Proceedings of Student-Faculty Research Day, CSIS, Pace University, May 8th, 2009

Face Biometrics: A Longitudinal Study

Faune Hughes, Daniel Lichter, Richard Oswald, and Michael Whitfield
Seidenberg School of CSIS, Pace University, White Plains, NY 10606, USA
{fh02789p, dl78906p, ro62178n, mw23749n}@pace.edu

Abstract

Faces change over time and this has been problematic for face biometric systems. Little research has been conducted in this area and this study reviews two face biometric systems, Neurotechnology's Verilook and Luxand's FaceSDK, and conducts experiments with the affects of aging in mind. Research was conducted on how anthropometrics is linked to facial biometric systems and the orbital areas of 13 candidates were analyzed. An extensive literature review of past and present face biometric applications was conducted and facial recognition software for laptops were reviewed for mobile user authentication.

1. Introduction

The increase in identity theft has caused a lack of trust among individuals. The proliferation of computer fraud has caused people to be apprehensive when communicating via technology. Since people communicate today through the Web it has become increasingly crucial that identity be validated. Businesses are also dependent on human computer interaction. Therefore, ongoing research into security applications is essential to the creation of a safety net, which will be beneficial to everyone [10].

In order to determine the feasibility of Facial Biometric applications, a review of current applications was conducted to assess the state of the technology. This study presents the results of a literature search and discusses experiments completed on relevant applications implementing facial biometrics and seeks to highlight references to describe the particular approach to solving the problems in biometric systems presented by aging.

2. Literature Review

2.1. Importance of Facial Biometrics

The growing need for enhanced security systems in government, commercial, and personal applications is increasingly being met by biometric identification methods. Biometric systems currently use fingerprints, iris, retina, palm vein, and faces for authentication. The two main functions of a biometric system are identification and verification.

For several reasons, "facial recognition technology should be considered as a serious alternative in the development of biometrical or multi-biometrical systems" [6]. It requires no interaction from the user and no advanced hardware. In contrast to fingerprints and eyes, the face does not have as many unique features that can be compared [6].

Areas that are of particular interest of the face and used for comparison are the "upper outlines of the eye sockets, the areas surrounding the cheekbones, the sides of the mouth, and the location of the nose and eyes" [7]. These areas are considered to hold the most distinct qualities of an individual's face. However, false acceptances are to be expected and are influenced by several factors such as lighting, an increase or decrease in weight, and aging.

2.2. Face Recognition Vendor Test

The Face Recognition Vendor Test (FRVT) 2006, conducted by the National Institutes of Standards and Technology is an internationally recognized large-scale experiment intended to document progress in face recognition in four important technical areas: high resolution still imagery (5 to 6 mega-pixels), 3D facial scans, multi-sample still facial imagery, and pre-processing algorithms that compensate for pose and illumination. The results of the FRVT 2006 test proved that there was improved performance by an order of magnitude over FRVT 2002. The 2006 test also established the first 3D face recognition benchmark and showed significant progress in matching faces under controlled and uncontrolled lighting. It is also worth noting that the FRVT 2006 showed that face recognition algorithms have the capability to perform better than humans [18].

2.3. Aging and Facial Recognition

Aging is likely to be the most challenging of problems for biometric technologies. Inherent in facial biometrics is the human aging factor and the possibility of false identification or failure of identification, due to facial morphology. Asking the question, "Can a face be recognized using an image taken 10 or 20 years prior?" is of concern to security, where authentication is essential.

The degree of variation that occurs in the face during aging of adults certainly affects outcomes for facial biometric systems. These changes have been studied sporadically in anthropological research and have received less attention in biometric-related literature [17].

According to W. Zhao, face recognition techniques perform best using images from well-controlled environments, but perform poorly when illumination varies in non-controlled environments. It is also challenging when large pose variations exist in the images due to their two-dimensional nature. To address this issue it is better to use three-dimensional images [24].

Roadblocks to pervasive implementation of current face recognition technology are reasons for high error rates. A reason is attributed to 2-D technology that is the basis of most of the current applications on the market. 2-D technology measures height, width and distance between feature points to make an identification which is flawed since faces are 3-D, with irregularly shaped features - noses, lips, ears, hair - that change in appearance as the face turns. Faces also reflect light and produce shadows, essentially creating new and different images. With 2-D technology, failure rates rise with changes in pose or expression or variable lighting [18].

2.4. Advantages of 3D Facial Recognition

Unlike its 2-D counterpart, 3-D face recognition uses the geometry of a subject’s facial structure. 3-D range cameras are used to capture the depth of an object instead of the color. In this way, the potential exists to achieve more accurate results. Range cameras may use optical imaging technologies such as triangulation, interferometry, and imaging radar [2].

