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THESIS

**COMPOSITE ARTISTRY MEETS FACIAL RECOGNITION
TECHNOLOGY: EXPLORING THE USE OF FACIAL
RECOGNITION TECHNOLOGY TO IDENTIFY
COMPOSITE IMAGES**

by

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September 2011

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**COMPOSITE ARTISTRY MEETS FACIAL RECOGNITION TECHNOLOGY:
EXPLORING THE USE OF FACIAL RECOGNITION TECHNOLOGY TO
IDENTIFY COMPOSITE IMAGES**

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ABSTRACT

Forensic art has been used for decades as a tool for law enforcement. When crime witnesses can provide a suspect description, an artist can create a composite drawing in hopes that a member of the public will recognize the subject. In cases where a suspect is captured on film, that photograph can be submitted into a facial recognition program for comparison with millions of possible matches, offering abundant opportunities to identify the suspect. Because composite images are reliant on a chance opportunity for a member of the public to see and recognize the subject depicted, they are unable to leverage the robust number of comparative opportunities associated with facial recognition programs.

This research investigates the efficacy of combining composite forensic artistry with facial recognition technology to create a viable investigative tool to identify suspects, as well as better informing artists and program creators on how to improve the success of merging these technologies. This research ultimately reveals that while facial recognition programs can recognize composite renderings, they cannot achieve a level of accuracy that is useful to investigators. It also suggests opportunities to better design facial recognition programs to be more successful in the identification of composite images.

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I. INTRODUCTION

A. PROBLEM STATEMENT

While valuable as an investigative tool, forensic imagery as a method of suspect identification is heavily reliant on the ability of the investigative agency to effectively distribute a particular sketch to the largest possible number of community members in order to find someone who can identify the wanted person. This method of circulation leaves the identification of the suspect somewhat to chance in that it relies solely on the possibility that someone who might know the identity of the wanted person would see the composite drawing. While the ability of investigators to generate forensic renderings of crime suspects is great due to the availability of artists and art programs, law enforcement officials are limited in their ability to circulate these renderings to a significant portion of the population.

Comparatively, while scenarios involving photographs of suspects in the commission of a crime offer the best opportunity for suspect identification and eventual criminal prosecution, occasions in which a suspect is captured on film in the commission of a crime are somewhat rare. This infrequency limits the investigators' opportunities to leverage facial recognition technology as an investigative tool for suspect identification.

This juxtaposition illustrates the value of this research. While investigators, creators of facial recognition programs, and forensic artists may have an idea about the ability to successfully merge these two disciplines, it is not known whether composite drawings can be used effectively in combination with facial recognition software programs to identify unknown persons.

B. RESEARCH QUESTIONS

1. Primary Research Question

How can composite forensic imagery be used with facial recognition technology to increase the efficacy of forensic imagery as an investigative tool to identify possible persons of interest?

2. Secondary Research Questions

a. What can composite sketch artists learn from this research to improve the level of success by which their composite drawings contribute to the identification of persons of interest in a facial recognition software environment?

b. What can creators of facial recognition software programs learn from this research to develop programs that recognize composite sketches more effectively and accurately?

C. TENTATIVE SOLUTIONS

Facial recognition programs are abundant, varied, and utilized by numerous law enforcement agencies to identify criminal suspects captured by video or still photography; however it is not currently known whether this technology is a viable method to identify criminal suspects depicted in forensic composite images. Integrating composite art into facial recognition technology provides an opportunity not only to expand the suspect identification capabilities of investigators but also to measure more precisely the usefulness of merging these technologies.

Sketch artists traditionally draw composite images by hand, but a new technology has emerged allowing less artistically talented individuals to complete composite images using a computer program. Images drawn by hand by forensic artists differ greatly in appearance from images created using a computer program. This research will also seek

to provide a better understanding of how the difference in the viability of each type of forensic image when entered into a facial recognition program will influence the efficacy of combining these two technologies.

While investigators may have a more prolific resource of forensic renderings of crime suspects, they have a limited ability to circulate these renderings to a significant portion of the population. Conversely, many law enforcement organizations utilize facial recognition databases with millions of photographs; however, without a photograph of the suspect who committed the crime, they are powerless to identify that subject using facial recognition software.

A possible solution to this problem is to explore the use of a facial recognition program to assist investigators in the identification of investigative leads depicted in composite images. This study will examine the merger of composite imagery with facial recognition technologies as a new opportunity to identify potential crime suspects. Facial recognition programs are abundant, varied, and used by numerous law enforcement agencies to identify criminal suspects captured by video or still photography, but it is not currently known whether this existing technology is viable for the identification of criminal suspects depicted in forensic composite images.

D. SIGNIFICANCE

This research will provide composite artists with information to assist them in creating images that are more precisely consumed by the facial recognition program, improving the program's ability to identify possible investigative leads, and it will provide facial recognition program designers with information that will assist in possible design changes that better support the use of composite artistry in the future.

The consumers of this research are forensic artists, facial recognition technology developers, and law enforcement, security, and investigative organizations at the municipal, state, federal, and international levels, both public and private. The intelligence community, criminal investigators, forensic artists, and the public regularly strive to identify those who may bring harm to our communities.

Government and law enforcement entities have invested billions of dollars in technologies that enable us to identify would-be terrorists and criminals through networked camera systems and facial recognition technologies. These programs enable law enforcement practitioners to identify threats and mitigate them in order to keep our communities safe. This research introduces a significant opportunity to expand the ability to identify criminals when no photographic representation exists of the individual committing the crime. These case studies will assess the merging of facial recognition technology and composite imagery to identify suspects in criminal investigations; it serves as one of the only known efforts to memorialize such information for future research.

If successful, the use of facial recognition programs to identify a person depicted in a composite image may increase the ability of investigators to locate suspects and solve crimes. Additionally, this method would save investigator time, be less reliant on the ability of an investigator to circulate or show a composite drawing to a large population of people, and increase the potential for the use of forensic imagery to be successful in identifying suspects. In addition, it is likely that forensic artists and facial recognition creators alike will learn more about the ability to merge these two disciplines, improving their ability to more closely integrate these tools for increased success in the identification of unknown persons. This success will be measured in terms of the overall average effectiveness of one medium compared to the other.

II. BACKGROUND

In lieu of a literature review, research in areas related to computer facial recognition and composite artistry is presented in this chapter. The overarching discipline of forensic artistry is discussed, followed by its four primary disciplines. This chapter highlights the important aspect of the forensic artist witness interviews and provides a baseline of information on the human memory process and its fallibility. This information provides a cursory understanding of the history, evolution, and future of composite art, composite imagery, and facial recognition technology. It illustrates the complexity of forensic art outside the parameters of creating an artistic representation and represents the full spectrum of the composite drawing process.

A. FORENSIC ARTISTRY

In today's era of CSI (Crime Scene Investigation) television shows, "Forensic Files" documentary programs, and twenty-four-hour access to "Court TV," the term "forensic art" can take on many meanings. The most common and well known of forensic art disciplines, composite imagery, is just one of several forensic art disciplines. To fully understand composite imagery, otherwise known as composite drawing, it is valuable to have a working definition of forensic artistry as a whole.

1. Forensic Art

Forensic art is any art used in conjunction with legal procedures or investigations. More specifically, forensic art is any art that aids in the identification, apprehension, or conviction of criminal offenders, or that aids in the location of victims or identification of unknown deceased persons (Taylor, 2001, p. 3). Forensic art is often multimedia in nature, with its primary purpose to present visual information. Even when the style of art and medium vary, all forensic art shares a common trait: it presents visual information (Stewart and Richlin, 1989).

Other aspects of forensic art include demonstrative evidence, which is usually used for case presentation in court, image modification and image identification such as video enhancement to improve the quality of photographic evidence, or the use of photo facial recognition programs for comparative identification, and reconstruction and postmortem identification aids, which usually involve the use of found human remains to create a representation of a deceased individual, either in two-dimensional or three-dimensional form.

2. History and Origins of Forensic Art

Forensic art is not a new discipline. It has been used in one form or another for decades to assist law enforcement in investigations and to portray criminal events. Early drawings published in local newspapers portrayed the accused criminal while sitting in the courtroom. Crime scene diagrams slowly became the accepted method of documenting the position of evidence at crime scenes, and as criminal trial proceedings have become more complex, investigators and prosecutors have come to rely on forensic artists to reconstruct the action at a scene, the collision of vehicles, the trajectory of projectiles, and almost anything else imaginable to illustrate elements of a criminal act. Forensic or composite imagery, the art of drawing faces of unknown persons, has been used to depict suspects, identify the dead, progress the age of a child to show what he or she might look like years later, and even to illustrate unique items of missing property.

A great historic example of the use of forensic artistry and forensic imagery is the well-known London England case of Jack the Ripper, a serial murderer who killed women at random by mercilessly dismembering them with a knife. Of the volumes that have been written about Jack the Ripper and the literal death grip he held over the city of London in the late 1800s, very little has focused on the efforts of police and investigators who were obligated to capture the villain and end the reign of terror (Cozart, 2009). During the mid- to late 1880s, there was a frequent stream of bodies found in alleys and floating in the Thames River in the Whitechapel area of London. The London

Metropolitan Police and the City of London Police were very quickly confronted with a different kind of criminal behavior for the first time. These horrific, violent and gruesome crimes were murders without an obvious motive.

In 1888, the field of police science was in its infancy. The so-called Jack the Ripper suspect may have been gruesome in his acts, but those same acts caused a revolution in the police sciences by forcing the police to develop new techniques and tactics for detecting unknown offenders, rather than simply laying hands on an obvious suspect (Cozart, 2009). It is thought that efforts attempting to solve these crimes led to many advances in the law enforcement investigative practice and technique of the time. Those advances include crime scene security, detailed inventories of evidence, and most significantly, numerous forms of documentation of various aspects of the crime.

For the first time, detailed measurements plotted on a sketch of the area located the precise placement of every item found at the crime scene (Cozart, 2009). Drawings of the deceased victims, depicting the injuries both at the crime scene and at the time of autopsy, were completed graphically. In addition to these new forms of documentation, this investigation is thought to be the first time that composite imagery was used to depict the features of the suspect in a composite drawing in order to inform the community of the suspect's appearance.



Figure 1. Jack the Ripper crime scene photo and related sketch.

Source: http://commons.wikimedia.org/wiki/Jack_the_Ripper



Figure 2. Artist depiction of additional victim at autopsy

Source: <http://photos.casebook.org/thumbnails.php?album=35>



Figure 3. Early “composite” depictions of Jack the Ripper

Source: http://en.wikipedia.org/wiki/Jack_the_Ripper

In 1888, the police and the press made an attempt to garner public assistance in identifying Jack the Ripper. Two suspect sketches (accuracy unknown) appeared in the *Illustrated Police News* on October 20, 1888. Unfortunately, these sketches were deemed more the artist’s impression of what a sinister and evil Jack the Ripper should have looked like than accurate sketches, which could have helped identify the suspect. While these pictures likely boosted the paper’s circulation, they did little to catch the true killer. The killer was never identified and remained at large. Then, without explanation, the homicides ceased.

Since the 1880s, suspect sketch artistry, now known as composite imagery, has improved greatly. Artists started paying more attention to details like head shape, hair length, and distance between eyes, nose, and mouth. The more sketches that were done, the more experienced artists realized that facial features could be broken into groups or sets, leading to the addition of the first attempts at automation of the process of creating a composite sketch.

In more recent history, the forensic imagery depictions of the “Unabomber” Ted Kaczynski in 1978 and the “Oklahoma City Bomber” Timothy McVeigh in 1996 represent well-known examples of forensic imagery that offered law enforcement the only physical representation of then unknown suspects on a crime rampage. In both cases, forensic imagery was used effectively to pursue domestic terrorism suspects, and in the case of McVeigh, the image created by the FBI forensic artist bore an uncanny resemblance to McVeigh, enabling several witnesses to confirm his presence at the scene of the bombing and at the truck rental office days prior to the crime.



Figure 4. Composite images of Unabomber Ted Kaczynski and Oklahoma City bomber Timothy McVeigh

Source: http://en.wikipedia.org/wiki/Ted_Kaczynski;
http://en.wikipedia.org/wiki/File:Aa_McVeigh_sketch_and_pic.jpg

3. Forensic Artists

Some forensic artists are trained in all of the forensic art disciplines, but more frequently forensic artists will specialize in one or two aspects of forensic art. Forensic artists enter the field of forensic art from many directions. In the case of forensic imagery, some are trained artists; others may be police officers that became interested in composite imagery out of necessity; and still others may be civilian employees of a law enforcement agency who have superior artistic and/or interview abilities. In the case of

those working in the field of image modification and facial recognition, these practitioners likely excel in computer skills and have a working knowledge of video- and photo-based programs.

4. Art or Science?

Many would argue that there is a requisite amount of science involved in forensic art. Most successful forensic artists collaborate with members of the scientific community for successful outcomes. This collaboration is most likely to occur in cases involving found human remains, but it is not limited to these types of investigations. Chemists, biologists, forensic anthropologists, and very often medical doctors of varied disciplines collaborate with forensic artists to piece together the details associated with a set of found human remains in order to determine the subject's age, sex, race or ethnicity, height, and weight. These details are all valuable clues in determining the identity of the victim.

B. COMPOSITE IMAGERY

Composite imagery is most precisely defined as graphic images made up from the combination of individually described component parts (Taylor, 2001). Composite imagery can be used to depict objects, evidence, wanted persons, missing persons, the face of found human remains, and even the age progression of missing children and wanted or missing adults. To the casual observer, composite imagery is often thought of as the sketches of wanted suspects shown on the six o'clock news, but composite imagery takes on many forms. Besides the sketches with which we are all familiar, there are several other forms of two-dimensional composite imagery—as well as three-dimensional facial reconstruction—that are considered composite imagery.

1. Composite Sketches

Composite imagery and the composite sketch are the most commonly known of the four categories of forensic art. A composite image of a suspect enables law enforcement and the public to better focus on a suspect's appearance based on victim and witness descriptions rather than on some erroneous image created in their own minds

based on their individual interpretation of a verbal or written description only. Knoxville Tennessee Detective Art Bohanan said:

A picture is worth a thousand words, they say, but a composite sketch is worth 800—it gives you something to work with. The description of a white male, 5’8”, with brown hair doesn’t do anything for you, but if you can put some type of face with the description, then you can start looking for that person. (Mulholland, 2011).

