Facilitating Fashion Camouflage Art

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ABSTRACT

Artists and fashion designers have recently been creating a new form of art – *Camouflage* Art – which can be used to prevent computer vision algorithms from detecting faces. This digital art technique combines makeup and hair styling, or other modifications such as facial painting to help avoid automatic face-detection. In this paper, we first study the camouflage interference and its effectiveness on several current state of art techniques in face detection/recognition; and then present a tool that can facilitate digital art design for such camouflage that can fool these computer vision algorithms. This tool can find the prominent or decisive features from facial images that constitute the face being recognized; and give suggestions for camouflage options (makeup, styling, paints) on particular facial features or facial parts. Testing of this tool shows that it can effectively aid the artists or designers in creating camouflage-thwarting designs. The evaluation on suggested camouflages applied on 40 celebrities across eight different face recognition systems (both non-commercial or commercial) shows that 82.5% ~ 100% of times the subject is unrecognizable using the suggested camouflage.

Categories and Subject Descriptors

I.4.9 [**Image Processing and Computer Vision**]: Applications.

General Terms

Algorithms, Measurement, Design, Experimentation, Security, Human Factors, Legal Aspects, Verification.

Keywords

Fashion Camouflage Art, Face Recognition.

1. INTRODUCTION

Recent technological advances, both in terms of hardware and software, as well as the increasing popularity of cameras and camera-enabled devices, have popularized face recognition from domains such as social networking to security checks. This in turn has led to controversary pertaining to privacy protection.

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To avoid being caught on camera, artists and designers have started exploring ways in which to thwart face detection, under the guise of high-fashion aesthetics (ambiguously deceptive fashion) [1] as shown in Figure 1. By utilizing makeup and hair styling, or other such aesthetic modifications, fashion/art design creates effective interference that renders the face unrecognizable[1] (and at times undetectable) to even advanced computer

Though this fashion-based camouflage art effectively breaks up the silhouette of the face, and covers certain facial features, it is difficult for the average person to expect to routinely camouflage their faces using the techniques shown in Figure 1. Unless a significantly larger number of people raise concerns about their privacy (at least enough to start wearing camouflage as shown in Figure 1), this camouflage art design is impractical for the following reasons: 1) the exaggerated design draws more attention to the wearers and makes them memorable (because they stick out more) as opposed to undetectable; 2) this design specifically aims to "trick" the Viola Jones face detection technique [2] and thus is not effective when other face detection/recognition techniques are used – for example, one commercial face recognition system [3] can successfully detect the faces in Figure 1 (b) and (c) as shown in Figure 2.

Figure 1. Fashion-based camouflage to avoid face detection [1].

[1] In this paper, "unrecognizable" refers both to the situation where the face is not recognized at all; or where the face is recognized incorrectly.

In fact, current advances in techniques are already able to tackle certain types of disguises, such as eyeglasses and masks, with respect to face detection and recognition [4][5]. However, we note that the ultimate goal of fashion-based camouflage is to protect privacy and thus, as long as the computer cannot recognize a subject's identity (i.e., even if a face is detected, as long as it is not recognized), the goal is achieved.

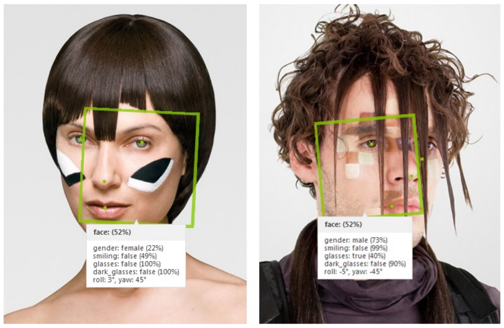

Figure 2. Camouflaged face can still be detected. Results from Sky Biometry Face Recognition [3].

As more artists and designers draw attention to this newly formed camouflage art, we want to have help these artists to have a more comprehensive understanding from computer vision perspective about how different types of camouflages interfere facial features and make the computer fail to recognize identity; and thus help them to create both effective and beautify designs on face. Apart from this, by analyzing effective camouflage inference on facial features that makes the face unrecognizable, we can pinpoint the weakness of current face recognition systems; and thus help researchers in face recognition to explore methods that can handle camouflage/disguises to improve accuracy - These are the main motivations for our study in this paper.

In this paper, we first define three types of fashion-based camouflage and give a comprehensive study of their various effects and interferences on different types of facial features; and then present a tool (developed by us) that can automatically locate the prominent or decisive features from facial images that allow the face to be recognized; and further provide effective camouflage suggestions to prevent the face from being recognized. To evaluate of the effectiveness of the camouflage suggestions, we collect 1200 facial images from 40 celebrities[2] and the results show that 82.5% ~ 100% of times the suggested camouflages can successfully make the subject unrecognizable by eight different face recognition systems.