Dr. Sooda Ramalingam has developed a new 3D system that is able to capture detailed images of faces while in motion [22]. This is viewed as a breakthrough because with previous systems, the subject needed to be within a controlled environment as well as stationary. Dr. Ramalingam states that this system “applies new mathematical algorithms and a stereo camera setup” [22]. A stereo camera setup uses two cameras allowing two lines of sight to cross each other at a single focus point [2], similar to how humans view objects. This new system photographs sections of a subject’s face and matches it to a template in the system. Ramalingam’s 3-D system is also believed to be faster than other systems like it and also allows real-time capture [22].

2.5. Age-Morphing

Face recognition research and technologies focus largely on the capabilities of computer algorithms to match stored, gallery images to digital images acquired from video sequences or still images for use in security and law enforcement venues. These algorithms try to reverse-engineer the human ability to innately recognize a familiar human face. However, one major aspect of this technology that has yet to be thoroughly explored is the effect of age-related craniofacial morphologic changes using the accuracy and reliability of Face Recognition technologies [19].

Instead of undertaking a longitudinal study, MITRE researchers use age-morphing features of FaceGen software to create age images covering many decades. Their premise is that controlling the aging variables allows them to isolate specific facial parameters for testing biometric systems. One of the more challenging variables to isolate is the way people age. If a person's photo in the system's database was taken 10 years ago, is it possible to identify the person today? To explore this question, MITRE researchers used the age-morphing features of FaceGen software to generate a series of synthetically aged images. Adjusting the images for a variety of poses, lighting situations, and facial positions provided a rich test environment for measuring biometric performance under multiple scenarios [19],[20].

2.6. Facial Recognition by Grid

Facial biometrics has been tested in different settings in the attempt to comprehend how different variables, when introduced, affect the outcome or validity of the testing. The purpose of using facial biometrics in a security situation may be to prevent imposters from attempting to break into a certain location. It is safe to assume that these people will be motivated to interfere with being correctly identified or attempt to alter their features in an attempt to gain access. In 1996, a computer science professor named Harry Wechsler developed technology to make facial recognition software more accurate based on individual components of the face. This approach was known as the recognition by parts approach. This approach used individual face components along with sequential recognition. The program will take portions that appear to be most relevant and compare them. In this manner the program is able to distinguish one face from another through comparison and elimination [9].

2.7. Liveness-Detection

Unfortunately, people have created ways to circumvent the technology of a 2-D facial biometric system. As an example, an intruder might try to fool a system by using a tangible photograph of someone they know who is in the database [11]. Most systems take for granted that the user will always be in the presence of an official person to maintain integrity. However, the question arises, what happens when an official does not accompany the user? For this reason, some systems are enabled with the capability to detect when pictures are being used since people never appear exactly the same in two different photographs. With this in mind the system can detect whether or not the subject is a live person. Intruders still are able to go around this by bending the photograph. This would create a distortion (or error) and would be perceived by the software to be an actual person. Other ways that “errors” could be introduced into a picture would be to add statistical noise to a digital image [11]. This would make the photo a unique, and assumed lively, image. To combat this modification, a researcher is working on using an algorithm to measure what is called the “optical flow - a measurement of the 3-D movement of two-dimensional information--to detect how parts of a real face should move in 3-D relative to each other” [11].

2.8. Facial Biometric in Use

The interest and use of facial biometrics are widespread and has already been used in various arenas. After the terrorist attacks of September 11, there were increased talks about the use of this technology in airports especially. However, out of the 19 terrorists, only 2 were actually known to the CIA and FBI leaving the database useless for the unknown 17 identities. Another point to take into consideration are that airports are full of fast moving crowds of people and a person would need to be still, unobstructed and close enough to the sensing camera to obtain an accurate photo [7]. These are just a few reasons why airport use may not be as effective. A point worth mentioning is the potential for drivers’ licenses or passports to be used. This would make up the best database to compare photos to. However, since it would be illegal to sell the photos to private companies, the government would need to find the most effective way to utilize this ready-made database.

Facial biometric systems seem to be the wave of the future for both identification and authentication. Wide ranges of applications are on the horizon. Facial biometric systems will enable access to secure and sensitive areas, such as energy supply facilities, nuclear power stations or emergency service control centers. Digital e-cards are opening up new opportunities for facial controls in the areas of banking and business. Public demand for these applications may be the driving force behind further progress in biometrics research [1].