One of the most important concepts to consider before evaluating this research is the investigative and artistic intent of creating a sketch, or “sketch quality” composite representation of an unknown person. The benefit of a “sketch quality” drawing (versus a portrait quality drawing) in the process of identifying an unknown subject is that “sketch quality” in a composite rendering offers a key advantage over a more photographically detailed drawing. When viewing a completed composite sketch, one is forced to apply a very fruitful margin for interpretation rather than a narrow and unforgiving scope (Taylor, 2001, p. 202).

While on one hand each artist likely strives for the perfect depiction of the described suspect in the context of artistic skill, the composite sketch is intended to depict a “likeness” of the suspect, not a precise portrait rendering. An effective composite sketch reminds its viewer of a few key elements of the suspect, or a noticeable detail, and not a complete and comprehensive portrait of the unknown person. The viewer of a composite sketch almost expects certain details to be off or imperfect. In this context, we must remember the difference between a portrait and a likeness. A portrait contains fine detail and is impossible to create without a photo or the actual subject of the portrait, but a likeness includes simple shapes.

In the “likeness” depicted in Figure 5, for example, eyebrows and the slight widow’s peak in the hairline, as well as the overall shape of the face, nose, and eyes enabled the identification of this suspect.



Figure 5. Similar shapes depict noticeable features. Source: Phoenix Police Department.

Composite imagery is often thought of solely as a method for identifying a wanted subject involved in criminal activity, but in the 1980s, law enforcement placed an increased emphasis on the problem of missing and endangered children (Taylor, 2001, p. 34). In the forensic imagery community, this resulted in a need for artists skilled in the techniques of age progression. With adult subjects age progression was usually accomplished through the updating of existing photographs. In the case of age progression of long-missing children, craniofacial growth data must be considered in order to account for facial evolution from childhood to adulthood. This process involves not only the study of the clinical evolution of human beings into adulthood but also the incorporation of familial traits into the renderings. The following is a twenty-year age progression of an adult homicide suspect.



Figure 6. Suspect at time of murder—twenty-year age progression composite—Suspect at time of arrest. Source: Phoenix Police Department.

2. Composite Imagery—Automation and Computer Aided Methods

For forensic imagery, one of the first attempts at automation of the composite sketch process came in the 1950s and was known as the Identi-KIT product; the similar British version produced years later was known as the PHOTO-FIT. The Identi-KIT used overlapping layers of clear plastic with various facial features printed on them (Cozart, 2009). The combination of a series of layers would create a composite representation of what a suspect might have looked like, however the choices of varied facial details were few, and these limitations made a realistic depiction of the suspect difficult to create. Likewise, the PHOTO-FIT utilized a series of facial features organized in the center of the face with a facial shape surrounding them.

The next evolution in forensic imagery was the development of computer programs that gave the nonartistic investigator an option in creating a forensic image of a crime suspect. Programs such as FACES and Photoshop produce programs designed especially for law enforcement to assist in creating composite images. Much like the

Identi-KIT, these programs are only limited by the number of choices and possible combinations that can be generated in the quest to create an image of a wanted subject.

Very few police departments have a full-time forensic artist—in many cases shrinking budgets mean a lack of funds for such a position. For strapped law enforcement agencies with an infrequent need for a forensic artist, computer software is a low-cost alternative. A yearly fee of \$50 or a one-time fee of \$3990, for example, gives a police department or sheriff's office access to thousands of facial features, hairstyles, tattoos, and other identifying marks—all of which are mixed and matched to create a composite (Mulholland, 2011).

While these programs are a good second choice when a forensic sketch artist is not available, this technology does not replace a talented composite artist. Even the president of the Identi-KIT software company, Paul Wright, notes that no computer software is the same as a great forensic artist. "The truly good police sketch artists who know what they're doing can make things on paper that we can't in the sense that it (the drawing) is infinitely variable, because you have a human being creating it" (Mulholland, 2011).

C. RECONSTRUCTION AND POSTMORTEM IDENTIFICATION AIDS

One of the most unpleasant and complicated tasks for law enforcement personnel is dealing with deceased bodies for whom no immediate means of identification can be found (Taylor, 2001, p. 303). There are two standard methods for postmortem identification: creation of a two-dimensional image—usually a composite sketch created from viewing the deceased or through the use of manipulation of X-rays of the skull—or creation of a three-dimensional image using the victim's skull to re-create facial features of the victim. Both two-dimensional and three-dimensional reconstruction methods create a facial rendering capable of entry into facial recognition programs.

Facial reconstruction from the skull is a very complex and detailed process. By comparing one skull to another, we are able to see the vast variability among people. To the trained eye of the anthropologist or skeletal biologist, the distinctions of race, ancestry, age, and sex are also usually determinable from the skull (Taylor, 2001, p. 362).

Both two- and three-dimensional methods of facial reconstruction have proven successful, but some cases may be more appropriate for one method over the other. Fragile or historic skulls may be too brittle to withstand the weight and pressure of applying clay, and skulls with facial damage may be compromised to the extent that they cannot support the application of clay accurately in damaged areas, lending more value to a two-dimensional reconstruction. Three-dimensional reconstruction offers the viewer an opportunity to see the re-creation from various perspectives and, in cases where personal belongings, clothing items, glasses, and jewelry were found, these items can be displayed with the three-dimensional representation.

1. Two-Dimensional Reconstruction through Forensic Imagery

When the remains of a deceased person are still in good enough condition to be recognizable, forensic artists may be able to draw a reasonable facial likeness of the individual. This is accomplished by either viewing crime scene photographs or, if possible, by viewing the actual body. This rendering will enable law enforcement officials to use the forensic image, rather than a photo of the deceased person, to attempt to identify the subject. Once a friend or family member identifies the deceased from a forensic re-creation, medical and dental records can be obtained to confirm the identification.

Postmortem drawing is used in cases involving suicides, homicides, and natural deaths, as well as traffic fatalities and other blunt trauma deaths, gunshot fatalities, drowning, and nonextensive fires.

2. Two-Dimensional Reconstruction through Image Modification

In cases where decomposition, blunt trauma, animal activity, or other facial flesh disfigurement is present and re-creating the face is not possible through simply drawing the deceased, image modification may assist the forensic artist in creating an image of the unknown person. Two-dimensional reconstruction involves the artist's use of the skull as a starting point for estimating facial features.

Tissue depth and various predetermined formulae for individual features are added to increase the artist's understanding of the deceased's facial structure. The skull is then photographed or radiographed (X-rayed) and tracings are made of both frontal and lateral views of the skull. The artist is then able to create a forensic image of the victim, based on the shape of the skull and through additional input from a forensic anthropologist regarding the locations of specific facial features such as the eyes, tip of the nose, and ear cavity position.

If the forensic artist must resort to using the skull as a means for identification or formation of a composite representation, this method is the more cost effective of the two methods involving the skull, and it leaves the skull intact, undisturbed, and available for further examination.

3. Three-Dimensional Reconstruction

Three-dimensional reconstruction, sometimes called facial sculpture or skull reconstruction, is a method of forensic art used to identify skeletal remains. The artist and the anthropologist collaborate to construct the facial features of the unknown individual on the basis of the underlying cranial structure (Taylor, 2001). In situations where a deceased person is found in advanced or complete decomposition, the creation of two-dimensional drawings may not be an option for identification. In these cases, where the remains are skeletonized, a three-dimensional method of re-creating the facial features of the deceased may be the best opportunity to identify the subject. In a three-dimensional format, viewers of the completed re-creation are able to see the representation from various perspectives, giving the viewer a better opportunity to recognize the deceased.

The fifty-five-year-old case of "Boulder Jane Doe," for example, was solved with a 3-D reconstruction of the victim's head. The victim's niece recognized the victim from the 3-D rendering.



Figure 7. “Boulder Jane Doe” 3-D reconstruction.

Source: http://www.dailycamera.com/news/ci_13658937

D. DEMONSTRATIVE EVIDENCE

Artistic representations presented as visual evidence can be used as demonstrative evidence in court. Using sophisticated computer programs, artists can enhance otherwise blurry videos and photographs, creating animated versions of the commission of the crime. By using global positioning satellite technology (GPS), artists are able to plot precisely the location of every piece of evidence at a crime scene, depicting the scene visually in ways that were never before imagined. Using GPS technology, points of investigative interest at complex traffic collisions can be plotted on a map, and investigators can visually experiment with varied scenarios to determine the cause and manner of the collision. These depictions can be used later at trial to depict complicated vehicle and crime scene dynamics in a simplified way, enabling juries to have a clearer understanding of what occurred.

Demonstrative evidence may be presented as a slide show, PowerPoint presentation, a large diagram or other drawing, or even an enhanced still photograph. As technology advances, crime scene animation videos have become a more prevalent form of demonstrative evidence. Videos can depict the “action” at the crime scene, showing a car collision, an assault, the discharging of a firearm, blood spatter dispersal, and any

number of additional dynamic activities. They can illustrate building floor plans and large geospatial areas to enable a better understanding of large or complicated scenes.

Such visual aids serve to explain and simplify complex concepts and provide understandable explanations for what may have occurred at a scene. In addition, animated depictions of rather gruesome evidence, or of deceased persons, can eliminate the shock to those viewing the evidence, minimizing the hardship to the loved ones of the deceased who may be present in court. Visual evidence of this nature has been used for several hundred years to depict crime scenes and autopsy results, as well as the location of items of evidence found at crime scenes.

E. IMAGE MODIFICATION AND IMAGE IDENTIFICATION

Image modification and image identification are methods of manipulation, enhancement, comparison, and categorization of photographic images (Taylor, 2001). While image modification has some relevance to this research, aspects of image identification, through facial recognition technology, play a large part in this study.

1. Image Modification

Image modification is a forensic art technique used to alter or enhance a photograph for the purpose of age progression, age regression, updating, or changing a subject (Mancusi, 2000). Image modification in the context of a criminal investigation is usually accomplished through one of two forensic art techniques. The enhancement can be drawn or painted on an image of the subject, or enhancements can be created digitally utilizing a computer and any number of specialized software programs. Age progression techniques are at times considered image modification.

2. Image Identification—Facial Recognition Technology

What is facial recognition technology? Humans have always had the innate ability to recognize and distinguish between faces, yet computers only recently have shown the same ability. Work on using computers to recognize faces originated in the mid 1960s (Bonsor & Johnson, 2008). Facial recognition from still images is one of the leading

image-based biometrics. For example, the U.S. Department of State operates one of the largest facial recognition systems in the world. In 2004, the original photo database was populated with 35 million visa photos. Currently (2011) the database contains over 75 million photographs, integrating several Department of State photo resources. The database is actively used for visa processing and yields as many as 2,000 matches in an hour (Identix Corporation, 2004). In applications where illumination and view angle are highly controlled and image resolution is high, recognition rates for the leading still-image facial recognition systems is very high (Schmitt et al., 2010, p. 1).

What is facial recognition and how does it work? A facial recognition system is a computer application used to automatically identify or verify a person from a digital image or a video frame from a video source. Facial recognition programs are often used in security systems to assist in the identification of a person, utilizing a robust bank of photographs of known persons. They are also used extensively by law enforcement agencies to identify unknown subjects in various types of photographs.

Every face has numerous landmarks, or peaks and valleys, which make up facial features. Much like locations of identification on a fingerprint, these facial landmarks, known as nodal points, are measured creating a numerical code. Each human face has approximately 80 nodal points, for example, the distance between the eyes, width of the nose, depth of the eye sockets, shape of the cheekbones, and length of the jaw line.

The most traditional facial recognition technique is identification of persons through the use of a mathematical algorithm designed to identify specific landmarks or features from an image of the subject's face. There are two types of applications of this algorithmic method, geometric algorithms and photometric algorithms.

a. *Geometric Algorithm*

An algorithm expressed geometrically may identify the relative position, size, and/or shape of the eyes, nose, cheekbones, and jaw forming a mathematical representation for this geometric relationship between features.

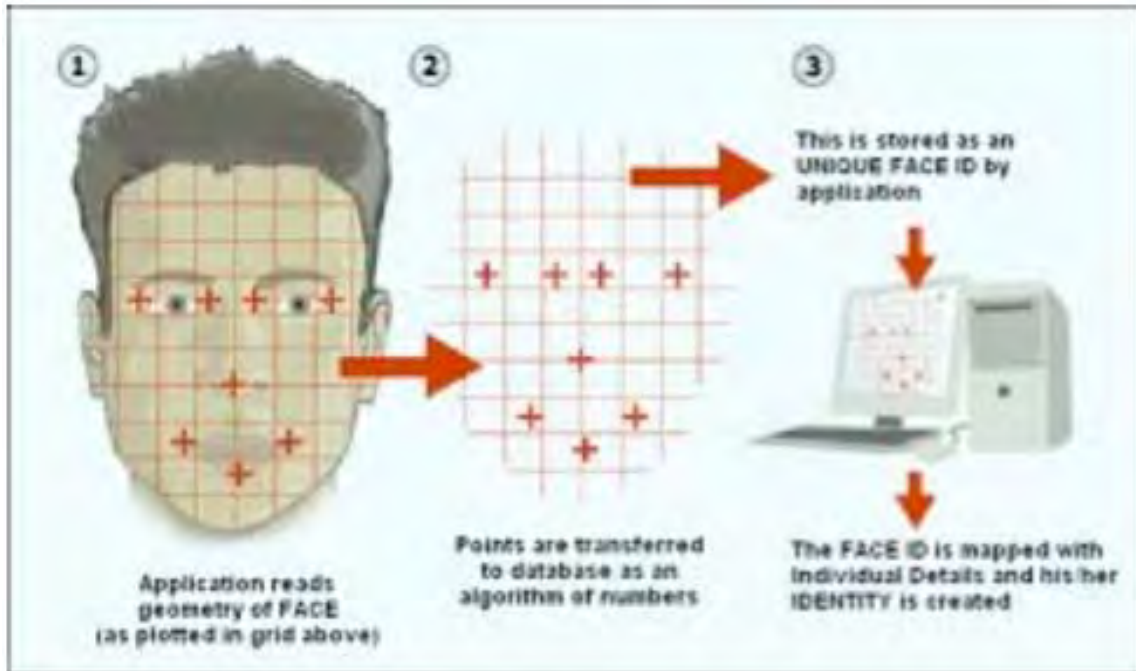


Figure 8. Geometric algorithm.