The remainder of this paper is organized as follows: Section 2 provides an overview of work related to that which is presented herein, and Section 3 gives comprehensively study on camouflage types and interference on facial features. The facilitating tool that can automatically locate prominent facial features and give camouflage suggestions is then presented in Section 4. The evaluation on 40 celebrities camouflaged facial images against eight face recognition systems is given in Section 5. Finally a discussion on the conclusions and plans for future work appears in Section 6.

[2] All images of the 40 celebrities are publicly available on Internet, and collected only for research purpose. The dataset is available under appropriate terms and conditions. To request the dataset, please contact the authors.

2. RELATED WORKS

In the 1960s, researchers started to explore techniques in automatic face recognition from facial images, and over the course of the last several decades, it has become clear that the operational use of facial recognition on high-resolution frontal images taken in a controlled environment is feasible. This is ratified by the National Institute of Standards and Technology (NIST) Face Recognition Vender Test (FRVT) 2007 report [6]. In general, some face recognition algorithms extract facial features (geometric, holistic, or local) and find matches by comparing the features (e.g. [19][16]). Some other face recognition algorithms normalize a gallery of face images to generate compressed representation of face data and find matches by comparing face data (e.g. [15]).

As the utilization of face recognition applications on PCs and mobile devices has become more widespread, the concerns about privacy have arisen and people have started to be deceptive about their appearance, to hide from machines using camouflage. In general, there are two types of camouflage: concealment or deception. For example, army face paint is concealment camouflage; while the Dazzle pattern on ships during World War I is the deception type. As for human facial camouflage, there are several obvious approaches – for example, sunglasses are a known occlusion that some algorithms account for. There are also other functionally effective disguises, such as the use of a hood or facial mask; however these disguises make the wearer's intent to hide too obvious. As an alternative, the project called "CV Dazzle" in [1] pioneers the fashion camouflage art: exploring ways of using makeup and hairstyle or other modifications to transform a subject – the *deception type of camouflage*. As shown in Figure 1, the CV Dazzle project uses exaggerated hairstyle and high contrast patches on the cheeks to fool the Viola Jones Face Detector. However, as pointed out by DIS Magazine [7], the key to a good face-detection thwarting fashion-based camouflage should be inconspicuousness. To achieve an "inconspicuous" fashion camouflage, CV Dazzle is not yet practical.

Since ancient times, people have reported certain optical illusions caused by lighting conditions, shades, colors, etc. In modern times, artists or designers have adopted the concept of optical illusion in makeup to create different visual effects on a subject's face (change each facial parts and create different appearances) [8][9]. Examples in Figure 3 illustrate the visual illusion effects created using makeup products and fashion accessories [10]: the makeup instructor without any makeup (a) wears a regular makeup on a daily basis (b); however using advanced makeup she makes herself look similar to Angelina Jolie (c), Taylor Swift (d), and a Japanese Geisha (e) using makeup products and wigs. And she successfully disguised herself: a test on Google Face Search engine [11] and Baidu Face Search Engine [12] successfully recognized her in (a) and (b); while for (c) the top matching candidates returned are Angelina Jolie; and Taylor Swift is returned as first match for (d); while random match results (many different suggested matching subjects) are returned for (e). The deceptive camouflage in Figure 3 shows that one can successfully make oneself not just look different, but also look like a completely different person, by using colors, shades, and accessories (for occlusion).

It should be noted that more and more people choose plastic surgery to alter their appearances nowadays, given its increasing social acceptance and affordability. Though plastic surgery also

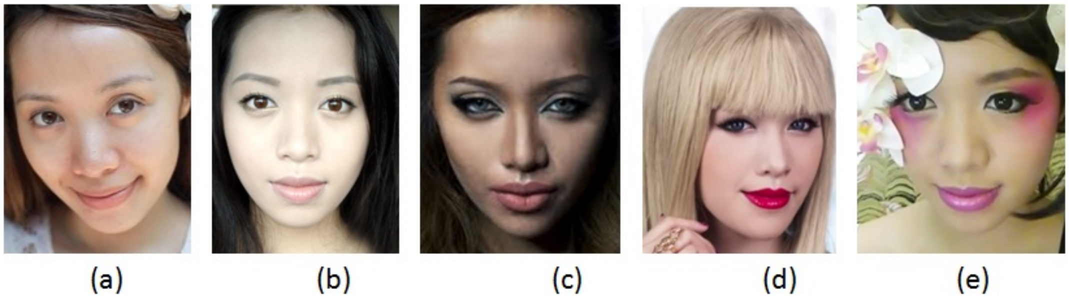

Figure 3. How makeup creates different visual effects on same subject.

functions as one type of camouflage that prevents a subject from being recognized, it is not the focus of this paper.

3. CAMOUFLAGE TYPES, INTERFERENCES, AND EFFECTIVENESS

From Figure 3, we can see clearly the illusive power of makeup and hairstyle. In order to understand why these illusion effects can fool algorithms and render the face "unrecognizable", in this section we first define three types of fashion camouflage; then study their camouflage interferences on different facial features; and explore the effectiveness of these camouflages.