2.9. Facial Biometrics on PDAs and Laptops

The advent of mobile devices has created the need for securing private and important information on Personal Device Assistants (PDAs) and laptops. Because of portability and, the fact that many mobile devices have cameras, biometrics on these devices can be seen as a viable technology. However, there are several challenges for implementing this type of system on a PDA. A lot of image processing is necessary and therefore speed (the system must make an accurate decision in real time) and memory are of great concern. The equipment must have a Floating Point Unit. If the device does not have one, it must be simulated using the unit’s CPU, again requiring a lot of speed. With continued research and trials biometrics will soon be feasible for PDA and cell phones because the devices are constantly being used [14].

Facial biometrics for the laptop has been around for a while. In 2000, Sony integrated Keyware’s facial recognition software in the webcam of their laptops [21]. More recently, Lenovo now uses Veriface software in their IdeaPad’s webcam [3]. Also, there are several other software packages available for the laptop such as FacePresence and Face Recognition System by Matlab. The true challenge now is in being able to equip PDAs with this technology.

3. Anthropometrics

3.1. Anthropometric Landmarks

Anthropometry is the study and measurement of human physical dimensions [4] and is used heavily in Face Biometrics. Dr. Leslie G. Farkas has worked extensively with Anthropometrics and defined 47 points of the face [8]. The points or otherwise called anthropometric landmarks can be used by facial recognition systems to identify the unique facial measurements of each candidate. Systems measure the distance between these landmarks and analyze the face’s overall structure, shape, and proportions. The system then compares these measurements to other photos in order to look for a similar match. In Figure 1, we see six anthropometric landmark pairs.

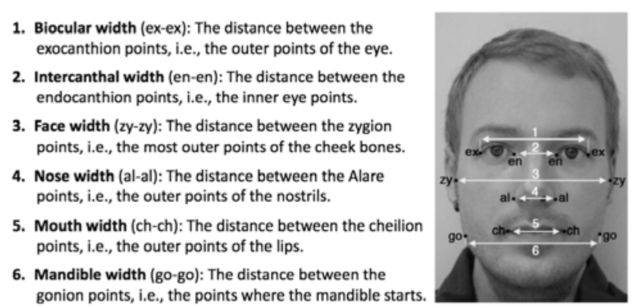


Figure 1. Six anthropometric landmark pairs as mentioned in [8]. Biometric systems measure the distance between these landmarks and compare these measurements to other photos in order to look for a similar match.

3.2. Anthropometrics & Age

Age, lighting and facial expressions have been known to interfere with face recognition systems. There has been extensive work in trying to eliminate the influence that light and expressions have through the use of 3D face recognition systems. However, there have not been major breakthroughs on how to remove the age factor [15].

Many factors of a person's face can change throughout years of aging such as wrinkles, weight gain, corrective lenses, and the overall shape of the head [12]. There is however, some areas of the face where the anthropometric landmarks remain unchanged such as in the areas surrounding the eyes [16].

We believe if more focus is placed on the eye landmarks when using a facial recognition system we can get better results matching between ages when measuring this area.

3.3. Orbital measurements

In order to test our hypothesis that claims the distance between eyes do not change much over time, we focused on the orbital measurements of our photos, which derive from four anthropometric landmarks in the eye area. We measured the intercanthal width (the distance between the endocanthion points, i.e., the inner eye points) and the biocular width (the distance between the exocanthion points, i.e., the outer points of the eye) [8].

After each photo was digitized, they were measured by using Microsoft Visio. This software allowed us to pinpoint the orbital landmarks on each subject's face, then allowed us to measure between them (Figure 2). Because of various methods we used for digitizing the photos, we had a diverse range of image resolutions and image sizes. To prevent this factor from interfering with the comparison of our orbital measurements, we normalized the measurements by dividing the mean and standard deviation by a larger landmark on the face, the mandible width.

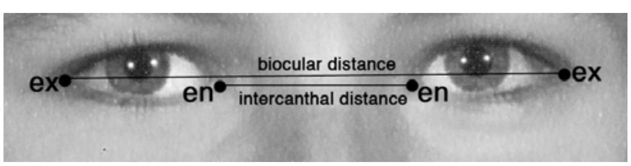


Figure 2. The orbital region of the eyes: biocular width (ex-ex) & intercanthal (en-en) width. These anthropometric landmarks were pinpointed and measured with Microsoft Visio.

Figure 3 shows the orbital measurements. Although there were plenty of subjects where both the biocular and intercanthal width barely changed over time (subjects B, H, J, and R), there were others that had inconsistencies (subjects F, I, and V). Upon closer analysis subject F's images contained various facial expressions that could make it difficult to measure certain points around the eyes (smiling causes squinting for example). Also producing irregular measurements could be the angle of the face. This can result in a shorter mandible width to be measured (again for normalization purposes) and will thus throw off the rest of the measurements. These reasons for inconsistencies were relevant for subjects I and V as well.