Source:

http://www.google.com/search?q=facial+recognition+geometric+algorithm&hl=en&client=safari&rls=en&prmd=ivns&source=lnms&tbn=isch&ei=d4VrTsf0KpPKiAKv-ryqDg&sa=X&oi=mode_link&ct=mode&cd=2&ved=0CAwQ_AUoAQ&biw=1224&bih=650

b. Photometric Algorithm

An algorithm is expressed photometrically when these facial features in combination are given a specific numerical representation based on distilling an image into numeric values and comparing the values to other values.

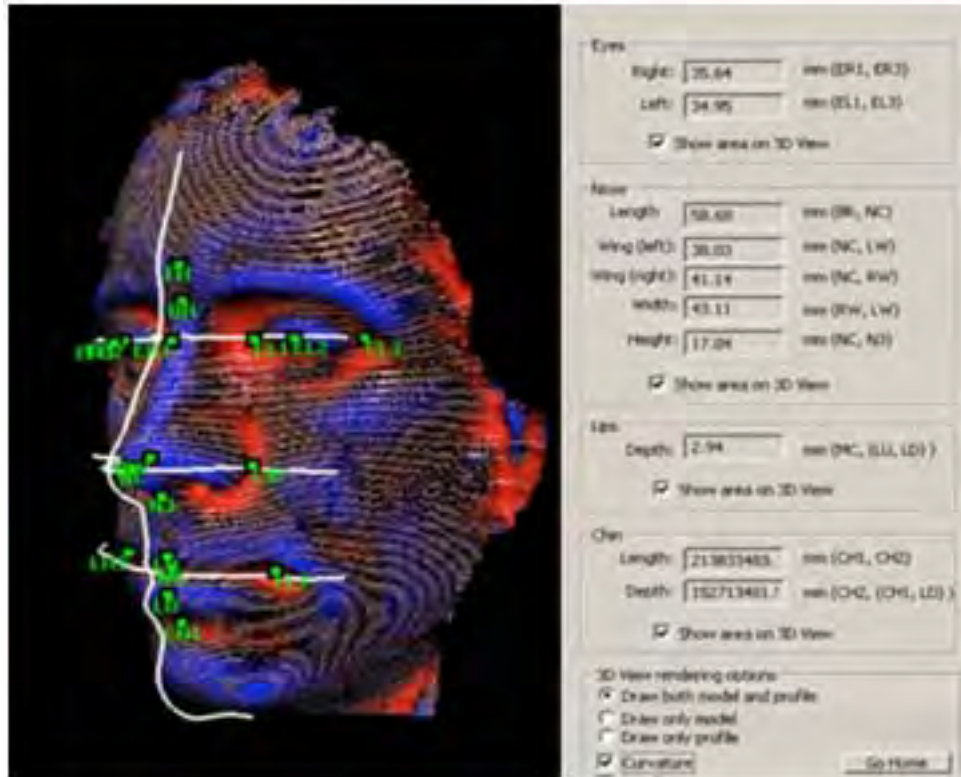


Figure 9. Photometric algorithm

Source:

http://www.google.com/search?q=facial+recognition+geometric+algorithm&hl=en&client=safari&rls=en&prmd=ivns&source=lnms&tbn=isch&ei=d4VrTsf0KpPKiAKv-ryqDg&sa=X&oi=mode_link&ct=mode&cd=2&ved=0CAwQAUoAQ&biw=1224&bih=650

c. The Facial Recognition Program Used for This Research

There are many facial recognition products on the market available to law enforcement, all with varied features and searching methods. The facial recognition program utilized in this research is the Image Investigation System (IIS), which was developed by Hummingbird Defense Systems, a Scottsdale, Arizona-based company. This system uses a geometric algorithm, focusing on 17 geometric facial relationships, and it is equipped with case tracking (regulated management of intelligence information) that is compliant with the U.S. Code of Federal Regulations, Title 28 (CFR28). This particular program starts with a focus on the eyes and examines their relationship to other

areas or points on the face creating the geometric algorithmic representation of each image. The program does not use age, sex, race, or ethnicity in its search criteria.

The IIS program is housed at the Arizona Counter Terrorism and Information Center (ACTIC) located in Phoenix, Arizona, and is operated by the Maricopa County Sheriff's office. Two hundred forty state, local, and federal investigators, analysts, and support personnel from forty-three different agencies are assigned to the center, including the FBI Joint Terrorism Task Force (JTTF) and the Field Intelligence Group (FIG), conducting both criminal and intelligence investigations. The IIS is regularly used by these agencies to solve crimes.

The number of images in the database exceeds 30 million, and IIS can provide search capabilities for photographs, video, and surveillance still photographs of wanted suspects and known or suspected terrorists. The IIS database is constantly supplied with new photographs from the Arizona Motor Vehicle Department (driver's license and state ID cards), mug shots from Arizona jail bookings since 1998 (4.5 million photos currently), the U.S. Justice Department's Joint Automated Booking System (JABS), and the state's sex offender database, consisting of over 12,000 pictures. The ACTIC facial recognition unit is capable of comparing a single image to the 30 million photos in its database in 15 seconds or less (Bristow, 2010).

d. Processing a Photograph in IIS

The process for comparative analysis of an unknown offender photograph using the IIS consists of "enrolling" the pictures of unknown suspects into the program. The program then uses the geometric algorithm to create a numeric representation of the face of the unknown person. Once this numeric representation is determined, it is compared against the numerical representations of all the photographs of known subjects in the database. Within 15 seconds, the program delivers a list of possible matches. It also stores the image of the unknown person and compares it to new photographs entered into the system subsequent to this analysis, affording investigators the ongoing potential to identify the suspect.

i. Identification of Possible Matches

The possible matches identified by the system are then reviewed by a Facial Recognition Unit detective who visually compares the picture of the unknown suspect with the pictures associated with the possible matches to determine which photographs warrant further investigation by the case detective who submitted the unknown suspect photograph. Because this program does not use age, race, ethnicity, or sex to identify possible suspects, the Facial Recognition detective will eliminate possible suspects that are obviously not the same sex, race, or close enough in age to the suspect picture being enrolled.

ii. Inconsistencies in Photographic Standards

This visual review is also necessary because, despite the high performance of still-image systems in controlled conditions, performance can drop quite rapidly as variations in view angle, illumination, occlusion, or viewing distance increase or as image resolution decreases (Schmitt et al., 2010, p. 2). Essentially, all photographs are not taken with the same levels of focus, lighting, angle, distance, and facial perspective. Subjects who take photographs of themselves in a mirror also present a new variable, requiring the photograph to be reversed before it is enrolled into the database. These variables can cause slight differences in the photographic representations of the subjects. While the inputting of the photographs into the program is a quick and easy process, the visual review process is time intensive. The ACTIC Facial Recognition Unit processes an average of 9000 individual comparisons per month (Bristow, 2010).

iii. Programmatic Range

The Facial Recognition Program has the ability to search at various levels of inclusion. These levels of inclusion translate to a percentage of certainty or possibility. If a search is conducted at a high level of certainty, 95% for example, the program may identify a small number of possible matches, but due to photographic differences between the subject in the commission of the crime and the photos in the database, searching at a high level of certainty might unintentionally eliminate the true photographic match from the list of possible suspects. Conversely, searching at a low

level of certainty, 50% for instance, could yield an unwieldy number of photographs, requiring the reviewing detective to view tens of thousands of photographs to identify a match, a process that is not practical.

The standard search percentage for the ACTIC Facial Recognition Unit is 90%. At this percentage the program is likely to identify approximately 500 possible matches for visual review. This number is considered productive for the furtherance of most cases accepted for facial recognition program searches. This standard will be used in the case study to determine the usefulness of composite picture hits in the database.

F. THE INTERVIEW PROCESS AND THE PITFALLS OF EYEWITNESS DESCRIPTIONS

In preparing a high-quality composite image, the interview is everything (Taylor, 2001, p. 137). The ability to successfully and effectively interview witnesses and victims of crimes is key to creating the most accurate forensic image possible. Many psychological and medical studies have been conducted regarding human cognition and perception, the impact of trauma on memory, facial recognition, eyewitness identification, and interview techniques. These elements and many more have direct bearing on the work of a forensic artist. As if it is not difficult enough to deliver an accurate artistic representation of a person of interest, forensic artists must also know about the ability or inability of human beings to remember.

1. The Interview

At some point during any investigation, there will come a time to interview and question people. There are unique differences between interviewing a witness and interrogating a suspect (Cozart, 2009). The process of creating a composite drawing involves the artist's skillful interview of an eyewitness to the crime, followed by the creation of an artistic rendering of the described suspect. A witness can be a knowing observer of the crime, a victim, and even an unwitting bystander, unaware of the crime afoot. These observers are often asked to describe the suspect of the crime with enough

detail that a skilled forensic artist can draw a likeness of the suspect's face. Although recognizing people by their faces is something people commonly do without having to think about it, the processes involved in face recognition are far from simple (Nickoh, 2003).

While few, if any, forensic artists or their renderings have been challenged in court, the descriptions provided to the artist by those present at the scene are frequently questioned. In order to maximize their effectiveness, forensic artists must understand the human memory process and be cognizant of the issues that can reduce the reliability of eyewitness descriptions. This knowledge allows the forensic artist to give consideration to the use of specific interview techniques that minimize the opportunities to garner inaccurate accounts or descriptions of crime suspects and maximize the forensic artist's ability to create an accurate rendering of the suspect.

The police composite artist, whose function is to develop an image based on an observer's recollection of a person or event, must have a strong knowledge of the dynamics of human memory. This enables the artist to more effectively retrieve the information needed to create the composite drawing. Forensic art experts, as well as psychologists, describe this interview as a process in which the composite forensic artist balances common sense and experience with relevant theories about memory (Domingo, 1989). Some artists and police agencies make the mistake of believing that strong drawing skills are the only criterion for productive composite drawing. In fact, a mediocre artist with superior interview and people skills is preferred over a skilled artist with mediocre interview skills. The ideal composite artist possesses strong drawing skills as well as strong interview skills (Taylor, 2001, p. 138).

The paradox of eyewitness testimony is that, although justice professionals regard it as having a low level of reliability, it is the most important form of testimony as far as jurors are concerned (Nickoh, 2003). Although juries and decision makers place great reliance on eyewitness identification, they are often unaware of the potential danger of false memories and misidentification. In this context, the purpose of the composite drawing can be thought of as a quest for absolute truth. Absolute truth is reflective of reality, not someone's personal view of reality.

In creating a likeness of a suspect, the artist focuses on identifiable features of the subject, the first of which is the shape of the head, followed by unique or distinguishing features such as ears, facial features, and the relationship of facial features, to other facial features (distance, shape, angle, and position to name a few). It is these fine details that must be recalled with accuracy in order to create the appropriate likeness of the wanted person. The most important thing that must be remembered is that no artist, no composite, and no computer can provide an accurate picture without a witness who can provide a good description (Cozart, 2009).

Once finished, the composite drawing is not intended to be a portrait of the suspect but instead is designed to exhibit a likeness such that it will prompt those who view it to be reminded of specific features and feature relationships that may be similar to someone they know. Effective composite drawings may not completely represent the subject, but they accurately represent key details of the subject.

To further explore the link between an accurate forensic representation and a reliable description provided by those present at the scene of the crime, it is important to understand how human beings observe and remember what they have seen. In addition, how these witnesses are questioned has further bearing on the accuracy of the information garnered by the interviewer.

2. Original Memories

Many experts believe the concept of an “original memory” is a fallacy because the process of interpretation occurs at the very formation of a memory—thus introducing distortion from the very beginning (Engelhardt, 1999). From that point forward, the memory is subject to further opportunities for distortion. It is widely known that witnesses can distort their own memories without the help of a third party. This is because people rarely tell a story or recount events without a purpose. The act of telling and retelling a story is tailored to a particular listener. In telling a story, we edit out some details and emphasize others. The proverbial “fish story” is an example of this phenomenon in which the teller of the story changes the story with each telling and ultimately ends up believing the evolving story.

Many people become committed to their perceived original memory as a matter of personal pride or to avoid embarrassment. This is often a product of the subconscious mind and not necessarily a deliberate process. Once a witness states facts in a particular way or identifies a particular person as a perpetrator, they are often unwilling or unable—due to the reconstruction of their memory, to reconsider their original understanding or interpretation. When a witness identifies a person in a line-up, he is likely to identify that same person in later line-ups, even when the person identified is not the perpetrator or when the real perpetrator is present.

3. Fallibility of Witness Memories

Further complicating the ability of a forensic artist to gather accurate suspect descriptions are simple mistakes in memory. Memory errors fall into two classes: people can either completely fail to recall an event, or they may have an inaccurate recollection of the event (Green, 2009). Most people have very different attitudes about the two types of failure. Most understand that total memory failures are common. They can reflect about occasions when they have been unable to recall an event, so failures by other people are hardly surprising. In contrast, people are often overly optimistic about the accuracy of their retrieved memories, mostly because these errors have little practical consequence and often go unnoticed. This enables most people to become committed to the accuracy of their memory. Given the overconfidence in their own memory, people often place too much faith in the accuracy of eyewitnesses.

What causes our memory to be inaccurate? There are many reasons, but they fall into six basic categories: blurred memory, filling in for memory gaps, systematic distortion of perception, personal influences to memory, memory changes over time and with retelling, and finally—and most relative to the topic of forensic art—memory biased by question retrieval method. A skilled forensic artist is likely aware of all these impediments to accurate memory recall; however, combating them or adjusting for them in the interview process is a difficult task. Artists must consider the following potential pitfalls:

a. *Blurred Memory*

Images in our mind's eye are never as clear as the actual perception. For instance, everyone is familiar with their own bedroom, its general shape and size, as well as contents, but most people are at a loss to describe their bedroom in detail simply because they do not possess a memory of the room that is as detailed as actually looking at the room. Color is another example of the low resolution of human memory. There are thousands of colors, but color memory is very limited as to the shades of color within specific known colors. We are all familiar with ten to fifteen main colors, but shades of these colors can remain elusive to our memory. Finally, people do much better at picking between two objects when both are present, rather than when one is present and one is absent. This is important as it relates to viewing a live or photographic line-up of possible suspects. If the photo of the suspect or the suspect himself is not contained in the line-up, people may be inclined to choose from what they see, rather than rule out all possible suspects in the line-up in favor of a suspect who is not present in the array.

b. *Memory Fills in the Gaps*

Memory should be thought of as a reconstruction, not a record (Green, 2009). Eyewitnesses will often have insufficient information in the memory itself, so the reconstruction of the memory must invoke pieces of information from other sources. These sources can be preexisting schemas or other memories. People often understand their world through specific schemas or scripts—these are stereotyped mental models of objects and events. People can also confuse information sources. Memory source confusion, that is, including separate memories from other events in a more recent memory, is very common.