3.1 Types of Fashion Camouflage

In nature, camouflage either makes animals/objects hard to see (crypsis), or disguises them as something else (mimesis). In this paper, we define 3 types of fashion camouflage on face; they are described as below.

3.1.1 Occlusion

Fashionable occlusion can be achieved by using stylish hair or accessories, e.g. forehead is occluded in Figure 3(c) using a wig; and upper cheek is occluded in Figure 3(d) by decorative flowers. Camouflage using occlusion covers certain facial features and thus makes the facial area incomplete or changes texture/pattern on facial parts. Different styles of hair in general are used to cover face shapes and forehead; while other decorative facial accessories such as body stickers, jewel/stud details, false eyelashes, and fake mustaches are used for to alter texture/color/pattern of certain facial parts (as shown in Figure 4).

Figure 4. Fashion Occlusion on face: (Left) Hair occlusion on face shape, forehead, and partial eye. (Right) Face sticker occlusion on eye.

3.1.2 Transformation

A stylish transformation enables the subject to alter the shape or color of facial parts, and thus look different from themselves, or even look like other subjects. Transformation look is mostly achieved using makeup products. Figure 3(c) is a good example of this transformation – the subject "transforms" her face to reassemble Angelina Jolie's face while no occlusions are used. Fundamentals to makeup-based transformation, is using different colors and shades to create false depth perception. Take Figure 3(c) as an example – it can be seen that the subject has an obvious nose hump compared with the look before (Figure 3(a)). This effect is achieved by using highlights in the middle of nose and darker shades around nose bridge. Similarly, any facial part such as eye shape, lip size, and cheekbone can be altered using transformative makeup technique.

3.1.3 Designer Face Paint

Face painting is the artistic application of cosmetic paint to a person's face. In ancient times, face painting has been used for hunting, religious reasons, and military reasons; while in modern times it has become common for people to decorate their faces, especially cheeks. As a form of art, face painting is in general used in special events such as performance and festivals. Figure 5 shows two examples of face painting effect (before and after).

Designer face paint is a special case which can have both occlusion and transformation effect on face. Take Figure 6 (b) for example, not only the forehead is occluded, but the eyes, eyebrows, and lips are transformed by face painting. Thus, in later sections we will only study the effect and interference of occlusion and transformation as face paint camouflage has both effects.

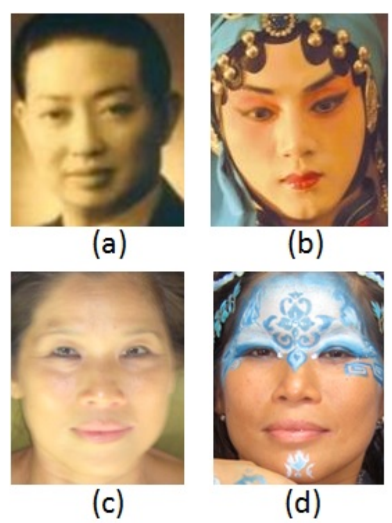

Figure 5. Effect of Face Painting: Peking Opera face painting before (a) and after (b). Casual face painting before (c) and after (d).

3.2 Camouflage Interference on Facial Feature

3.2.1 EigenFaces/FisherFaces

EigenFaces [14] is the most typical holistic representation in face recognition. It is based on lexicographic ordering of raw pixel values to yield one vector per image. And the dimensionality of the image vector corresponds directly to the size of the image in terms of pixels. Therefore, when the image is large, the high dimensional feature space slows or prohibits learning processing - the curse of dimensionality in the pattern recognition [13]. To deal with this, PCA (Principle Component Analysis) is employed in EigenFace and Linear Discriminant Analysis (LDA) is employed in FisherFace [15] to reduce the dimensionality. Theoretically, as performance increases with the dimension of the eigenspace, the Eigenface method does no better than correlation [16]. Thus, EigenFace is vulnerable to various illuminations, occlusions, expressions, etc.

As for FisherFace, though it outperforms EigenFaces with various illuminations and expressions, the performance drops rapidly when facial images are incomplete. This is because FisherFace tends to discount those portions of the face that are not significant for recognizing an individual, thus the reduced representation tends to mask the regions of the face that are highly variable (e.g. mouth area that is highly variable due to various expressions). The good (significant) features considered by FisherFace are stable ones such as face shape, nose, brows, and cheeks as they are relatively invariable across different illumination and expressions.

Now with a good understanding of how EigenFaces/FisherFace works, we can use corresponding fashion camouflages to exploit the weakpoints of the algorithms, thereby fooling them. From the discussion above, it is known that EgienFaces/FisherFace take a gallery of face images to generate compressed representation of face data during training; and find matches by comparing face data. In this scenario, occlusions on facial parts (face shape, cheek, nose) will achieve the goal of camouflage. Figure 6 show an example of using occlusions to make EigenFace and FisherFace incapable of recognizing Angelina Jolie.