Subject + Age	Biocular Width		Intercanthal Width	
	Mean	SD	Mean	SD
B_24	0.649	0.008	0.256	0.037
B_29	0.644	0.034	0.232	0.027
B_40	0.625	0.031	0.246	0.072
C_48	0.634	0.021	0.272	0.038
C_54	0.669	0.044	0.284	0.011
D_14	0.668	0.022	0.270	0.024
D_22	0.672	0.007	0.248	0.003
D_32	0.732	0.027	0.232	0.054
F_16	0.677	0.010	0.327	0.010
F_21a	0.725	0.007	0.346	0.003
F_21b	0.681	0.003	0.327	0.003
F_24	0.608	0.008	0.317	0.003
F_26a	0.709	0.037	0.284	0.013
F_26b	0.688	0.007	0.306	0.007
F_26c	0.689	0.010	0.306	0.006
H_56	0.670	0.032	0.245	0.012
H_66	0.682	0.037	0.282	0.020
I_20	0.949	0.475	0.317	0.164
I_42	0.729	0.055	0.233	0.064
I_52	0.697	0.050	0.271	0.072
J_21	0.711	0.037	0.216	0.032
J_39	0.709	0.029	0.224	0.015
O_24	0.678	0.023	0.261	0.044
O_32	0.703	0.046	0.264	0.048
O_43	0.724	0.065	0.291	0.031
Q_43	0.720	0.086	0.289	0.045
Q_48	0.679	0.020	0.228	0.044
R_16	0.646	0.014	0.240	0.039
R_26	0.645	0.006	0.228	0.009
R_47	0.693	0.050	0.251	0.044
S_27	0.693	0.017	0.243	0.020
S_49	0.624	0.016	0.258	0.043
U_13	0.767	0.035	0.298	0.045
U_29a	0.706	0.011	0.259	0.014
U_29b	0.713	0.008	0.294	0.003
V_15	0.682	0.040	0.295	0.029
V_23	0.751	0.098	0.213	0.029
V_33	0.620	0.044	0.272	0.062

Figure 3. These orbital measurements of the subjects were evaluated to look for similarities and differences between the biocular and intercanthal widths of 13 candidates over a span of multiple years.

4. Methodology

4.1. Database

Our database changed over the course of this study. We initially started with 75 photos of 23 subjects. After enrolling the photos into the two face biometric systems we tested, we noticed certain photos were either unaccepted by the programs or were measured inaccurately. In the end we reduced our photos to 44 photos of 19 subjects.

The photos were digitized in various ways by scanner, digital camera, or webcam. Since this is a longitudinal study most of our photos are old and thus must be scanned to be useable in the database. A specific naming system was used for the photos for organizational purposes. Each subject is assigned a letter followed by his or her age in that particular photograph.

4.2. Face Recognition Software

We evaluated two different face recognition software: Luxand FaceSDK 1.7 and Neurotechnology's Verilook 3.2. The demo for each software was used to study the results of each system's face recognition algorithm. Both software demos were installed under its own Windows XP Professional virtual machine for a stable working environment during experimentation.

The Luxand Face Recognition demo uses 40 feature points of the face for identification [13]. Multiple photos are enrolled into the system and then a single match photo is entered and compared to the enrolled database. The match results appear as similarity percentages (100% is an exact match). The false acceptance rate (FAR) can also be adjusted; lowering the FAR allows for fewer matches but more similar images. Increasing the FAR allows more matches but less accurate ones.

The Verilook system is dissimilar to the Luxand software in a number of ways. Verilook allows for enrollment with generalization. This extracts all of the features of a single person from multiple photos in order to create a generalized features template for one person, allowing for greater accuracy in the face recognition process [23]. Also of note, the Verilook demo returned a 180% similarity for an exact match, so its percentages were normalized for a better comparison to Luxand's results.

4.3. Mobile Face Biometrics Software

Facial biometrics software was also tested on a laptop using "FACE," a 360 Degree Web Face technology created for Windows XP and Windows Vista for user access control. The technology supports four angles and includes single sign-on [5]. The multi-angle feature makes it easy to use and during enrollment one does not have to be much concerned about the movement of the face.