Psychologists have long recognized that gap filling and reliance on assumptions are necessary survival skills to function in our society (Engelhardt, 1999). For instance, if we are traveling on a crowded or loud subway, we might hear garbled words like “next,” “transfer,” and “train.” Building on our personal experience, knowledge, and assumptions, we might put together the actual statement: “Next stop 53rd Street, transfer available to the F train.” If asked later, we might even “remember” that

we had heard the full statement from the beginning, even if we had not. This is a subconscious process that takes place daily as a matter of survival in the world.

c. Memory Systematically Distorts Perception

Memory tends to distort perception in systematic ways. People tend to remember colors as being brighter and more saturated than they actually were. Studies have shown that people who are asked to recall vehicle speeds tend to overestimate slow speeds and to underestimate fast ones. Memory is also biased toward expected events. If someone witnesses the beginning of a conversation in which the communicator is giving directions to a destination familiar to the witness, the witness may not hear the inaccuracies given in the directions because he or she knows the proper directions and expects them to be told accurately.

d. Memory Is Personal

Human memory does not exist so that an observer may accurately report previously seen events. Each witness extracts an interpretation that is meaningful in terms of his personal beliefs, experiences and needs. Once the interpretation occurs, the events themselves become relatively unimportant. This explains why multiple witnesses to the same traffic collision can report a different account of what occurred between the vehicles involved. Witnesses may report different colors of vehicles, direction of travel, and even different colors of traffic signals, and some may base their description on their understanding of relevant traffic laws, rather than what they really observed.

e. Memory Changes over Time and with Retelling

Numerous studies have revealed that memory can change significantly over time. Most commonly, witnesses incorporate information learned after the event into their memory. This information may be provided by other witnesses and is usually used subconsciously to fill in memory gaps. In addition, as people recall events over and over, they eliminate some details and add others. Forensic artists are often challenged to avoid providing a witness with additional information relevant to the crime, and many artists

avoid being briefed on the events surrounding the crime so that they are sure to gather the information provided only by the witness.

f. Memory Is Biased by Question Retrieval Method

Memories can be biased by the questions asked at the time of retrieval. Several well-known studies have shown just how much the question itself can provide information that witnesses can incorporate into their memory. Eliminating leading questions is key to a forensic artist's interview process.

Studies have been conducted on human memory and on subjects' propensity to remember erroneously events and details that did not occur (Engelhardt, 1999). Oftentimes the main cause of this deviation in memory is caused by a third party either intentionally or unintentionally introducing false facts into memory. In one study, conducted in the 1970s by Elizabeth Loftus, subjects were shown a film of a traffic collision and then asked questions about it. One question was "How fast were the cars going...?" Half were asked, "...when they hit each other?", and the other half were asked, "...when they smashed into each other?" Subsequently, when asked to estimate the speed of the collision, the "smashed" group estimated higher speed than the "hit" group. Amazingly, when asked if there had been any broken glass related to the collision in the film (there had not), the "smashed" group was more likely to "remember" having seen broken glass. This suggests that the schema being used to reconstruct a memory is influenced by the way questions are posed. The "smashed" group was *confabulating*, that is to say, they honestly believed that they had seen broken glass.

Successful forensic artists acknowledge at the onset of an interview that human memory does not operate as if it were a videotape camera. We do not simply record some event in our memory and then later retrieve an unblemished recollection of what happened. Human memory is much more fragile, suggestible, and prone to distortion and decay than we typically realize. As a result, mistaken eyewitness testimony rarely involves outright lies; instead, it usually corresponds to commonly occurring distortions in memory functioning.

After witnessing an event, people are sometimes exposed to new information that can actually change their memory. This postevent information effect often transpires as a result of dialogues with other people or in an effort to fill in the memory blanks and even in an effort to piece together a sequence of events that make the witness's observations more relative.

Because forensic artists are completely reliant on witness accounts of events, an awareness of these impediments to accurate memory recall is helpful as they move through the interview process in search of the most accurate information to create a facial image of the suspect.

G. CONCLUSION

While the literature provides a wealth of information on forensic imagery, facial recognition technology, and the investigative practices associated with both, the combined use of forensic imagery and facial recognition technology to identify unknown subjects of a criminal investigation is not well understood. This section will explore, in part, what has been accomplished to answer the question "How can composite forensic imagery be used with facial recognition technology to increase the efficacy of forensic imagery as an investigative tool to identify possible persons of interest?" It will provide a brief summary of what remains to be addressed.

Upon examination of the evolution of forensic imagery, the literature suggests that much of this artistry is based firmly in what artists have come to know scientifically about the human face and facial structure and how the underlying skeletal structure influences the appearance of the complex expressions that make up the face. The features that make up a face are numerous, some obvious and some subtle, yet all are important when attempting to represent the overall depiction of the person described to the artist. A detailed knowledge of anatomy, science, psychology, communication, and interview techniques are all necessary skills for the composite artist.

The research reveals not only the necessity for forensic artists to accurately document the person depicted in his or her representation but also the need for the artist to exploit certain memorable or pronounced facial features so that the drawing can help

its viewer better identify the unknown person it depicts. This can be thought of as the distinctiveness of proportional arrangement of facial features. This distinctiveness forms the subject's "look" and triggers recognition (Taylor, 2001). To this end, composite drawings by nature should only contain a given amount of detail based on the limits of the human memory, focusing on the most pronounced features. This is a stark contrast to a photograph or an artist's portrait of a subject seated before him or her, with every detail of the subject's appearance.

As we compare the art of forensic imagery with the technology of facial recognition, the literature reveals two methods for mapping facial structure mathematically. In the same way the forensic artist documents the relationship of facial features in a sketch, facial recognition technology views a photograph of a subject and expresses these facial relationships numerically. Whether it is photometrically or geometrically, the algorithmic representation of the face can be compared with other representations in an effort to identify similarities. A computer program conducts this comparison, and its results are the sterile outcome of mathematical algorithmic formulae. This process, however, is not completely free of human interpretation. Research suggests that this process is completed though human review of possible matches to help confirm the likelihood of identification of a true match.

The literature available on forensic imagery and facial recognition suggests that there are similarities in both processes. Both use the relationships of facial features to create and identify a representation that brings about recognition from the viewer. The literature also documents differences in these processes. Initially, facial recognition programs are scientific, precise, and free from human interpretation. Forensic imagery is quite the opposite, utilizing interpretation, communication, inference, and varied levels of artistic ability to create a representation. It is these similarities and differences in forensic imagery and facial recognition that help to formulate the question "How can composite forensic imagery be used with facial recognition technology to increase the efficacy of forensic imagery as an investigative tool to identify possible persons of interest?"

We have yet to learn whether these two very different methods of identifying human faces are suitable for comparison with each other. Does the creation of a sketch of

the human face lend itself to accurate interpretation of facial relationships mathematically? Does the forensically drawn image of a person express similarities in facial relationships in the same manner as a facial recognition program? Can a facial recognition program consume forensic images of human faces in a way that identifies possible suspects? Can the facial recognition program do so productively, and if it cannot be done at a level considered productive, what can composite sketch artists learn from this research to improve the level of success by which their composite drawings contribute to the identification of persons of interest in a facial recognition software environment? Conversely, what can creators of facial recognition software programs learn from this research to develop programs that recognize composite sketches more effectively and accurately?

III. METHODOLOGY

A. METHODOLOGY

Case study methodology was used for this thesis and consisted of a comparative analysis of several cases. Each case consisted of a group of composite sketches completed by a single artist. This research served to evaluate the efficacy of merging two previously separate identification technologies, composite art and photo facial recognition.

This methodology helped to identify how composite imagery can be used with facial recognition technology to increase the efficacy of forensic imagery as an investigative tool to identify possible crime suspects. The methodology also provided an opportunity to obtain information that is beneficial to both composite artists and facial recognition program designers who may continue to pursue this merger of their individual disciplines. Ultimately this research may aid future researchers in further study of these two identification disciplines.

The IIS Facial Recognition System used by the Arizona Counter Terrorism Information Center contains only photographs. Until now, composite sketches have not been entered into this system to test the ability of the technology to recognize a picture created in a medium other than photography. The primary media for hand-drawn composite sketches are pencil, pen, and charcoal. Composite images can also be created using a variety of software programs available to law enforcement. This research offered the opportunity to analyze the ability of the Facial Recognition Program to consume composite representations in both hand-drawn and electronically generated formats.

Throughout this research the terms “composite sketch or composite art,” “mug photo,” and “portrait style sketch” or “control sketch” will be used. Although these terms may be used interchangeably in casual discussions about this topic, it is important to note their differences in the context of this research.

Composite Sketch or Composite Art—The composite sketch, whether drawn by hand or through the utilization of a software program, is an artistic rendering of a wanted person created by the artist immediately following the commission of a crime using witness and victim descriptions. This rendering is created before authorities know the identity of the suspect and is intended to be a “likeness” of the wanted person, not a portrait.

Mug Photo—A mug photo is a photograph of a suspect taken at the time of arrest or incarceration. In the context of this research, the photo recognition database of mug photos also contains all Arizona drivers’ license photos.

Portrait Style Sketch or Control Sketch—For purposes of this research, portrait style sketches of suspects were made utilizing the suspect’s mug photo as a model. The goal of these sketches was to try to duplicate the depiction in the photograph exactly. These drawings were utilized as a control sample to establish the ability of the Photo Recognition Program to accurately identify the suspect’s mug photo from the portrait style drawing of the suspect depicted in the mug photo.

In addition to these terms, it is important to note the general method by which photographs, and now composite sketches of unknown persons, are entered into the facial recognition program in search of a matching photograph and ultimately the suspect’s identity. The process used to enter or “enroll” composite sketches into facial recognition followed the same procedure that is used to enroll photographs of unknown suspects. The process for comparative analysis of an unknown offender photograph using the IIS Facial Recognition Program starts with entering or enrolling the picture of an unknown suspect into the program.

Upon loading the photograph database, the program analyzes the photo and views it in the form of a geometric representation. This geometric representation is used to create an algorithm or numeric representation of the face of the unknown person. Once this numeric representation is determined, it is compared against the numerical representations of all the photographs of known subjects in the database.

The Facial Recognition Program has the ability to search with varied levels of inclusion, which are expressed in the form of a percentage. The percentage reflects the level at which an identifiable number of photographs are excluded from the search. For instance, a search at 90% exclusion reveals only the top 10% of best possible matches to the enrolled photograph, which may consist of 200–500 possible matches. A search at 40% exclusion reveals the top 60% of best possible matches and could yield millions of possible suspect photos. The higher the percentage of inclusion, the smaller the number of possible matches will be delivered.

Within 15 seconds of entering the photograph, the program delivers a list of possible matches. It also stores the image of the unknown person and compares it to new photographs entered into the system subsequent to this analysis, affording investigators the ongoing potential to identify the suspect. Ideally, a search resulting in no more than 500 possible matches is preferred. Subsequently, a program administrator visually reviews these matches looking for subjects who are obviously the incorrect age, race, or gender, thus reducing the number of possible matches delivered to the investigator for follow-up investigation.

1. Fact finding inquiries conducted prior to the analysis of cases

Three inquiries or tests preceded the examination of cases and were conducted to better understand how the facial recognition program would view composite sketches and how successfully the composite sketch might be utilized effectively with the facial recognition technology to identify suspects. In addition to testing the viability of this research, these inquiries also contributed to the author's understanding of how to organize and structure the analysis of the cases.

Prior to examining implementation of the actual case data related to the merging of composite imagery with a facial recognition program, it was necessary to determine whether the Facial Recognition Program could recognize a pencil medium “portrait style” sketch drawn from a mug photo as an image of a human face (Fact Finding Inquiry Number 1). Once this was determined, it was necessary to know whether the Facial Recognition Program could use this pencil medium “portrait style” sketch drawn from a

mug photo to locate the suspect's mug photo itself within the Facial Recognition Program database (Fact Finding Inquiry Number 2). If the technology did have the ability to recognize a portrait style pencil drawing, it was then necessary to determine whether it could also recognize a composite sketch (Fact Finding Inquiry Number 3). These fact finding inquiries are detailed below. The analysis and results will be found in subsequent chapters.

a. Fact Finding Inquiry Number 1:

Determination of the IIS Facial Recognition Program's Ability to Recognize a Composite Pencil "Portrait Style" Drawing as a Facial Representation

The purpose of this inquiry was to determine whether the Facial Recognition Program was able to recognize a facial sketch drawn in pencil medium. To test this aspect of the program, a forensic artist obtained the mug photo of a suspect who was arrested in a case in which he had completed a composite drawing of the then unknown suspect at the time of the crime. Utilizing the mug photo, which had already been entered in the Facial Recognition Program database, the artist drew a pencil "portrait style" drawing of the suspect from the mug photo. This generated a portrait quality representation of the suspect as he appeared in his mug photo, rather than the likeness created through the original composite drawing.

This pencil drawing was enrolled into the Facial Recognition Program to determine whether the program would recognize the drawing as a face and assign a numeric value to the picture using the geometric algorithm. Upon visual inspection of the sketch by the facial recognition system manager, he determined that the overall grey scale of sketches was too light, with very slight differentiation in features. Based on this feedback, the artist revised his sketch; darkening some of the lines in the area of the eyes, nose, and mouth to ensure that the features were recognizable (this program focuses on the eyes of a subject and the relationship of facial elements to the eyes). This revision did

not change the details in the portrait; it simply darkened them. The amended “portrait” sketch was entered into the Facial Recognition Program for comparison. (See Appendix A-1.)

b. Fact Finding Inquiry Number 2:

Determination of the IIS Facial Recognition Program’s Ability to Identify the Mug Photo of a Subject Using a Pencil “Portrait Style” Drawing of the Subject in the Mug Photo

The purpose of this inquiry was to determine whether the algorithmic representation of the pencil drawing created by the facial recognition software in inquiry number 1 could generate a possible match to the mug photo of the subject depicted in the drawing. To answer this question, the numeric representation of the “portrait style” drawing generated in inquiry number 1 was entered into the Facial Recognition Program for comparison with the photos in the database in an attempt to locate the mug photo used to create the sketch. This is the same process used with any photograph being enrolled into the database in an attempt to locate a suspect.