Figure 6. Facial Occlusions. (Left) Original Angelina Jolie facial image. (Right) Occlusion using hair and face sticker on the face on the left renders her unrecognizable.

3.2.2 Geometric Features

Early work using facial geometric features (e.g. ratios, distances) can be found in [17]. Later, researchers find more sophisticated features extraction techniques including vector of geometric features [18] (Figure 7(a)), Active Appearance Models [19] (Figure 7(b)), manually identified features [20] (Figure 7(c)), and Elastic Bunch Graphic Matching [21] (Figure 7(d)). Some techniques also combine geometric features together with other features (e.g. Gabor) to boost accuracy. Despite these variations of recognition techniques, the concept is basically to use distinct facial bio-geometrics on a subject face for recognition; and the accuracy of geometric feature-based method is highly dependent on the geometrical landmarks and geometrical constraints [22]. Moreover, no matter how the facial bio-geometric features are acquired (manually or located by algorithms), the key clue on getting the feature points are based on contour or gradient of the facial image; thus, whenever the facial parts are altered or occluded, the feature points and facial geometric features will be no longer accurate.

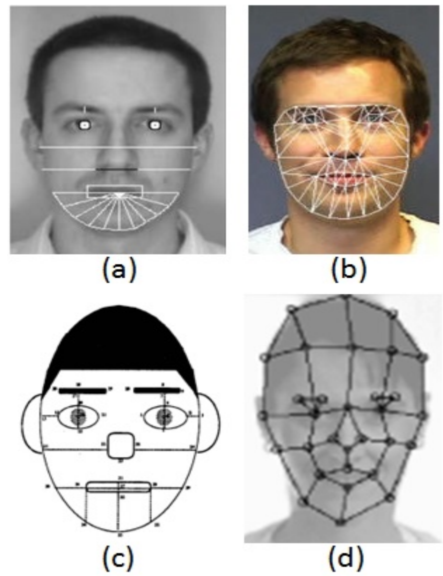

Figure 7. Various geometric features used in face recognition.

In this scenario, the goal of camouflage is to alter geometrics on face, such as face shape, eye shape, and lip size which can be achieved by Transformation camouflage. Figure 3 (b), (c) serves to illustrate this – the usage of makeup makes the geometric feature points on face different, and even inaccurate. As shown in the example in Figure 8 (a), the automatic fitted facial geometric landmarks fitting result (result is generated using Active Appearance Model [29]) gives a clear depiction of the subject's face; while on the transformed face (Figure 8 (b)) the fitting result is severely altered by the color shades created by makeup products.

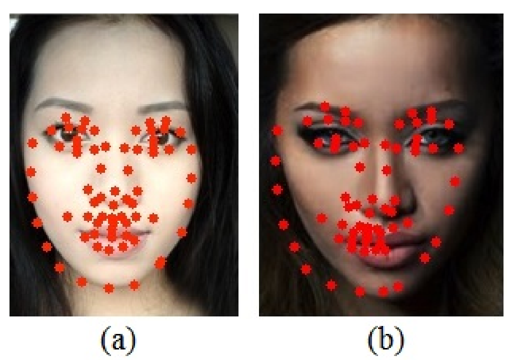

Figure 8. Example of transformation camouflage effects on Geometric Facial Features (results generated using Active Appearance Model [29]).

3.2.3 Local Pattern/Features

Unlike EigenFaces or geometric features that are extracted from the whole facial area, local patterns/features are extracted from a local area or patch from the facial image, e.g. eye area, or a 3*3 sized window area. The most popular local features used in face recognition systems are Local Binary Pattern [23] and Gabor Features [24]. In general, most of local areas from facial images are isolated using alignment first; and then patterns or features are extracted from each isolated local area; by combining all local features or patterns the final matching result will be given. Local feature based face recognition methods in general perform better because they are robust against local change on face while other parts of face remains unchanged.

In this scenario, the best way for fashion camouflage to trick local feature based algorithm is to alter two or more facial parts details – and this can be achieved using any type of camouflage: the occlusion, the transformation, or the designer facial paint. Figure 3(b)(c), Figure 5(a)(b) are good examples for altering local facial parts/features: it can be seen clearly that the face shape, the eye, the nose, and the lips are all different from the original look and this renders the subject unrecognizable. Moreover, as multiple facial local areas are altered by camouflage, the combined local features of face are no longer guaranteed to give correct face recognition results.