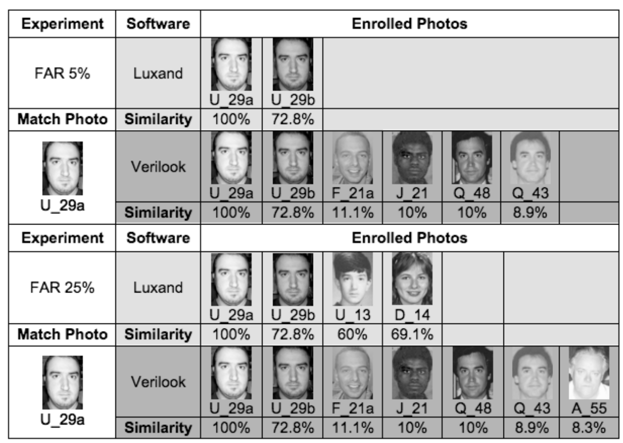
One of the great features of the software is the live detection setting where you can prevent intruders from accessing through the use of a photograph. Without this feature on, it was discovered that a tangible photograph could be used for authentication of a live enrollee.

5. Results of Facial Recognition Experiments

As a check on both systems all matched photos returned a 100% similarity (after normalization) to the same enrolled photos within the database. It should be noted that some experiments might have returned more matches but only a maximum of seven returned photos were documented for each experiment. The following sub-sections discuss the experiments we performed using the Verilook and the Luxand facial biometric systems.

5.1. Changes in False Acceptance Rates

When one alters the false acceptance rate, they are increasing or decreasing the margin of error allowed in the detection of similarity between the matched and enrolled subjects within the database. Figure 4 illustrates the differences between a 5% and a 25% FAR between the two systems. When using U_29a as the match photo, the number of returned enrolled photos increased when the FAR was adjusted from 5% to 25%. Verilook returned more matches than Luxand, but images with small similarity rates. Also of note, photos U_29a and U_29b were taken only months apart with the same camera, and with the subject exhibiting the same facial expression, thus explaining the high similarity rate between the two photos.

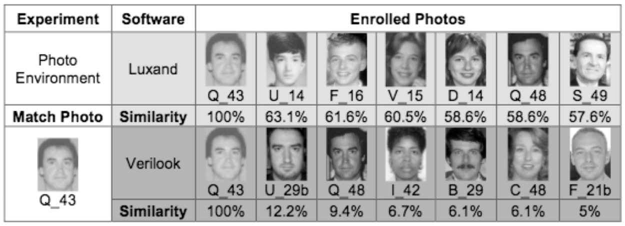


Experiment	Software	Enrolled Photos						
FAR 5%	Luxand	U_29a	U_29b					
Match Photo	Similarity	100%	72.8%					
U_29a	Verilook	U_29a	U_29b	F_21a	J_21	Q_48	Q_43	
	Similarity	100%	72.8%	11.1%	10%	10%	8.9%	
Experiment	Software	Enrolled Photos						
FAR 25%	Luxand	U_29a	U_29b	U_13	D_14			
Match Photo	Similarity	100%	72.8%	60%	69.1%			
U_29a	Verilook	U_29a	U_29b	F_21a	J_21	Q_48	Q_43	A_55
	Similarity	100%	72.8%	11.1%	10%	10%	8.9%	8.3%

Figure 4. The results of the Luxand and Verilook systems using both a 5% and 25% false acceptance rate. The Verilook system provided more photos but less accurate ones.

5.2. Photo Environment

Photos are created in different environments and this should be taken into account when dealing with facial biometric systems. Photo environments can change depending on the purpose for which it was taken, such as a photo created for an ID of some kind, as many of our photos were used for in the past.



Experiment	Software	Enrolled Photos						
Photo Environment	Luxand	Q_43	U_14	F_16	V_15	D_14	Q_48	S_49
Match Photo	Similarity	100%	63.1%	61.6%	60.5%	58.6%	58.6%	57.6%
Q_43	Verilook	Q_43	U_29b	Q_48	I_42	B_29	C_48	F_21b
	Similarity	100%	12.2%	9.4%	6.7%	6.1%	6.1%	5%

Figure 5. The similarity results when Q_43 was used as the match photo in the Luxand and Verilook systems. The significance of the results are the subjects are all using a frontal pose and that most were taken for a photo ID of some kind.

The similar photos that appear in figure 5 were mostly taken in a professional environment causing the subjects to have similar properties to the match photo, Q_43, which was originally taken for a driver's license ID. Professional environments force the candidate to pose in a particular manor, usually a frontal (full-face) pose, and are usually lit properly.