The Facial Recognition Program has the ability to search with varied levels of inclusion. This search for the suspect’s mug photos utilizing the pencil “portrait style” sketches of the mug photos was done first at a low degree of certainty and then increased to a higher level of certainty. Ultimately a 90% certainty level was used to locate a possible suspect. This is the same standard of certainty used when comparing photographs of unknown persons to photographs in the database. (See Appendix A-2).

c. Fact Finding Inquiry Number 3:

Can the IIS Facial Recognition Program Identify Potential Investigative Leads Suspects Using a Composite Drawing of the Suspect?

This inquiry used the original composite sketch of the suspect depicted in the “portrait style” sketch in inquiries 1 and 2. The forensic artist had completed this sketch immediately following the crime. This composite was created using witness and

victim descriptions obtained in a standard composite imagery interview. The purpose of this inquiry was to determine whether the algorithmic representation of the pencil composite drawing (not the “portrait style” drawing) created by the Facial Recognition software could generate a possible match to the mug photo of the subject depicted in the drawing. A composite image is intended to be a likeness of the subject in question, not a portrait, making this an important inquiry.

Having previously isolated the ability of the Facial Recognition Program to recognize a pencil medium “portrait style” drawing of the same suspect created by the same artist, this inquiry allowed a separate understanding of the ability of the Facial Recognition Program to recognize a pencil medium composite sketch of the suspect. This analysis allowed for comparison between the two results both visually and quantitatively. (See Appendix A-3.)

d. The Case Studies

Each case consisted of a group of composite sketches completed by a single artist. The composite images of each of the suspects were enrolled into the Facial Recognition Program in order to determine the level of inclusion at which the suspect’s mug photo would appear. This level is expressed in the form of a percentage. Through this percentage we are able to understand the level of effectiveness for each composite drawing. These cases were aggregated in total, per artist, and per artistic medium in order to understand the efficacy of merging these technologies.

B. SAMPLE

This research consists of four cases. Each case was associated with a single forensic composite artist and his or her composite artistry. Because this analysis required the ability to compare composite representations of suspects with actual mug photos of the suspects, only composite images with identified suspects were studied. Due to this constraint the number of individual composite representations examined per artist was dependent upon the number of representations associated with identified suspects.

The artists submitted the composite drawings and mug photos of all their viable cases in which a suspect had been identified. The analyses of these cases answers the stated research questions by providing data regarding the ability of the facial recognition system to identify a suspect through enrollment of a composite image of the suspect into the Facial Recognition System. Using the standard for successful photographic entry into Facial Recognition, a comparison can be made to understand whether that standard can be met in the use of composite drawings.

All the cases are similar in that they are associated with a composite drawing of a person of interest associated with a real crime, documented through the forensic interview process. They were all enrolled into the same facial recognition software program, the sole program used by law enforcement in the state of Arizona. The variables associated with this process include different artists (with varied artistic and interviewing skill levels), the number of investigative cases used per artist, and the drawing medium used to create the composite (hand-drawn sketch or computer generated composite).

In an effort to provide a visual comparison of a “portrait style” drawing to a composite drawing, the first sixteen composite art samples tested included a control drawing of the suspect created from the suspect’s mug photo. The display of the composite drawing, the mug photo, and the control or “portrait style” drawing allows a qualitative evaluation by the reader of the visual accuracy of the composite sketch compared to the accuracy of the “portrait style” control sketch. While it was not necessary to replicate the inclusion of this control drawing with all the composite drawings, analysis of these sixteen cases including the control drawings provides data comparing the ability of the facial recognition system to identify a suspect through enrollment of a “portrait grade” drawing of the suspect (used as the control drawing) created by the artist for this analysis, against the system’s ability to identify the same person through the enrollment of a composite image of the suspect drawn at the time the crime occurred. (See Appendix B-1 through B-16.)

The cases are as follows:

1. Case Study Number One

Artist: Artist #1.

Job Title: Forensic Photo Specialist II, full-time Composite Artist.

Forensic Art Discipline: Composite Artist and 2D/3D Facial Reconstruction.

Medium: Hand-drawn composite images.

Training: Almost no formal training in art or interview techniques. This artist is self-trained, has attended several seminars, and has read extensively on the topic.

Years of forensic art experience: This artist has been practicing general art skills since childhood and has practiced composite sketch artistry for 16 years. The artist has completed over 200 composite renderings during this period.

Number of Composite Sketches Utilized: 20 (See Appendix B-1 through B-20.)

2. Case Study Number Two

Artist: Artist #2.

Job Title: Volunteer Forensic Artist.

Forensic Art Discipline: Composite Artist.

Medium: Hand-drawn composite sketches.

Training: This artist began drawing prior to a career in law enforcement and did not receive formal training in composite artistry.

Years of forensic art experience: This artist is a retired police officer with 30 years of law enforcement experience. The artist has practiced composite artistry for almost 50 years.

Number of composite sketches utilized: 9 (See Appendix C-1 through C-9.)

3. **Case Study Number Three**

Artist: Artist #3.

Job Title: Information Specialist/Forensic Artist.

Forensic Art Discipline: Composite Artist, 2D Design.

Medium: Hand drawn composite sketches.

Training: Life drawing and 2D Design; interview training: interviewing children of sexual abuse; FBI Forensic Facial Imaging.

Years of forensic art experience: General Art Experience 25 years, Forensic Art 5 years.

Number of composite sketches utilized: 8 (See Appendix D-1 through D-8.)

4. **Case Study Number Four**

Artist: Artist #4.

Job Title: Police Officer/Detective.

Forensic Art Discipline: None.

Medium: FACES 3.0 Computer Software.

Training: Basic training provided by the Faces 3.0 computer tutorial.

Years of forensic art experience: This artist is a certified police officer possessing basic training in interview and criminal investigation. The artist has used the Faces 3.0 composite art program for less than 2 years.

Number of composite sketches utilized: 2 (See Appendix E-1 and E-2.)

C. **DATA COLLECTION**

The data collection process followed the same format for each artist. As previously noted, the artist reviewed his or her forensic composite imagery portfolio to identify which of their cases had arrested suspects associated with them. These composites were submitted for enrollment into the Facial Recognition database. Because the suspect mug photo in the case is known to the researcher, the location of each mug photo within the Facial Recognition Database was noted in order to later determine how

deeply into the database the program had to search to locate the mug photo. The Facial Recognition Program reflects this depth as a percentage. Because the database searches for algorithmic matches, it searches first for the most similar photographic match to the composite, and then continues searching less likely matches. Because the researcher knows the location of the correct mug photo, this percentage is easily identified.

As an example, a 90% result suggests that the mug photo is located using the enrolled composite in the first 10% of the database. This means that the database delivered 500 possible matches, one of which was the correct mug photo. In a real world scenario where the suspect is not known, a Facial Recognition Program administrator would then visually inspect the 500 mug photos looking for visual matches and ruling out photos of individuals who are the incorrect sex, race, or age.

A 40% result suggests that the database delivered 60% of its total photographs before locating the mug photo. In this scenario, this means that the database delivered several million possible matches, one of which was the correct mug photo. It would not be reasonable for a Facial Recognition administrator to visually search through several million mug photos.

Each suspect's mug photo and the composite representation are displayed in an individual table along with the data collected from the enrollment in the facial recognition program. As previously noted, in an effort to provide a visual comparison of a portrait drawing to a composite drawing, the first sixteen composite art samples tested included a control drawing of the suspect created from the suspect's mug photo. The display of the composite drawing, the mug photo, and the control or "portrait style" drawing allows a qualitative evaluation by the reader of the visual accuracy of the composite sketch compared to the accuracy of the "portrait style" control sketch.

D. DATA ANALYSIS

This quantitative data was analyzed and compared to the data associated with other drawings by the same artist, as well as other artists, and other composite mediums (sketches versus computer-aided images). In the first sixteen cases in which a control image was used, the difference in the percentage number matches between the control

image and the composite image allowed a comparative analysis of the difference in success between the two images. These analyses help determine the success with which forensic artistry can be used with facial recognition technology as a viable investigative tool to identify possible persons of interest.

With regard to the qualitative data gathered, an examination of the artist's general skill, training, and experience was noted to determine if there was a relationship between the level of training and experience and the level of success of enrolling the composite images in the Facial Recognition Program.

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IV. ANALYSIS

A. ANALYSIS OF THE FACT FINDING INQUIRIES CONDUCTED PRIOR TO THE ANALYSIS OF CASES

Three inquiries or tests preceded the examination of cases, and were conducted to better understand how the facial recognition program would view composite sketches and how successfully the composite sketch might be utilized with the facial recognition technology to identify suspects.

1. Fact Finding Inquiry Number 1:

Determination of the IIS Facial Recognition Program's Ability to Recognize a Composite Pencil "Portrait Style" Drawing as a Facial Representation

When the "portrait style" drawing of the suspect's mug photo was entered into the Facial Recognition Program, it was immediately recognized as a face and given a numeric representation for comparison to other photographs in the database. (See Appendix A-1.)

2. Fact Finding Inquiry Number 2:

Determination of the IIS Facial Recognition Program's Ability to Identify the Mug Photo of a Subject Using a Pencil "Portrait Style" Drawing of the Subject in the Mug Photo

Upon enrollment of the "portrait style" drawing into the Facial Recognition Program, the level of certainty was successfully raised to the standard threshold of 90% without elimination of the suspect photograph from the list of possible matches. At 90% the program yielded a list of 200 possible matches (Appendix A-2.)

A visual comparison of the "portrait style" drawing with the suspect mug photo shows very little difference. Facial structure and facial features appear to be almost identical and skin tone and shading in the facial features is precise.

3. Fact Finding Inquiry Number 3

Can the IIS Facial Recognition Program Identify Potential Investigative Leads Suspects Using a Composite Drawing of the Suspect?

Upon enrollment of the composite representation into the Facial Recognition Program, the suspect mug photo was eliminated as a possible suspect at the 41st percentile. At 41% the suspect's mug shot was among 3,333,585 other possible matching mug shots. (See Appendix A-3.)

A visual comparison of the composite sketch and the mug photo qualitatively reveals several obvious differences between the composite sketch and the suspect mug photo. Skin tone and overall appearance of the composite image is very dark, suggesting to the viewer the suspect could be African-American, not Hispanic. In addition, facial hair depicted in the composite suggests a very different jaw line and lower facial structure. There are, however, some commonalities between the mug photo and the composite image. The suspect's drawn face and pronounced cheekbones and lips seem to suggest similarities.

B. ANALYSIS OF THE CASE STUDIES

This research consists of four cases. Each case was associated with a single forensic composite artist and his or her composite artistry.

1. Case Study Number One

Case study number one consisted of 20 suspect composite images completed by a single artist. These composite sketches were completed at the time the crime occurred. When enrolled in the Facial Recognition Program, the composite drawings in case number one ranged between 14% and 50% level of certainty in identifying the true suspect mug photograph. On average, the composite sketches in case number one located the suspect at the 30.1% level of certainty.

In this case, in addition to the composite images completed at the time the crime occurred, the first sixteen suspect composite comparisons also include sixteen control

“portrait style” drawings of the suspects created by the artist, utilizing the suspect mug photos as a guide. In the first 16 comparisons, each of the suspect’s three images (mug photo, portrait style control sketch drawn from the mug photo, and the original composite representation completed before the suspect was known) is displayed in an individual table along with the data collected from the enrollment into the facial recognition program for both the “portrait style” drawing and the composite drawing. This offers a visual qualitative representation of the relationship between the three representations of each suspect, as well as a quantitative representation of the data gathered.

The 16 control drawings created by artist number one ranged between 40% and 90% level of certainty in identifying the true suspect mug photograph. On average the control sketches in case number one located the suspect at the 74.4 % level of certainty. On average, the control drawings in case number one yielded a suspect identification at a 44.3% higher success rate than the composite drawings.

The level of success of these individual suspect comparisons is expressed in the form of a percentage. Table 1 displays the level of success for each of the control drawings and each of the composite sketches, together with the number of possible suspect mug photos delivered as a possible suspect match for the composite sketch. In addition, an average is expressed for both the total number of control sketches and composite sketches.

Table 1. Case #1 Results

Suspect Number	Control Sketch Percentage	Composite Sketch Percentage	Number of Results
1	90	41	3,333,585
2	64	19.6	9,440,604
3	80	27	9,993,950
4	41	50	805,977
5	90	32	9,680,141
6	75	27	9,268,733
7	85	30	9,609,148
8	70	34	7,256,929
9	90	48	1,430,263
10	90	25	9,356,222
11	40	19.4	9,578,119
12	70	21.6	9,976,483
13	75	20.5	9,838,220
14	55	25	8,752,649
15	85	36	5,607,497
16	90	48	2,418,042
17	N/A	34	8,743,000
18	N/A	20	9,687,204
19	N/A	14	9,737,479
20	N/A	30	9,625,441
Average	74.40%	30.10%	

2. Case Study Number Two

Case study number two consisted of nine suspect composite images completed by a single artist. These composite sketches were completed at the time the crime occurred. When enrolled in the Facial Recognition Program the composite drawings in case number two ranged between 18% and 57% level of certainty in identifying the true suspect mug photograph. On average, the composite sketches in case number two located the suspect at the 38.2% level of certainty.

Table 2. Case #2 Results

Suspect	Control Sketch Percentage	Composite Sketch Percentage	Number of Results
1	N/A	30	9,141,207
2	N/A	18	9,864,248
3	N/A	57	297,380
4	N/A	31	9,949,301
5	N/A	45	3,348,795
6	N/A	57	352,922
7	N/A	35	8,350,489
8	N/A	27	9,871,423
9	N/A	44	4,373,285
Average		38.20%	

3. Case Study Number Three

Case study number three consisted of eight composite images. When enrolled in the Facial Recognition Program the composite drawings in case number three ranged between 47% and 19% level of certainty in identifying the true suspect mug photograph. On average, the composite sketches in case study number three located the suspect at the 28.1% level of certainty.

Table 3. Case #3 Results

Suspect	Control Sketch Percentage	Composite Sketch Percentage	Number of Results
1	N/A	47	2,039,137
2	N/A	19	9,295,728
3	N/A	36	9,377,816
4	N/A	25	9,540,682
5	N/A	21	9,567,465
6	N/A	33	9,534,779
7	N/A	22	8,893,227
8	N/A	22	9,760,121
Average		28.1%	

4. Case Study Number Four

Case study number four consisted of two suspect composite images completed by a single artist. These composite sketches were completed at the time the crime occurred. In this case two separate crimes occurred, and it was later learned that the same suspect had committed these crimes. A police detective using a computer software program completed these composite drawings. This is the only case in this research in which a software program was used to complete the composite drawings.