3.3 Camouflage Effectiveness

From the discussion in Section 3.2, we already know how to trick specific face recognition algorithms using certain types of camouflage. However, most existing face recognition systems (commercial or non-commercial) combine different features and techniques to achieve better accuracy. Take Figure 6 (Right) as an example, the occlusion camouflage is effective against EigenFace and FisherFace; however it is not effective against several other techniques such as biometric feature matching. Given an input face, we therefore, want to know how to maximize the camouflage effect across different face recognition algorithms - what position, what size, or which features to interfere with.

3.3.1 Camouflage Positions

In face recognition algorithms, no matter which features are extracted, contour (shape) information is one of the key factors. For example, as addressed in Section 3.2.1 the accuracy of FisherFace depends on whether a complete face shape is available; without contour information it will be very difficult to find facial geometric features or isolate each facial parts. Another example can be clearly seen in Figure 8 – the camouflage successfully confused the face recognition algorithm on extracting geometric facial features (the shape information). Thus, camouflages that can interfere with the contour or shape information would make the feature extraction more difficult and inaccurate for the algorithms. For example, by styling hair, one can successfully transform her face from square-face-looking into round-face-looking.

In this scenario, the positions of camouflage should be in general around the geometric facial contour regions - on the forehead that covers the upper face shape; around jawline and chin that covers the lower face shape; around the eyes that covers the eye contour; around the lip that covers the lip contour; or on the nose bridge that covers the nose contour. Figure 9 shows an illustration of all these effective camouflage areas on face.

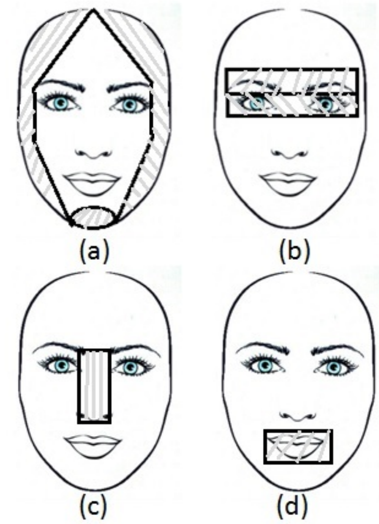

Figure 9. Effective camouflage positions: (a) face shape coverage; (b) eye/eyebrow coverage; (c) nose coverage; and (d) lip coverage.

3.3.2 Camouflage Size

The size of occlusion or painting could technically be as small as a dot, or as large as the whole face. When the size of occlusion or painting pattern increases, the result of camouflage in turn tends to get better. The example in Figure 10 demonstrates this: as the hair occlusion covers more facial area (the coverage percentages on face from (a) to (d) are ~15%, ~25%, ~35%, and ~50%), the return results (returned by Google [11] and Baidu [12]) of face search as less accurate. When the size of camouflage is as big as about half of the face (Figure 9(d)), no matching result is returned at all. This half-face-sized occlusion (Peek-A-Boo Bangs [25]) is a fashion style started since 1940s and it becomes a classic and beautiful style for any woman.

One thing to note here is that, the larger the camouflage is, the intention of occlusion is more obvious – this is not our goal. In this case the Peek-A-Boo Bangs is an exception since it is a well-accepted and applied style. In general, it is not desirable to have a more than 50% occlusion or painting on face on daily basis.

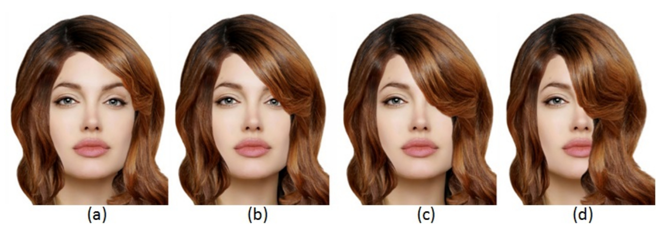

Figure 10. Effect of different sized camouflage.

3.3.3 Prominent Facial Features for Camoufla*c*e

Recall from Section 3.2, no matter what features are extracted, and what training method is used, the ultimate goal is to find the prominent features *PF* of one subject that can maximize the between-class difference and minimize within-class difference. This also works in cognitive science - people remember the most significant features of a face and recognize that feature to identify a subject. For example, Angelina Jolie is famous for her unique lips and face shape while Charlie Chaplin is famous for his hat and mustache. Thus, when we camouflage the prominent features *PF* on a subject's face the result is guaranteed to be effective. In this scenario, location of camouflage should be put on at/around the prominent facial parts. For example, in Figure 11 we show an example by camouflaging the lip area of Angelina Jolie (Figure 10(a)) by designer face painting (a black cat design [26]); and the top matched face returned (from Google and Baidu) for the camouflaged face (Figure 10(b)) is no longer Angelina Jolie. According to PicTriev [27], the similarity of Fig. 10(a) and Angelina Jolie is 80%; while the similarity drops to 23% for Fig. 10(b) when the lip is camouflaged.