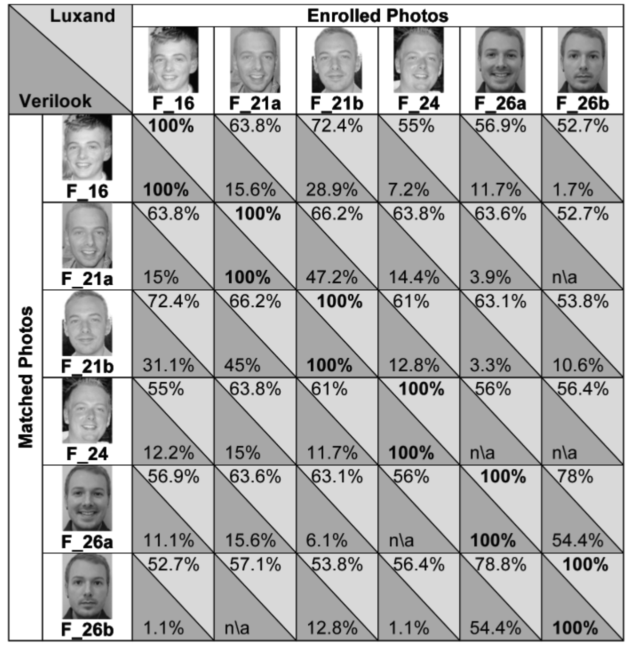
Both Luxand and Verilook systems recommend controlled image environments when capturing photos within a database, so lighting, angles, and facial expressions will not interfere with the system. Since many of our photos, besides the ones in figure 5, were not taken in controlled environments our results were not as accurate as they could have been. Even though the images in figure 5 were set in controlled environments, they were not all taken for the same purpose causing them to have different properties.

5.3. Similarity Matrix

The similarity matrix (figure 6) illustrates the accuracy in both the Luxand and Verilook software by showing the similarity percentages of a single person over a ten year span. The Luxand results are symmetric, meaning that photo a against photo b yields the same results as b against a. Verilook's results were not symmetric however.

Both systems were accurate in how they proved the youngest photo, F_16, was the most dissimilar from the oldest photo, F_26b. F_16 also had the most similarity to the second to youngest age, F_21a and F_21b. For this experiment, it is important to note that only the photos from one candidate were entered into the database of each system.

Some inaccuracies occurred such as F_26b having a closer similarity to F_21b than it does with F_24 in the Verilook system. Luxand also had inaccuracies such as F_16 having a higher similarity to F_26a than to F_24 (Verilook also had this inaccuracy). A probable reason for these inaccuracies were the photo environments of the subject. Good examples of similar environments are photos F_26a and F_26b. Even though the subject in each photo had a different facial expression, the same camera and location were used, causing the similarity results to be more accurate.

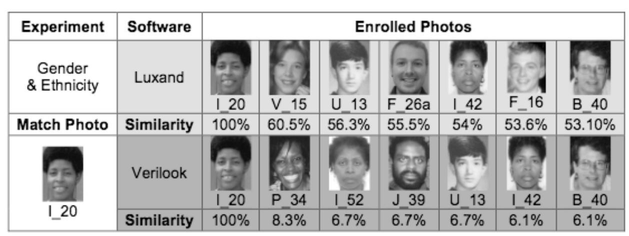


Matched Photos (Luxand / Verilook)	F_16	F_21a	F_21b	F_24	F_26a	F_26b
F_16	100% / 100%	63.8% / 15.6%	72.4% / 28.9%	55% / 7.2%	56.9% / 11.7%	52.7% / 1.7%
F_21a	63.8% / 15%	100% / 100%	66.2% / 47.2%	63.8% / 14.4%	63.6% / 3.9%	52.7% / n\a
F_21b	72.4% / 31.1%	66.2% / 45%	100% / 100%	61% / 12.8%	63.1% / 3.3%	53.8% / 10.6%
F_24	55% / 12.2%	63.8% / 15%	61% / 11.7%	100% / 100%	56% / n\a	56.4% / n\a
F_26a	56.9% / 11.1%	63.6% / 15.6%	63.1% / 6.1%	56% / n\a	100% / 100%	78% / 54.4%
F_26b	52.7% / 1.1%	57.1% / n\a	53.8% / 12.8%	56.4% / 1.1%	78.8% / 54.4%	100% / 100%

Figure 6. The similarity matrix using a single subject over a course of ten years. The Luxand system was symmetric, however the Verilook was not. "N\A" was used when a match was not returned.

5.4. Gender and Ethnicity

Race and gender, two identity features that are common in distinguishing individuals, are detected inaccurately with the Luxand system.



