents and their parents. Their time, efforts, and interest are greatly appreciated. I thank those at CONTACT Rape Crisis center and the faculty and staff at Marshall University Forensic Science Center, especially John Sammons and Catherine Rushton, for their help with recruitment of participants. I thank Dr. Charles Francis for his time to talk to me and interest in the project, Bruce Day for his assistance in obtaining IRB approval. I thank Josh Brunty, Dr. Terry Fenger, Ian Levstein, and Corporal Robert Boggs for their support as advisors and encouragement in developing this project idea and their patience as road bumps were encountered. Finally, I thank Dr. Pamela Staton for the encouragement and providing me the opportunity of an internship with MUFSC and the West Virginia State Police Digital Forensics Unit.

References

Cakmak, H.B., Cagil, N., Simavli, H., Raza, S. (2012). Corneal white-to-white distance and mesopic pupil diameter, *International Journal of Opthamology,* 5(4), 505-509.

Dezfoli, F.N., Dehghantanha, A., Mahmoud, R., Binti, N.F., Sani, M., Daryabar, F. (2013). Digital forensic trends and future, *International Journal of Cyber-Security and Digital Forensics*, 2(2), 48-76.

Dowden, D. (2013). Facial recognition: the most "natural" forensic technology, *Evidence Technology Magazine*, September-October Issue, 10-14.

Eldib, M. Y. &Onsi, H. M. (2011). Human Age Estimation Framework Using Different Facial Parts, *Egyptian Informatics Journal*, 12(1), 53-59.

Fenger, Terry. Video evidence and forensic video comparison. Powerpoint. Received June 2, 2014.

Fu, Y., Guo, G-D., & Huang, T. (2010). Age synthesis and estimation via faces: A survey, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, 32(11), 1955-1976.

Guo, G-D., Mu, G., Fu, Y., Dyer, C., & Huang, T.S. (2009). A study on automatic age estimation using a large database, *IEEE International Conference on Computer Vision (ICCV'09),* 1986-1991.

Guo, G-D. & Mu, G. (2011). Simultaneous Dimensionality Reduction and Human Age Estimation via Kernel Partial Least Squares Regression, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR'11),* 657-664.

Guyomarc'h, P. & Stephan, C.N. (2012). The validity of ear prediction guidelines used in facial approximation, *Journal of Forensic Sciences,* 57(6), 1427-1441.

Hak, J.W. (2011). Legal and practical responses to the most common challenges faced by forensic video analysts. Received from Dr. Terry Fenger 6/4/2014.

Hollingsworth, K., Bowyer, K.W., Flynn, P.J. (2009). Pupil dilation degrades iris biometric performance, *Computer Vision and Image Understanding*, 113, 150-157.

http://www.oxforddictionaries.com/us/definition/american_english/selfie

http://legal-dictionary.thefreedictionary.com/child

http://www.legis.state.wv.us/wvcode

Jain, A., Bolle, R., & Pankanti, S. (1999). Biometrics: Personal identification in networked society. (pp. 20-41). Norwell, MA: Kluwer Academic Publishers.

Johnson, D.B., Perlin, V.E., Rohde, M.M., Thomas, A.C., Luu, C.Q., & Change, J. (2013). Establishing likelihood ratios for patterned garment comparisons from seam measurement data, *Journal of Forensic Sciences*, 58(3), 631-644.

Lavezzo, M.M., Schellini, S.A., Padovani, C.R. & Hirai, F.E. (2009). Evaluation of pupillary diameter in

preschool children, *Neuro-ophthalmology,* 33(6), 313-317.

MacLachlan, C. & Howland, H.C. (2002). Normal values and standard deviations for pupil diameter and interpupillary distance in subjects ages 1 month to 19 years, *Ophthalmic and Physiological Optics,* 22(3), 175-182.

Poonguzhali, N. & Ezhilarasan, M. (2013). Iris indexing techniques: A review, *International Journal of Computer Applications*, 73(18), 23-29.

Rocha, A., Scheirer, W., Boult, T., Goldenstein, S. (2010). Vision of the unseen: Current trends and challenges in digital image and video forensics, *ACM-CSUR pre-publication.*

Understanding dymanic range in digital photography. Retrieved June 9, 2012. http:/www.cambridgeincolor.com/tutorials/dynamic-range.htm

Watson, A.B. & Yellott, J.I. (2012). A unified formula for light adapted pupil size, *Journal of Vision*, 12(10), 1-16.

Zeng, J., Ling, H., Latecki, L.J., Figzhugh, S., & Guo, G-D., Analysis of facial images across age progression by humans, *ISRN Machine Vision*, Vol. 2012, Article ID 505974