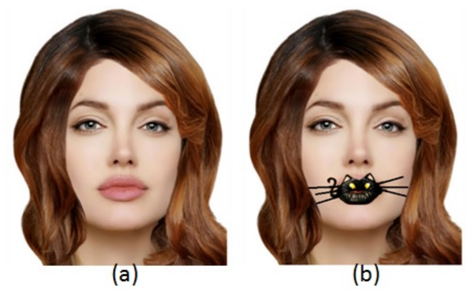

Figure 11. Example illustrating the camouflage of prominent facial features.

4. AUTO-CAMOUFLAGE SUGGESTIONS

From Section 3 we ascertain that the most effective camouflage is one that can camouflage the prominent features at the proper location with proper size. Based on this, we develop a tool that can facilitate camouflage art from a given input face by providing effective camouflage suggestions on prominent facial feature automatically.

4.1 Prominent Feature Extraction

In order to find the prominent features on face, we adopt the idea of automatic caricature generation by analyzing facial features [28], since the key characteristic of automatic caricature generation is to exaggerate the facial features that are not within the statistical normal range (e.g. Angelina Jolie's bigger-than-normal lips are always exaggerated in caricature).

In this paper, we divide the face area into 7 components: face shape, left eye, right eye, left eyebrow, right eyebrow, nose, and lip. And the Prominent Feature set ***PF*** is defined as any subset *C'* of the seven components *C* such that the geometric features of any face component C_i in *C'* is out of statistical normal range[3], where the geometric features extracted here are: (1) the ratio R_i of length to width of C_i, and (2) the size S_i of the C_i.

To find the prominent features that are out of normal range, it is necessary to perform quantitative analysis to obtain important statistics of the face components. Thus, we used 3755 facial images from the MUCT face dataset [30] for the measurement. Since the MUCT dataset has manually labeled landmarks (the illustration of the facial landmarks can be seen in Figure 12), thus the geometric features calculated from each face component C_i are presumably accurate. To compensate for the possible difference in imaging distance, we set the unit length to be the distance between the two inner eye corners. We also set the origin to be the midpoint between the two eyes. Aside from the normalized locations of the individual landmarks, the coordinates of the bounding box for each face component are also recorded.

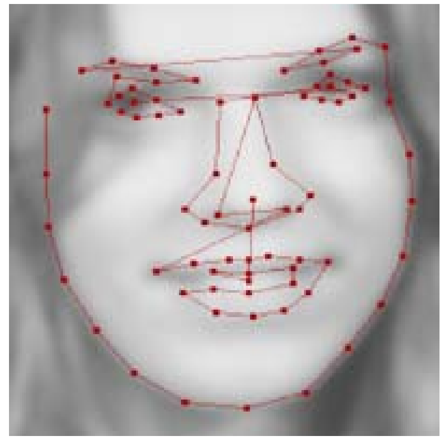

Figure 12. Illustration of 76 landmarks on face [30].

Table 1 lists some of the statistics of the resulting measurement. Note that these numbers were calculated using only middle 50% of the samples. This practice will limit the range of 'normal' samples and increase the chance of finding face components that are out of normal range.

With the statistic ranges set, for a given input face *F*, we first apply *Active Appearance Models* (AAM) [29] on the face to automatically get 76 landmarks on face (as shown in Figure 11). Then we calculate the geometric features of each component C_i, and if it is out of the statistical normal range, the component C_i is then put into the set of Prominent Features ***PF***.

Table 1. . Some statistics of face component measurement – the normal range of length to width ratio *R*.

Face Component	Normal Range
Face shape	1.1833 ~ 1.5179
Right eye	1.4921 ~ 1.7033
Left Eye	1.4921 ~ 1.7033
Right Eyebrow	3.9046 ~ 4.2738
Left Eyebrow	3.9046 ~ 4.2738
Nose	0.4478 ~ 0.5826
Lip	1.5731 ~ 2.1942

4.2 Camouflage Suggestions

Based on the discussion in Section 3, for each prominent facial feature (face component), we give the most effective camouflage types and suggestions. In some cases, certain type of camouflage can alter multiple components, e.g. a Bob hairstyle can cover face shape, eyebrows, and maybe partial eyes. In Figure 13 we give examples of each type of camouflages. Table 2 lists the effective camouflage type for each face component.

[3] In this paper, the *Statistical Normal Range* of facial geometric features is learned from quantitative analysis of 3755 subjects' facial geometric features and determined from the middle 50% of these samples.

It needs to be noted here that the intention of the work in this paper is to help the designers to create effective camouflage designs; not exact camouflage design patterns or options for the designers as designers have different tastes when creating a particular camouflage design. By understanding the fashion camouflage effect on face recognition algorithms and finding the prominent facial features ***PF*** of a subject's face *F*, we provide the tool to designers to give them a rough idea (e.g. what type of camouflage and where) about effective camouflage design for the subject and they can customize their own design based on it.