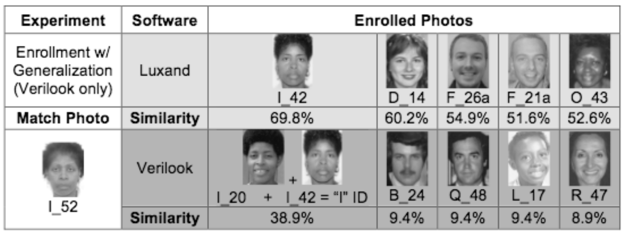
Experiment	Software	Enrolled Photos						
Gender & Ethnicity	Luxand	I_20	V_15	U_13	F_26a	I_42	F_16	B_40
Match Photo	Similarity	100%	60.5%	56.3%	55.5%	54%	53.6%	53.10%
I_20	Verilook	I_20	P_34	I_52	J_39	U_13	I_42	B_40
	Similarity	100%	8.3%	6.7%	6.7%	6.7%	6.1%	6.1%

Figure 7. Upon our results, the Verilook software was more accurate in detecting similarities among both gender and ethnicity. The Luxand system had difficulty in this area.

Figure 7 shows that the Luxand system has difficulty matching according to skin pigmentation and between gender distinctions as well. The two closest matches to I_20, an African-American female, are a Caucasian female and male. The Verilook system had better results with the first two matches for I_20 representing the same gender and ethnicity and even including the same candidate at an older age (I_52).

5.5. Enrollment with Generalization

A unique feature of the Verilook system is enrolling with generalization. This creates a combined facial template from multiple photos of a single candidate allowing for better matches.



Experiment	Software	Enrolled Photos				
Enrollment w/ Generalization (Verilook only)	Luxand	I_42	D_14	F_26a	F_21a	O_43
Match Photo	Similarity	69.8%	60.2%	54.9%	51.6%	52.6%
I_52	Verilook	I_20 + I_42 = "I" ID	B_24	Q_48	L_17	R_47
	Similarity	38.9%	9.4%	9.4%	9.4%	8.9%

Figure 8. Photos I_20 and I_42 used the enrollment with generalization feature from the Verilook system to create a combined ID titled "I". This allowed both I_20 and I_42 to be the closest match to I_52. Note that I_20 is not included in Luxand's matches.

As seen in figure 8, enrolling with generalization allowed Verilook to combine I_20 and I_42 into a single feature template with the ID of "I". The Luxand system was still able to produce a good result by having I_42 as the closest match to I_52. However, the younger photo of this subject, I_20, is nowhere in Luxand's results. The Verilook system includes both the I_20 and I_42 photos as the closest match to I_52 because of the generalization feature.

6. Summary

The purpose of this paper was to study the affects of age in a face biometric system and to review face biometric technology available on PDAs and laptops. This was done through an extensive literature review of past and current face biometric technologies and experiments. Anthropometry was also studied as it explains how facial biometric systems analyze the feature points of a subject's face. The orbital area of a subject is believed to be mostly stable throughout their lifetime and it is believed if more focus is placed in this area it would benefit the problem of aging with facial biometric systems.

The comparison between the Verilook and Luxand facial recognition systems proved both applications have there strengths and weaknesses. Verilook's enrollment with generalization feature would benefit a facial biometric system that is concerned with aging since it allows all photos of a single candidate to be merged as a single ID, allowing for better matching of a subject who has photos spanning over many years. The Luxand system was more symmetrical in its results of matching a single person over a ten year span.

Advice for future work in this area would be to use photos from a public accessible database such as the MORPH database used in [16]. The photos in the MORPH database were taken in an image controlled environment and are made available for the purpose of studying the affects of aging. Since both the Verilook and Luxand systems require a strict image controlled environment, the MORPH database would provide such an environment and would help to give additional research to this face biometrics longitudinal study.

7. References

[1] C. Busch, "Facing the future of biometrics: Demand for safety and security in the public and private sectors is driving research in this rapidly growing field," *EMBO reports,* [Online document] Jul. 2006 [cited 2008 Nov 8], Available at HTTP: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1490310

[2] B. Curless, *New Methods for Surface Reconstruction from Range Images*, [Online document] pp. 1-17,1997, [cited 2008 Dec 1] Available at HTTP: http://www.graphics.stanford.edu/papers/curless_thesis/ch1.ps.gz

[3] P. Eng, "A Lenovo laptop that knows your face," *Consumer Reports Electronics Blog,* [Online article] Apr. 2008, [cited 2008 Nov 14], Available at HTTP: http://blogs.consumerreports.org/electronics/2008/04/a-lenovo-laptop.html

[4] "Ergonomics glossary," *Environmental and Occupational Risk Management, Inc.* [Online dictionary] 2008, [cited 2008 Nov 5], Available at HTTP: http://www.eorm.com/solutions/manage/ergo_glossary.asp

[5] "FACE," [Online document] 2008, [cited 2008 Dec 1], Available at HTTP: http://face.360degreeweb.com

[6] "Face biometrics," [Online article] 2008, [cited 2008 Nov 14], Available at HTTP: http://www.neurotechnology.com/face-biometrics.html

[7] "Face recognition," [Online article] [cited 2008 Nov 20], Available at HTTP: http://www.biometricsinfo.org/facerecognition.htm

[8] L.G. Farkas, *Anthropometry of The Head and Face*, 2nd Ed., Raven Press, 1994.