When enrolled in the Facial Recognition Program the two composite drawings in case number four delivered a 48% and 26% level of certainty in identifying the true suspect mug photograph. On average, the composite sketches in case number four located the suspect at the 37% level of certainty.

In this case, in addition to the composite images completed at the time the crime occurred, a control “portrait style” drawing of the suspect created by the artist, utilizing the suspect mug photos as a guide is included. Each of the suspect’s three images (mug photo, portrait style control sketch created from the mug photo, and the original composite representation completed before the suspect was known) is displayed in an individual table along with the data collected from the enrollment into the Facial Recognition Program for both the “portrait style” drawing and the composite drawing. This offers a visual qualitative representation of the relationship between the three representations of each suspect as well as a quantitative representation of the data gathered.

The two composite renderings created by this artist were created at separate times, related to separate crimes. It was later learned that the suspect was the same in both these crimes. Although the composite drawings in this case are different, the suspect mug photo and the “portrait style” control drawing for both composite drawings are the same. The control drawing in this case located the suspect mug photo at a 29% level of certainty. The level of certainty of the control drawing in this case was 8% less than the level of certainty of the average of the composite drawings.

Table 4. Case #4 Results

Suspect	Control Sketch Percentage	Composite Sketch Percentage	Number of Results
1	29	48	1,071,564
2	29	26	9,999,083
Average	29%	37%	

C. COMPARATIVE ANALYSIS OF ALL FOUR CASE STUDIES

The four case studies used in this research yielded varied results. It is important to note that variables, including the ability of victims and witnesses to recall information, artist training and experience in art and interview techniques, the medium used to create the drawings, and how the Facial Recognition Program actually interprets these drawings all had some influence in the success of the Facial Recognition Program's ability to locate suspect mug photos. The varied sample sizes per case also make an artist-to-artist comparison difficult to quantify. Conclusions regarding the case studies are drawn with these variables in mind.

1. Comparative Analysis of All Artists' Composite Sketch Percentages

A comparison of the individual case composite sketch percentage averages offers a view of the level of success of each artist in utilizing a composite sketch to locate the suspect's mug photo. In addition, a comparison of cases where control drawings were created offers a view of each artists' level of success in utilizing a control sketch, drawn from the suspect mug photo, to locate the suspect's mug photo. The artists' averages ranged from 28.1 to 38.2 percent.

Table 5. Artist Comparison

Artist	Composite Sketch Percentage	Control Sketch Percentage
1	30.1	74.4
2	38.2	N/A
3	28.1	N/A
4	37	29
Average	33.4	51.7%

2. Comparative Analysis of Individual Artist Experience and Training in Relation to Their Success in Utilizing a Composite Sketch to Locate a Suspect Mug Photo

The artists' training and experience ranged from almost none in the case of a detective recently trained to use the Faces 3.0 Composite software system to an artist with almost 50 years of training and experience.

Table 6. Artist Experience and Training

Artist	Composite Sketch Percentage	YEARS OF EXPERIENCE
1	30.1	15
2	38.2	50
3	28.1	25
4	37	2
Average	33.4%	

V. RESULTS

While investigators, creators of facial recognition programs, and forensic artists may have an idea about the ability to successfully merge the two disciplines of composite art and facial recognition programs, it is not known whether composite drawings can be used effectively in combination with facial recognition software programs to identify unknown suspects. The results of this research helps to understand how effectively composite forensic imagery can be used with facial recognition technology to increase the efficacy of forensic imagery as an investigative tool to identify possible persons of interest.

In addition, these results offer some information to artists as well as facial recognition program creators to improve the level of success by which composite drawings are consumed by facial recognition programs to enable more effective and accurate identification of persons of interest.

A. RESULTS OF THE PRE-CASE STUDY INQUIRIES

1. Fact Finding Inquiry Number 1

Determination of the IIS Facial Recognition Program's Ability to Recognize a Composite Pencil "Portrait Style" Drawing as a Facial Representation

A visual examination of the "portrait" drawing in comparison to the suspect mug shot reveals remarkable similarities. The portrait drawing is an almost exact replication of the suspect mug photo. Facial proportions and shading are precisely duplicated.

Upon enrollment into the Facial Recognition Program, the drawing was immediately recognized as a facial image. Not only did the system recognize the drawing, it assigned a numeric representation to the drawing, allowing it to be compared against photographs within the database (See Appendix A-1.)

2. Fact Finding Inquiry Number 2

Determination of the IIS Facial Recognition Program's Ability to Identify the Mug Photo of a Subject Using a Pencil "Portrait Style" Drawing of the Subject in the Mug Photo

The Facial Recognition Program can accurately identify a reasonable number of possible suspects, including the known suspect, utilizing a pencil medium "portrait style" control sketch. At the 90% search level, the program identified 200 possible mug photo matches to the drawing, including the true suspect mug photo. This 90% search level is the same search level deemed effective when using a photograph of an unknown suspect to search for a mug photo. Such a result is within the range deemed acceptable for a visual search of the photographs for a suspect match, making the search for this suspect using this particular portrait style drawing a viable method of locating the suspect. It is important to note that this is not reflective of a real world scenario in which a composite drawing would be used. The composite drawing would not be nearly as accurate as this portrait style sketch (See Appendix A-2.)

3. Fact Finding Inquiry Number 3

Can the IIS Facial Recognition Program Identify Potential Investigative Leads Suspects Using a Composite Drawing of the Suspect?

An examination of the composite drawing and the mug shot photograph of the suspect revealed several similarities. The shape of the suspect's head, hairline, jaw line, lips, and upper brow area bear a resemblance to the suspect. Skin tone and facial hair differ slightly in the composite drawing. As is customary with a composite sketch, several facial features are recognizably similar, yet many others are not.

Quantitatively, the mug photo in comparison with the composite representation of the suspect was eliminated as a possible suspect at the 41st percentile, a full 50% sooner than the portrait style sketch was eliminated in the first inquiry. At 41% the suspect's

mug shot was among 3,333,585 other possible matching mug shots. The database can in fact locate the suspect's mug photo using a composite sketch for comparison but not at a level deemed effective in the context of a real-world investigation.

B. RESULTS OF THE CASE STUDIES

1. Case Study Number One

The composite drawings in case number one ranged between a 14% and 50% level of certainty in identifying the true suspect mug photograph. This means that, in a best-case scenario, 50% of the database, or 805,977 photographs, would have to be reviewed in order to locate the suspect mug photo. In the worse case scenario, 86% of the database, or 9.7 million photographs, would have to be reviewed in order to locate the suspect mug photo. On average, the composite sketches in case number one located the suspect at the 30.1% level of certainty.

The 16 control drawings created in case number one ranged between a 40% and 90% level of certainty in identifying the true suspect mug photograph. This means that, in a best-case scenario, 10% of the database, or two photographs, would have to be reviewed in order to locate the suspect mug photo. In the worse case scenario, 60% of the database, or 3.3 million photographs, would have to be reviewed in order to locate the suspect mug photo. On average the control sketches in case number one located the suspect at the 74.4 % level of certainty. Both these levels of certainty are far below the level deemed effective for investigative purposes.

2. Case Study Number Two

Nine composite sketches were used in this case study. The composite drawings in case number one ranged between an 18% and 57% level of certainty in identifying the true suspect mug photograph. This means that, in a best-case scenario, 43% of the database, or 2,000 to 3,000 photographs, would have to be reviewed in order to locate the suspect mug photo. In the worse case scenario, 82% of the database, or 9.8 million photographs, would have to be reviewed in order to locate the suspect mug photo. On

average, the composite sketches in case number two located the suspect at the 38.2% level of certainty. This level of certainty is far below the level deemed effective in the context of a real-world investigation.

3. Case Study Number Three

The composite drawings in case number three ranged between a 21% and 47% level of certainty in identifying the true suspect mug photograph. This means that, in a best-case scenario, 53% of the database, or 2,039,137 photographs, would have to be reviewed in order to locate the suspect mug photo. In the worse case scenario, 79% of the database, or 9.6 million photographs, would have to be reviewed in order to locate the suspect mug photo. On average, the composite sketches in case number three located the suspect at a 28.1% level of certainty. This level of certainty is far below the level deemed effective in a real-world investigative scenario.

4. Case Study Number Four

This case study serves as the only example of the use of a computer generated composite sketch to identify a suspect mug photo in the Facial Recognition Program. Two composite sketches were used in this case study. As a method for providing an opportunity for qualitative analysis, a control drawing was created for each case and entered into the system. This control drawing represents the artist's best effort to depict the suspect as accurately as possible, using the mug photo as the subject of the drawing. This control drawing provides an opportunity to view a suspect depiction that represents a best-case scenario of creating an accurate sketch of the suspect.

The control drawing can be compared side by side with the composite drawing and the mug photo to allow a visual assessment of the accuracy of each drawing to the suspect mug photo. In addition, the control drawing results provide an opportunity for a quantitative comparison between the control drawing results and the composite drawing results. Because this sample only contains two composite representations, arriving at conclusions about the use of computer generated composite drawings in the Facial Recognition Program is difficult.

The composite drawings in case number four resulted in a 48% and 26% level of certainty in identifying the true suspect mug photograph. This means that, in a best-case scenario, 52% of the database, or 1 million photographs, would have to be reviewed in order to locate the suspect mug photo. In the worse case scenario, 74% of the database, or almost 10 million photographs, would have to be reviewed in order to locate the suspect mug photo. On average, the composite images in case number four located the suspect at the 37% level of certainty.

The single control drawing created in case number four resulted in a 29% level of certainty in identifying the true suspect mug photograph. This means that, in a best-case scenario, 71% of the database, or 9.8 million photographs, would have to be reviewed in order to locate the suspect mug photo.

This control drawing yielded a suspect identification at an 8% lower success rate than the artist's composite drawings, meaning that the artist's composites were more accurate than the actual control drawing created using the mug photo as a model. Overall, the level of certainty at which the suspect mug photo was identified is far below the acceptable threshold deemed effective for real world investigations.

C. COMPARATIVE RESULTS OF ALL FOUR CASE STUDIES

1. Comparative analysis of all cases average composite sketch percentage

A comparison of the individual case composite sketch offers a view of each artist's level of success in utilizing a composite sketch to locate the suspect's mug photo. In addition, a qualitative comparison of cases where control drawings were created offers a view of each artist's level of success in utilizing a control sketch drawn from the suspect mug photo to locate the suspect's mug photo.

The combined artists' composite sketch percentage was 33.4%. While several drawings within each case study showed promise overall, on average the drawings

completed by these composite artists, although visually or qualitatively skilled, fall far short of being an effective means of identification of a suspect using the Facial Recognition system.

2. Comparative Analysis of Individual Artist Experience and Training in Relation to Their Success in Utilizing a Composite Sketch to Locate a Suspect Mug Photo

Forensic art experts agree that training in art, forensic art techniques, and interview techniques positively influences the artist's ability to be successful in the creation of effective forensic sketches. In addition, the opportunity to practice these techniques brings a level of experience that enhances the artists' abilities to improve their technique. In this analysis, the training and experience of each artist was examined in terms of their level of success.

Given the varied and very limited sample size, it is difficult to identify conclusively to what extent the level of artist experience and training influences their success when using a facial recognition program. However, it appears that experience followed by training seems to influence the level of success when entering hand drawn composite sketches into the program. The artists in cases 1 and 2 have had significantly more experience in composite sketch artistry, and their success level suggests that this experience may be a contributing factor.

VI. CONCLUSION

Government and law enforcement entities have invested billions of dollars into technologies that enable us to identify would-be terrorists and criminals through networked camera systems and facial recognition technologies. These programs enable law enforcement practitioners to identify threats and mitigate them in order to keep our communities safe. This research introduced a significant opportunity to expand the ability to identify criminals through the use of composite images in facial recognition databases when no photographic representation exists of the individual committing the crime.

This research served to evaluate the feasibility of merging two previously separate identification technologies. Facial recognition programs are abundant, varied, and utilized by numerous law enforcement agencies to identify criminal suspects captured by video or still photography. However, it was not known whether this technology was a viable method to identify criminal suspects depicted in forensic composite images. The evaluation of a set of cases integrating composite art into facial recognition technology provided an opportunity to explore the possibility of expanding the suspect identification capabilities.

Specifically, this research analyzed how composite forensic imagery could be used with facial recognition technology to increase the efficacy of forensic imagery as an investigative tool to identify persons of interest. The research also served as an opportunity for composite artists and facial recognition program creators to learn how they can improve the level of success by which composite drawings are consumed by facial recognition programs more effectively and accurately.

A. OVERALL EFFICACY

This research provides important insights regarding the efficacy of utilizing forensic illustration in a facial recognition environment. The facial recognition program recognizes a composite sketch as a facial image and accurately assigns a numeric

representation to the sketch, just as it would to a photograph. In addition, using a “portrait style” control sketch of the suspect’s mug photo, the program can efficiently link the control sketch to the mug photo at a high level of accuracy.

These case studies focus on the ability of the Facial Recognition Program to effectively identify a suspect using a composite drawing. While the ability to locate the suspect’s mug photo in the database using a composite sketch shows promise, in order to be an effective method of investigation, the composite sketch would need to be searched at the 90th percentile and still retain the suspect mug photo in its list of possible suspects. Although the merging of forensic illustration with facial recognition technology is a viable opportunity to further criminal investigations and identify suspects, utilizing current systems does not yield results at a level deemed productive by practitioners.

In order to understand why the program is unable to use the composite representation to effectively recognize the suspect’s mug photo, it is important to recall how the facial recognition program identifies possible suspect matches. Every face has numerous landmarks, or peaks and valleys, which make up facial features. Much like locations of identification on a fingerprint, these facial landmarks, known as modal points, are measured, creating a numerical code. Each human face has approximately 80 modal points: for example, the distance between the eyes, the width of the nose, the depth of the eye sockets, the shape of the cheekbones, and the length of the jaw line. The program creates a numeric representation of this face using these precisely measured and located landmarks.