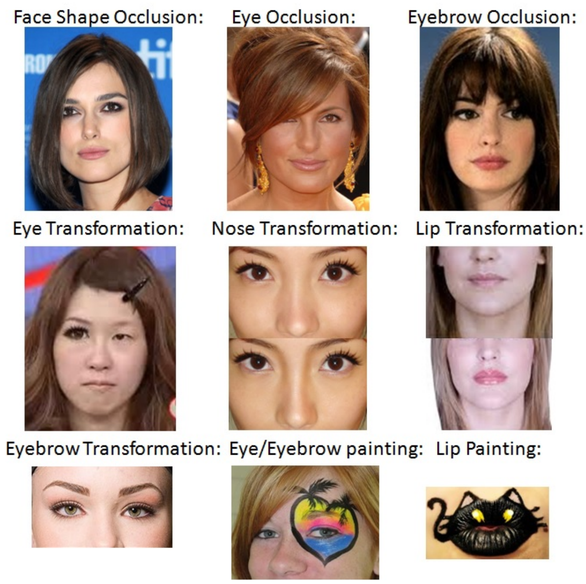

Figure 13. Examples of different types of camouflages on different face component.

Table 2. Effective camouflage types for each face component.

Face Component	Camouflage Type
Face shape	Hair Occlusion
Right eye	Occlusion, or Transformation, or Painting
Left Eye	Occlusion, or Transformation, or Painting
Right Eyebrow	Hair occlusion, or Transformation, or Painting
Left Eyebrow	Hair occlusion, or Transformation, or Painting
Nose	Transformation
Lip	Transformation, or Painting

5. EVALUATION AND APPLICATION

5.1 Evaluations

To evaluate the effectiveness of camouflage suggestions, we collected 1200 facial images of 40 celebrities with different styles, poses, illuminations, etc (Appendix A gives a full list of all these 40 celebrities). The reasons that we pick celebrity samples for evaluation are: (1) it is easy to collect a large number of samples of the same person with different conditions; (2) samples of celebrities have various fashion styles (hair, makeup), training on these samples will make the recognition robust against general facial changes; and thus if the camouflage suggestions are effective on celebrity samples, the suggestions will in general be effective on average people. All these collected sample images of celebrities are high-resolution images with normal illumination condition and they are all frontal or near-frontal facial images of the celebrities. Figure 14 givens one sample of Lucy Liu's frontal facial image and an example of camouflage suggestion for Lucy Liu.

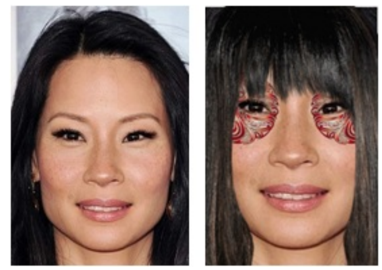

Figure 14. Camouflage Suggestion for Lucy Liu.

To evaluate the effectiveness of camouflage suggestions, we selected one default hair style (Figure 15(a)), two default eye paints (Figure 15(b)), one default lip paint (Figure 15(c)), one default color/shades for nose transformation (Figure 15(d)), and one face paint design for chin occlusion (Figure 15(e)). In this paper, we choose only these fixed camouflage designs and apply these camouflage effects on the subjects' face using digital image processing software (e.g. PhotoShop) for experiments and performance evaluation as we do not have fashion designers involved in the project yet (examples of camouflaged face generated in this paper can be seen in Appendix B). However, in the short future we will invite volunteers and beauty consultants to generate designers' camouflage facial images for future performance evaluation.

Figure 15. The default camouflage patterns used in the experiments in this paper.

For each input facial image, based on the suggestions, the default camouflage is applied to the face. We evaluated the suggestions on different face recognition systems: EigenFaces, FisherFace, Elastic Bunch Graphic Matching (EBGM), Local Binary Pattern (LBP), Gabor, Google+, PicTriev, and Baidu (the last three are commercial face recognition systems, and the last two do not require training). If the face recognition system still recognizes the celebrity, then the camouflage suggestion fails; otherwise the camouflage is successful. To evaluate the performance of suggested camouflage, we query the 40 camouflaged facial images generated according to the suggestions and collect the matching results. Successful Camouflage Rate (*SCR*) is used as evaluation metric that is calculated using Equation 1. Table 3 gives the evaluation results (the *SCR* over eight different face recognition systems).

$$SRC = \frac{number\ of\ unrecognized\ subjects}{number\ of\ all\ subjects} \times 100\%$$

Equation 1.

Table 3. Evaluation Result of camouflage suggestions.

Face recognition Systems	Successful Camouflage Rate (*SCR*)
EigenFace	100%
FisherFace	100%
EBGM	85%
LBP	90%
Gabor	87.5%
Google+	85%
PicTriev	82.5%
Baidu	90%

From Table 3, we can find that the camouflage suggestions work effectively (85% ~ 100%) on each single type of non-commercial face recognition algorithms.