[9] J. Freeman, "Biometrics puts technology and identify face to face," *The Mason Gazette*, [Online article] Nov. 2006 [cited 2008 Dec 1], Available at HTTP: http://gazette.gmu.edu/articles/9358

[10] B. Friedman, P. H. Khan Jr., D. C. Howe, "Trust online," *Communications of the ACM*, vol. 43, no. 12, Dec., pp. 34-40, 2000.

[11] D. Graham-Rowe "Looking for signs of life," *Technology Review*, [Online Article] Jul. 2007 [cited 2008 Nov 15], Available at HTTP: http://www.technologyreview.com/printer_friendly_article.aspx?id=19056&channel=infotech&section=

[12] H. Ling, S. Soatto, N. Ramanathan, and D. W. Jacobs, "A study of face recognition as people age," *IEEE 11th International Conference on Computer Vistion* (ICCV), Oct., pp. 1-8, 2007.

[13] *Luxand FaceSDK 1.7: Face Detection and Recognition Library Developer's Guide,* [Online Document] 2008, [cited 2008 Nov 6], Available at HTTP: http://www.luxand.com/download/Luxand_FaceSDK_Documentation.pdf

[14] C. K. Ng, *PDA Face Recognition System Using Advanced Correlation Filters*, [Online document] 2005, [cited 2008 Oct 28], Available at HTTP: http://www.ece.cmu.edu/research/publications/2005/CMU-ECE-2005-007.pdf

[15] U. Park, Y. Tong, and A. K. Jain, "Face recognition with temporal invariance: a 3D aging model", *8th IEEE Int'l Conference on Automatic Face and Gesture Recognition.*, Sept. 2008.

[16] E. Patterson, K. Ricanek, M. Albert, and E. Boone. "Automatic representation of adult aging in facial images," *Proceedings of the 6th IASTED International Conference on Visualization, Imaging, and Image Processing (VIIP '06)*, August 2006.

[17] E. Patterson, A. Sethuram, M. Albert, K. Ricanek, and M. King, "Aspects of age variation in facial morphology affecting biometrics," *In BTAS '07: Proc. First IEEE International Conference on Biometrics: Theory, Applications, and Systems*, pp. 1–6, 2007.

[18] P. J. Phillips, W. T. Scruggs, A. J. O'Toole, P. J. Flynn, K. W. Bowyer, C. L. Schott, and M. Sharpe, "FRVT 2006 and ICE 2006 large-scale results." *NISTIR 7408*, March 2007.

[19] K. Ricanek Jr., E. Boone, and E. Patterson, *Craniofacial Aging Impacts on the Eigenface Face Biometric*, [Online document] 2006, [cited 2008, Nov 8], Available at HTTP: http://people.uncw.edu/ricanekk/ppt/VIIP06ImpactsAge/CraniofacialAgingImpacts%20Eigenface.ppt

[20] K. Ricanek, Jr. and T Tesafaye, "MORPH: A longitudinal image database of normal adult age-progression", *7th International Conference on Automatic Face and Gesture Recognition*, 2006 (FGR 2006), pp. 341-345, April 2006.

[21] "Sony integrates Keyware biometric technology into its new webcam," *Business Wire*, [Online article] Nov. 2000, [cited 2008 Nov 14], Available at HTTP: http://www.allbusiness.com/technology/software-services-applications-internet-social/6577824-1.html

[22] N. Syed, "New 3-D image systems to provide reliable face biometrics," [Online article] Nov. 2008 [cited 2008 Dec 1] Available at HTTP: http://www.herts.ac.uk/news-and-events/latest-news/New-3D-Image-Systems.cfm

[23] *Verilook 3.2 Algorithm Demo,* [Online Document] 2007, [cited 2008 Dec 1], Available at HTTP: http://www.neurotechnology.com/download/VeriLook_3_2_Standard_SDK_Trial.zip

[24] W. Zhao, R. Chellappa, P.J. Phillips, and A. Rosenfeld, "Face recognition: A literature survey," *ACM Computing Surveys (CSUR)*, vol. 35, no. 4, Dec., pp. 399-458, 2003.