Conversely, the creation of composite imagery is not a precise process. Composite art is defined as a graphic image made up from the combination of individually described component parts (Taylor, 2001). Composite sketches by nature are not intended to be precise representations. Psychologists have found that people are not very good at recalling a face after just a single encounter. Accuracy diminishes if the witness has to describe a face so that someone else can draw a picture. This is because the witness is asked to pick out features one by one—eyes, nose, mouth, and so on – so the face can be constructed (Avril & Graham, 2011). Research reveals that our brains do not

perceive a face in this way—like a laundry list of parts—but as a coherent whole. This combination of lack of precision and difficulty in recalling and describing facial features does not lend itself to the creation of a precise or “portrait style” composite drawing.

While qualitatively a human being may be able to look at a composite sketch and recognize key features that resemble a person known to the viewer, a computer program does not have the ability to recognize these nuances. The facial recognition program relies specifically on a precise relationship between facial features in order to deliver possible matches. Composite images simply do not depict these facial relationships precisely.

B. LESSONS LEARNED FOR ARTISTS AND FACIAL RECOGNITION PROGRAM DEVELOPERS

This research provides composite artists with information to assist them in creating images that are more precisely consumed by current facial recognition programs, improving the program’s ability to identify possible investigative leads. Much of this information was learned through the interactive process and communication between the artists and the facial recognition program manager as identified in the cases. Through input from the program manager, images were drawn more clearly to add contrast and definition to the drawings, increasing the software’s ability to recognize details.

Sketches created with less definition were not as successfully enrolled in the program as those that were drawn with contrast, clear lines, and obvious shading. In addition, composite drawings containing suspects depicted with hats had to be modified to remove the headwear. This headwear caused problems with the program’s ability to distinguish a facial feature from the headwear. While this information was beneficial for the consumption of composite images for the purpose of this research, these adjustments do very little on a broad scale to improve the ability of current facial recognition technology to recognize composite images.

This research reveals two key pieces of information regarding composite art and its compatibility with photo facial recognition technology. The first is that composite images are not created with the intent to draw a portrait of the unknown suspect, and the

second is that there are numerous artistic styles used to create composite images. The mere fact that composite images are used to identify unknown suspects and that facial recognition programs are used to identify unknown suspects does not necessarily mean that the two disciplines are directly compatible in terms of integrating the two technologies, as they exist today.

Photographs of unknown suspects remain fairly constant in their composition, clarity, detail, and accuracy, and photograph-to-photograph comparisons in a facial recognition program are made using the same technological language. This is not the case when comparing composite sketches to photographs.

Composite images are created to highlight the noticeable and unique facial features of an unknown suspect. These unique facial features are showcased to trigger recognition in the human observer, who is capable of inference, recognition of finite detail, and the ability to draw conclusions based on their discretionary observations. Facial recognition programs do not possess these cognitive and discretionary skills; rather, their recognition of possible suspect matches is based solely on geometric and mathematical formulae, making them incapable of recognition of nuanced or inferred similarities between a composite image and a photograph. In short, the creation and viewing of composite images by human beings is subjective and open to interpretation.

Adding to this subjectivity is the fact that composite artists create composite images using various artistic styles. Some depictions are lightly shaded and suggestive of very basic artistic lines and shapes, while others are created with definition, contrast, and very well-defined lines and detail. This continuum of artistic style and clarity is far from the uniform appearance of photographic representations. Future research into these styles and how they are consumed by a facial recognition program may help program designers build a program that better understands this format, one that is very different from one that analyzes photographs. Continuing these case studies with a much larger sample size would be beneficial in the process to identify artistic styles and continue to learn how the Facial Recognition Program interprets these varied styles.

This research is likely more beneficial to facial recognition program designers than it is to composite artists. While there is little that composite artists can do on a large scale to improve the consumption of their art by these programs, this research provides facial recognition program designers with information that will assist in possible design changes that better support the use of composite artistry in their programs in the future. Current software programs rely on specific facial relationships, which contribute to the creation of a precise algorithmic representation. It is this very precision that makes consumption of composite images so difficult for these programs.

Instead of focusing on facial relationships, a program that focuses more on general facial features such as lines, shading, and overall facial shape to create the algorithmic representation may be more successful in matching mug photos to composite images. Michigan State University researchers are currently trying to develop a software program that reads these facial details in this way (Homeland Security Newswire, 2011). Software that finds high-level features, such as the structural distribution and the shape of the eyes, nose, and chin, from both the sketch and the photo would likely be more successful in matching composite sketches to mug photos. Currently the Michigan State research has only been able to perfect its software to identify the correct person 45% of the time. This level of success is still far below the level deemed effective in the context of a real-world investigation.

C. CHALLENGES AND LIMITATIONS OF THE RESEARCH

This research set out to determine the efficacy of using composite sketches in a photo facial recognition environment. In attempting to evaluate the effectiveness of such an idea, multiple artists were used, each with varied sample sizes, experience, training, and artistic style. These variables limited the ability to make comparisons from case to case without first acknowledging the differences in each case sample.

This research was limited in sample size as well. The IIS Facial Recognition Program is used and populated by data sources specific to the state of Arizona (with some federal data source exceptions). This required that the composite samples come from Arizona cases only, somewhat limiting the overall sample size. In addition, because it

was necessary to know the identity of the suspect, only composite representations with identified suspects could be used, further limiting the sample size. In addition, very few samples utilizing composite art software programs were available for this research. While many Arizona agencies utilize this technology, none reported cases in which suspects had been identified.

The four case studies used in this research yielded varied results. It is important to note that variables, including the ability of victims and witnesses to recall information, artist training and experience in art and interview techniques, the medium used to create the drawings, and the process by which the Facial Recognition Program actually interprets these drawings all had some influence in the success of the Facial Recognition Program's ability to locate suspect mug photos. Varied sample sizes per case also made an artist-to-artist comparison difficult to quantify. Conclusions regarding the case studies were drawn with these variables in mind.

D. REMAINING QUESTIONS OR ISSUES

Due to the very small sample size of electronically created composite images using a composite art software program; this research was unable to evaluate the admission of electronically created composite drawings into the Facial Recognition Program. Increasing the sample size in future research to include more electronically created composite images would enable a better evaluation of the use of these composites in a photo facial recognition environment.

E. CONCLUSION

These research findings suggest an opportunity to explore the creation of a different type of facial recognition program that may consume composite images more effectively. Clearly, current photo facial recognition technology is already capable of recognizing a composite image as a facial representation—but not in the form that translates well to locating the suspect's mug photograph at an effective level using current facial recognition programs. Program designers have an opportunity to fine-tune existing technology to more effectively link composite images to suspect mug photos.

The success of these experiments shows great promise for expansion of the usefulness of composite artistry as a tool to identify suspects on a much larger scale than previously experienced. As our country's efforts in homeland security continue, the ability of investigators to enter composite drawings into a facial recognition program capable of consuming composite images more effectively will allow a composite drawing to be exposed to 30 million possible matches, far more effectively using the composite drawing to find the suspect and ultimately impact crime and criminal activity.

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APPENDIX A

FAST FINDING INQUIRY #1

APR 11 - 10:00 AM

Case 744



Case 744



Case 744



Notes: Current size of database at time of run = 27145819

Appendix A I

FACT FINDING INQUIRY #2

Aug 11 - Booking 01

Gen. Tol.



POW 20-000641



Notes: Current size of database at time of run = 27145819

Agenda 4 of 4

FACT FINDING INQUIRY #3

Aug 11 - Boston 01

Case 11111



Case 11111



Notes: Current size of database at time of run = 27145819

Agenda 1.1

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APPENDIX B

Step 11 - Summary

Composite Sketch



Person	% of Results	Database Map
01	1	Yes
02	1	Yes
03	117	Yes
24	1129	Yes
25	4007	Yes
41	3,333,565	Yes

PCAF ID: 202611



Control Image



Person	% of Results	Database Map
01	1	Yes
02	14	Yes
03	64	Yes
24	644	Yes
25	17141	Yes

Notes: Current size of database at time of run = 27145819

Appendix B 1

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Run #1 - Group 10

Persons	5 of Results	Success Rate
00	1	0%
01	1	0%
02	121	0%
20	1100	0%
21	1000	0%
22	10000	0%

Person 20000000



Control Image



Persons	5 of Results	Success Rate
00	1	0%
01	01	0%
02	000	0%
03	0000	0%
04	01000	0%
05	01000	0%

Notes: Current size of database at time of run = 27,896,787

Appendix B

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Row VI - Group 09

Composite Image



Persons	% of Results	Success Rate
00	1	0%
01	2	0%
02	12	0%
03	100%	0%
04	100%	0%
05	100%	0%

Row VI - Group 09



Row VI - Group 09



Persons	% of Results	Success Rate
00	1	0%
01	2	0%
02	12	0%
03	100%	0%
04	100%	0%
05	100%	0%

Notes: Current size of database at time of run = 27,896,787

Appendix B.1

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Step 11 - Output

Persons	5 of Results	Success Map
00	1	70
01	4	70
02	20	70
70	90	70
80	4700	70
90	207400	70

Person 1 - 000000



Control Image



Persons	5 of Results	Success Map
00	1	7
01	14	7
02	100	7
70	740	7
80	2000	7
90	4770 500	7

Notes: Current size of database at time of run = 27,886,787

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Gregorio J. Allen



Group VI - Group 05

Persons	% of Results	Database Size
05	1	95
06	10	95
07	125	95
79	1900	95
80	17000	95
81	14000 001	95

02912-00000000



Gregorio J. Allen



Persons	% of Results	Database Size
05	1	95
06	10	95
07	125	95
79	1900	95
80	17000	95
81	14000 001	95

Notes: Current size of database at time of run = 27,896,787

Appendix B 5

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Row VI - Group VI

Composite Image



Persons	3 of Results	Database Size
10	1	1
10	10	1
10	250	1
10	1000	1
10	10000	1
10	100000	1000

Row VI - Group VI



Composite Image



Persons	3 of Results	Database Size
10	1	1
10	10	1
10	100	1
10	1000	1000
10	10000	1000

Notes: Current size of database at time of run = 27,896,787

Appendix B

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Row VI - Group 07

Composite Image



Persons	3 of Results	Success Rate
00	1	90
01	4	70
02	62	70
03	1000	70
04	1770	70
05	1400 100	70

Reference Image



Control Image



Persons	3 of Results	Success Rate
00	1	4
01	1	70
02	40	70
03	800	70
04	1000	70

Notes: Current size of database at time of run = 27,896,787

Appendix B 7

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Step 11 - Group 10			Step 12 - Group 10		
Composite Photo	Persons	% of Results	Database Size	Persons	% of Results
	50	1	70		70
	50	2	70		70
	50	10	70		70
	70	7000	70		70
	80	6000	70		70
	90	770000	70%		70%
Composite Photo	Persons	% of Results	Database Size	Persons	% of Results
	50	1	70		70
	50	2	70		70
	50	10	70		70
	70	500	70		70
	80	200	70%		70%

Notes: Current size of database at time of run = 27,806,787

Appendix B.4

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Row VI - Group 09

Composite Image



Persons	% of Results	Success Rate
00	1	0%
01	10	0%
02	50	0%
03	1000	0%
04	10100	0%
05	147000	0%

Actual Person



Actual Person



Persons	% of Results	Success Rate
00	1	0%
01	10	0%
02	100	0%
03	1000	0%
04	1000	0%

Notes: Current size of database at time of run = 27,886,787

Appendix B-9

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Row 11 - Group 100

Composite Image



Persons	% of Results	Success Rate
00	1	0%
01	1	0%
02	10	0%
03	100	0%
04	100	0%
05	100	0%

POTENTIALITY



Composite Image



Persons	% of Results	Success Rate
00	1	0%
01	1	0%
02	10	0%
03	100	0%
04	100	0%
05	100	0%

Notes: Current size of database at time of run = 27,896,787

Appendix B 10

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Query #1 - 8/26/2017

Composite Image



Persons	% of Results	Success Rate
00	1	0%
01	1	0%
02	2	0%
20	10	0%
21	757	0%
22	756-100	0%

Query #2 - 8/26/2017



Control Image



Persons	% of Results	Success Rate
00	1	0%
01	1	0%
02	00	0%
20	00	0%
21	2700	0%
22	2700-100	0%

Notes: Current size of database at time of run = 27,896,787

Appendix B-11

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Query #1 - Composite			Query #2 - MUGSHOT		
Composite Image	Persons	% of Results	Similarity Map	Mugshot Image	
	00	1	90		
	00	1	90		
	00	100	90		
	70	1000	90		
	00	10000	90		
	710	1000000	90%		
Composite Image	Persons	% of Results	Similarity Map		
	00	1	90		
	00	2	90		
	00	100	90		
	00	1000	90		
	00	10000	90%		

Notes: Current size of database at time of run = 27,896,787

Appendix B.12

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Query #1 - 8/26/2018

Composite Image



Persons	% of Results	Success Rate
00	1	0%
01	2	0%
02	00	0%
03	00	0%
04	000	0%
05	0000	0%
06	00000	0%

PCAP 1 IMAGE/1



Control Image



Persons	% of Results	Success Rate
00	1	0%
01	1	0%
02	0	0%
03	00	0%
04	000	0%

Notes: Current size of database at time of run = 27,896,787

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COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Row 11 - Strong 99%

Composite Image



Persons	% of Results	Database Size
10	1	99
10	10	99
10	100	99
10	100	99
10	1000	99
10	10000	99

Reference Image



Control Image



Persons	% of Results	Database Size
10	1	99
10	10	99
10	100	99
10	100	99
10	1000	99
10	10000	99

Notes: Current size of database at time of run = 27886787

Appendix B 14

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Row 11 - Group 101

Persons	% of Results	Database Size
00	1	70
01	1	70
02	10	70
70	000	70
80	1000	70
90	1000 200	700

Row 12 - Group 101



Control Image

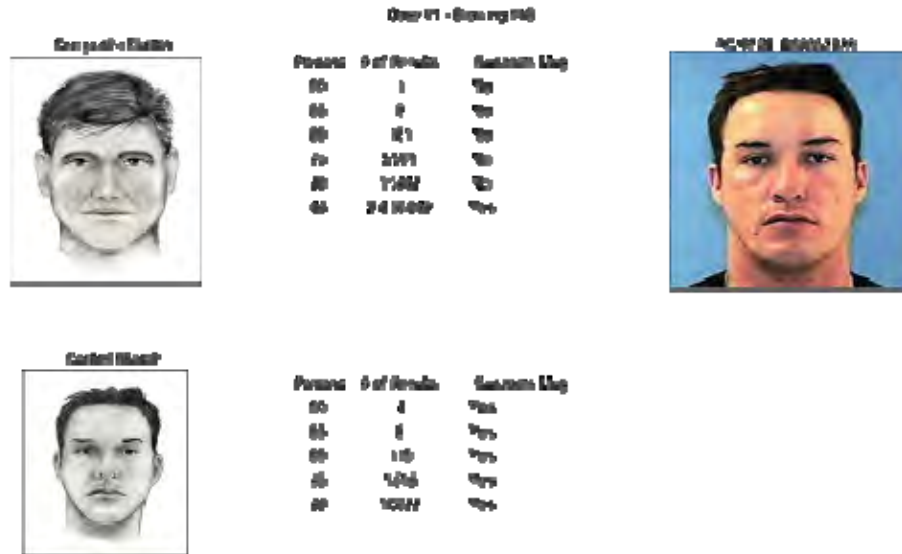


Persons	% of Results	Database Size
00	1	70
01	10	70
02	000	70
70	1000	70
80	1000	70