As for the commercial face recognition systems (Google+, PicTriev, and Baidu), since these systems combines several face recognition algorithms to make the matching results more accurate, the camouflage suggestions are less effective compared with non-commercial algorithm overall. Further analysis on these three commercial face recognition system finds that: (1) PicTriev is a commercial website designed for celebrity matching which has better pre-knowledge (training) from a large set of celebrity sample images; thus the camouflage suggestions are least effective on PicTriev. (2) Unlike PicTriev, Baidu is a newly launched service which mainly serves in China, and thus has less pre-knowledge about western celebrities (the 40 celebrities selected are mostly American singers, pop star, etc) – therefore the suggested camouflage works as effective as LBP (the non-commercial face recognition algorithm). (3) As mentioned earlier, unlike the service provided by PicTriev and Baidu, Google+ requires manual training (Google+ service is similar to Facebook auto-tagging, the training is updated based on manual label each time), and thus the training on Goolge+ is the same as those non-commercial algorithms.

The overall effectiveness (***Successful Camouflage Rate***) of the suggested camouflage is satisfying over the celebrities sample set. As discussed before, if the camouflage suggestions are effective on celebrity samples, the camouflage suggestions will in general be effective on average people. (as the samples of celebrities have various styles (hair, makeup) which helps with robust training).

5.2 Applications

As mentioned before, the main motivations for our study in this paper is to facilitate artists or designers to efficiently create camouflage design that can make face unrecognizable for machines. For any input face, the tool will automatically find the prominent face components and then give suggestions about where to put the design and which type of the designs would be most effective. This study targets at helping artists or fashion designers to create an alternative facial appearance that is unrecognizable for a subject from computer vision perspectives; while we do not encourage criminal usage of this tool. Moreover, the camouflage design is supposed to be artistic, which is also presumably not suitable for any criminal usage.

On the other hand, as face recognition serves in various important application areas such as security check, the study in this paper also helps the researchers to pinpoint the weak points of current face recognition systems. And further by understanding the camouflage interferences and effects, the researchers in face recognition can find robust algorithms to identify faces while there are camouflages or disguises.

6. FUTURE WORK AND CONCLUSIONS

6.1 Future Work

As a pioneer, CV Dazzle started exploring fashion camouflage art for anti-face-recognition. Within the last several decades, researchers have put significant effort in making face recognition algorithms more and more accurate; while little or no work has been done on "hacking" these algorithms to fail them. Moreover, there is quite a few studies on tackling face recognition under fashion variations. In this paper, we define three types of fashion camouflage, and explore the camouflage effect on certain features in the purpose of privacy protection. However, we believe these to be only the tip of the iceberg, and future work should explore more on the characteristics of fashion camouflage effect on face recognition and further quantify the effect and study each type of camouflage's effect on different facial features. We also suggest exploring better methods on how to locate prominent facial features.

In this paper, all experimental images are simulated using image morphing algorithm or generated by image processing tool (e.g. PhotoShop); and the fashion touch up is based on the research done by Adam Harvey (author of CV Dazzle). In the short future, we will invite several fashion consultants and make up specialists and volunteers to get realistic facial images with fashion camouflage effect for studies and experiments.

6.2 Conclusions

In this paper, we define three types of fashion camouflages and explore their effects on certain facial features. Based on the comprehensive study of fashion camouflages, we develop a tool that can facilitate digital art design for fashion camouflage with the goal of anti-face-recognition. This tool can first find the prominent facial features from input facial image; and then give suggestions for camouflage options (makeup, styling, paints) on particular facial components from computer vision perspectives to artists. Evaluation of this tool shows that it can effectively aid the artists or designers in creating effective (thwarting) camouflage designs. The evaluation on suggested camouflages that applied on 40 celebrities across eight different face recognition systems (both non-commercial or commercial) shows that 82.5% ~ 100% of times the subject is unrecognizable using the suggested camouflage.

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APPENDIX A: Full list of 40 celebrities used for evaluation.

Adele
Adriana Lima
Amy Adams
Angelina Jolie
Anne Hathaway
Audrey Hepburn
Beyonce
Britney Spears
Cameron Diaz
Claudia Schiffer
Eva Longoria
Gisele Bundchen
Halle Berry
Isabelle Adjani
J. K. Rowling
Jaclyn Smith
Jane Pauley
Janet Evanovich
Jennifer Aniston
Jennifer Lopez
Jessica Alba
Jody Watley
Julia Roberts
Kate Hudson
Katy Perry
Keira Knightley
Khrystyne Haje
Louise Erdrich
Lucy Liu
Margo Timmins
Megan Fox
Michelle Pfeiffer
Natalie Portman
Nicole Kidman
Nicollette Sheridan
Oprah Winfrey
Paulina Porizkova
Talisa Soto
Taylor Swift
Vivian Wu

APPENDIX B: Samples of camouflaged celebrity facial images.