Notes: Current size of database at time of run = 27886787

Appendix B 10

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS



Notes: Current size of database at time of run = 27886787

Appendix B 10

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

APR 01 - 08:00 PM

Composite Image



Persons	9 of Results	Similarity Map
00	4	7%
00	4	7%
00	21	7%
70	27%	7%
80	100%	7%
90	5.471000	7%

APR 01 - 08:00 PM



Notes: Current size of database at time of run = 27886787

Agenda: 01/12

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Query 01 - 8/26/2018

Composite Image



Persons	% of Results	Retention Map
00	1	70
00	2	70
00	42	70
70	175	70
80	4717	70
90	7607.001	70

Query 01 - 8/26/2018



Notes: Current size of database at time of run = 27886787

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COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Query 01 - 01/01/2019

Composite Image



Persons	9 of Results	Maximum Map
00	1	70
00	2	70
00	21	70
70	000	70
00	000	70
00	0 70 400	70%

Query 2 - 01/01/2019



Notes: Current size of database at time of run = 27886787

Appendix B 10

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Query 01 - 8/24/2020

Composite Image



Persons	9 of Results	Similarity Map
00	1	70
00	4	70
00	21	70
70	1.15	70
00	4700	70
70	7001-001	70%

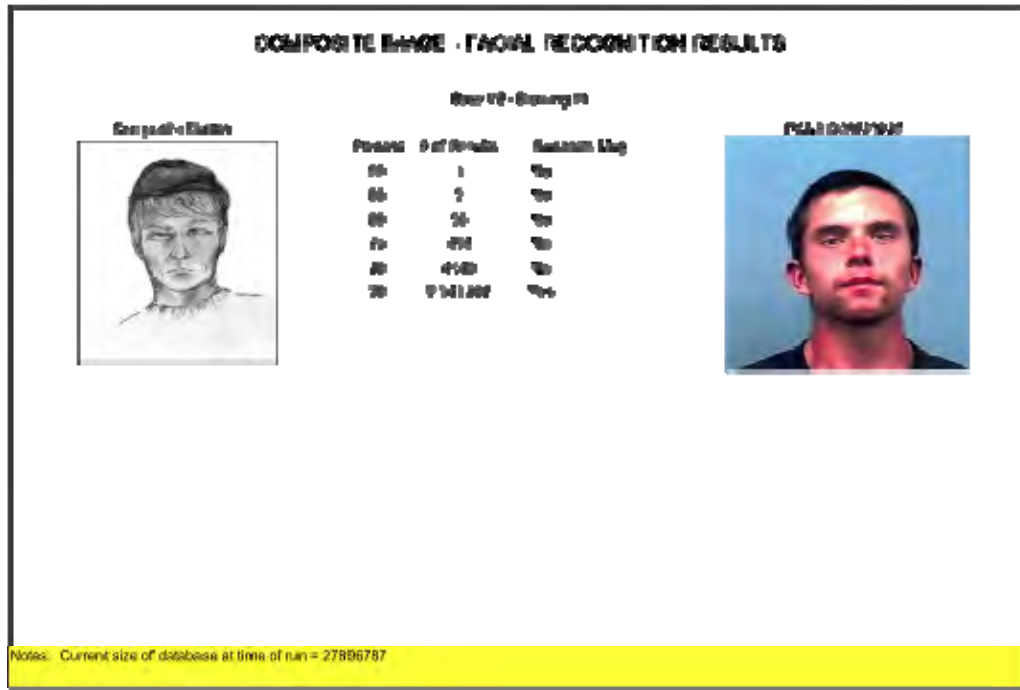
Query 01 - 8/24/2020



Notes: Current size of database at time of run = 27886787

Agenda: 8/20

APPENDIX C



Appendix I

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

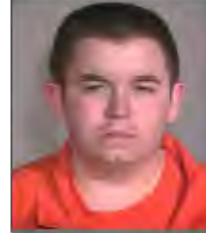
Composite Image



Group 10 - Group 10

Person	3 of Results	Similarity Map
00	3	70
00	100	70
00	100	70
70	100	70
00	100	70
10	100	70

Group 10 - Group 10



Notes: Current size of database at time of run = 27886787

Appendix 2

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Row 10 - Group 10

Persons	9 of Results	Retention Map
00	1	70
00	4	70
00	100	70
70	7000	70
00	10000	70
00	200000	70%

Actual Photo of CC*



Notes: Current size of database at time of run = 27896787

Appendix 1

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Show 10 - Strongest			100% 100% Live	
Composite Image	Persons	3 of 10-sets	Maximum Size	
	10	3	75	
	14	10	75	
	15	14	75	
	16	15	75	
	17	16	75	
	18	17	75	
	19	18	75	
	20	19	75	
	21	20	75	
	22	21	75	
	23	22	75	
	24	23	75	
	25	24	75	
	26	25	75	
	27	26	75	
	28	27	75	
	29	28	75	
	30	29	75	
	31	30	75	
	32	31	75	
	33	32	75	
	34	33	75	
	35	34	75	
	36	35	75	
	37	36	75	
	38	37	75	
	39	38	75	
	40	39	75	
	41	40	75	
	42	41	75	
	43	42	75	
	44	43	75	
	45	44	75	
	46	45	75	
	47	46	75	
	48	47	75	
	49	48	75	
	50	49	75	
	51	50	75	
	52	51	75	
	53	52	75	
	54	53	75	
	55	54	75	
	56	55	75	
	57	56	75	
	58	57	75	
	59	58	75	
	60	59	75	
	61	60	75	
	62	61	75	
	63	62	75	
	64	63	75	
	65	64	75	
	66	65	75	
	67	66	75	
	68	67	75	
	69	68	75	
	70	69	75	
	71	70	75	
	72	71	75	
	73	72	75	
	74	73	75	
	75	74	75	
	76	75	75	
	77	76	75	
	78	77	75	
	79	78	75	
	80	79	75	
	81	80	75	
	82	81	75	
	83	82	75	
	84	83	75	
	85	84	75	
	86	85	75	
	87	86	75	
	88	87	75	
	89	88	75	
	90	89	75	
	91	90	75	
	92	91	75	
	93	92	75	
	94	93	75	
	95	94	75	
	96	95	75	
	97	96	75	
	98	97	75	
	99	98	75	
	100	99	75	

Notes: Current size of database at time of run = 27886787

Appendix 1

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Run 10 - Group 05

Composite Image



Persons	Set Results	Success Rate
00	1	0%
01	20	0%
02	204	0%
03	1200	0%
04	10000	0%
05	170000	0%

Reference Image



Notes: Current size of database at time of run = 27886787

Appendix B

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Run 10 - Group 10

Composite Image



Persons	# of Results	Success Rate
10	1	10%
100	25	25%
1000	250	25%
10000	1000	10%
100000	10000	10%

Reference Image



Notes: Current size of database at time of run = 27886787

Appendix B

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Row 10 - Group 10

Person	9 of Results	Matched Map
00	1	7%
01	2	7%
02	121	7%
20	722	7%
21	1 000	7%
22	6 700 000	7%

PC: 01/01/2000-10:00:00



Notes: Current size of database at time of run = 27886787

Appendix 2

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Row 10 - Group 10

Person	9 of Results	Matched Map
00	1	Yes
00	15	Yes
00	200	Yes
20	2700	Yes
00	1700	Yes
00	1001000	Yes

PC: 00 2011 2000-100000



Notes: Current size of database at time of run = 27806787

Appendix B.4

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Run 10 - Group 10

Persons	9 of Results	Maximum Map
00	1	70
00	4	70
00	500	70
70	5400	70
80	17700	70
01	4757360	70%

0000 - 0000-0



Notes: Current size of database at time of run = 27886787

Appendix 10

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APPENDIX D

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Run #3 - Group 19

Person	% of Results	Retention Day
26	1	Yes
66	66	Yes
88	254	Yes
79	1000	Yes
80	12000	Yes
62	2477 157	Yes

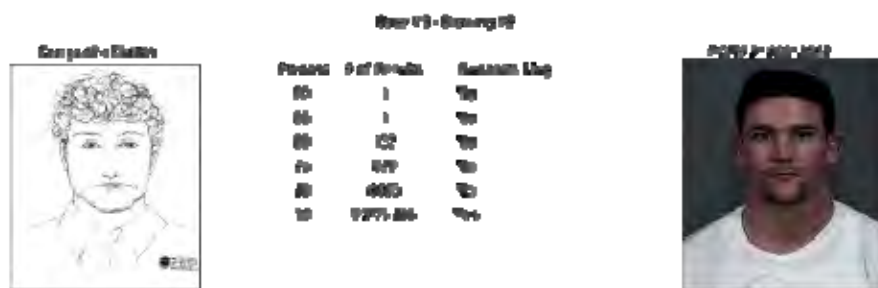
Person #19-001214



Notes: Current size of database at time of run = 27896787

Appendix I

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS



Notes: Current size of database at time of run = 27886787

Appendix 2

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Score VS - Group 09

Persons	# of Results	Success Rate
00	1	0%
01	2	0%
02	256	0%
03	1000	0%
04	10000	0%
05	100000	0%

Score VS - Group 09



Notes: Current size of database at time of run = 27886787

Appendix B 1

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image		Group VS - Group 01		Group VS - Group 01	
Person	3 of Results	Person	3 of Results	Person	3 of Results
01	1	01	1	01	1
02	11	02	11	02	11
03	22	03	22	03	22
04	33	04	33	04	33
05	44	05	44	05	44
06	55	06	55	06	55
07	66	07	66	07	66
08	77	08	77	08	77
09	88	09	88	09	88
10	99	10	99	10	99

Notes: Current size of database at time of run = 27896787

Appendix B.1

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Group 13 - Group 15

Persons	# of Results	Success Rate
13	1	7%
14	1	7%
15	10	7%
16	10%	7%
17	10%	7%
18	10%	7%

Group 13 - Group 15



Notes: Current size of database at time of run = 27886787

Appendix B 5

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Row 13 - Group 03

Composite Image



Persons	3 of Results	Similarity Map
00	200	70
00	1000	70
00	400	70
70	1000	70
00	7000	70
70	7777 777	70

Reference Image



Notes: Current size of database at time of run = 27896787

Appendix B 6

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Group VS - Group 07			Group 07
Person	3 of Results	Similarity Map	Person 07
01	1	75	
02	25	75	
03	25	75	
04	1,000	75	
05	1,000	75	
06	1,000	75	
07	1,000	75	

Notes: Current size of database at time of run = 27896787

Appendix 7

COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Step 13 - Output 13

Composite Image



Person	9 of Results	Similarity Map
00	12	7%
00	14	7%
00	142	7%
70	151	7%
80	1475	7%
10	7700 101	7%

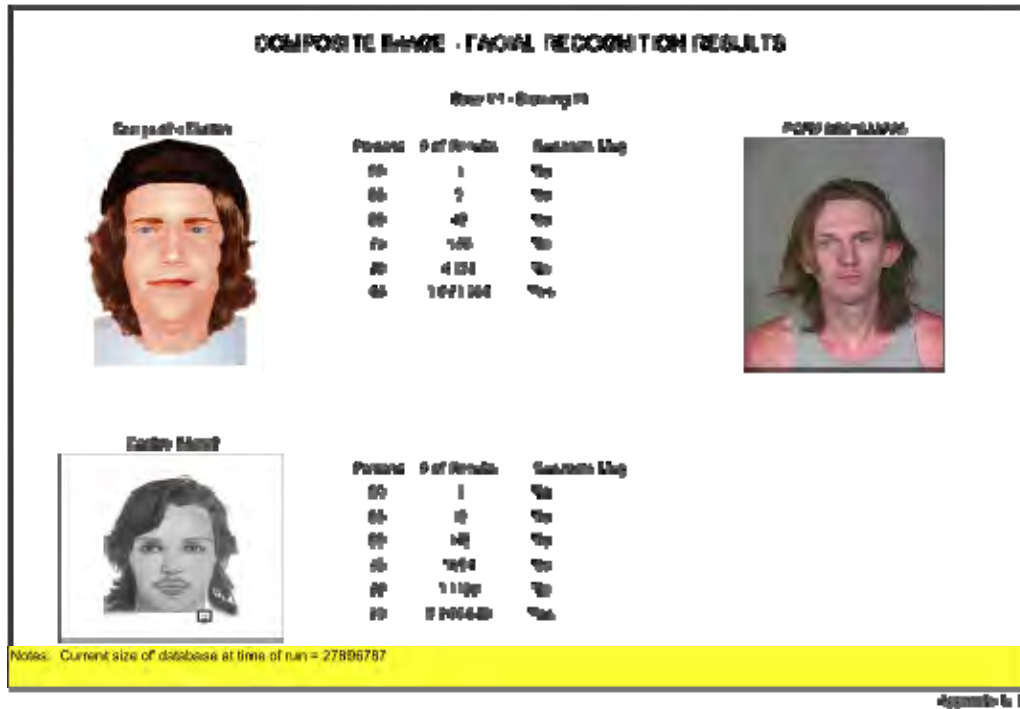
Person 101-101



Notes: Current size of database at time of run = 27886787

Appendix B-3

APPENDIX E



COMPOSITE IMAGE - FACIAL RECOGNITION RESULTS

Composite Image



Row 11 - Group 11

Person	# of Results	Success Rate
00	1	0%
01	1	0%
02	100	0%
03	1000	0%
04	10000	0%

Row 11 - Group 11



Composite Image



Person	# of Results	Success Rate
00	1	0%
01	1	0%
02	100	0%
03	1000	0%
04	10000	0%
05	100000	0%

Notes: Current size of database at time of run = 27886787

Appendix 12

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