Capabilities of automatic and manual face morphing

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Abstract: In a common scenario, one passport including its biometric features belongs to one person. This and only this person *should be* successfully matched to the biometric picture which is in the person's passport in the situation of an Automatic Border Control (ABC). But what if two or more persons are successfully matched to one passport? With the procedure of morphing faces, it is possible to get a promising acceptance rate for both persons. This work compares an automatic with a manual approach for creating morphed faces. In addition, the region in which a sufficient match rate for both persons is reached is determined to hide the second face as well as possible from manual inspection.

Keywords: Face morphing; face detection; automatic border controls

1 Introduction

Face recognition systems have become one of the most popular biometric authentication methods in the last years. It is based on the fairly unique biometric characteristics of a human face. One of their advantages the the property of a contactless capturing of face images with the help of an arbitrary high resolution camera system which is highly accepted by the data subjects. In addition to this, the capability of a visual inspection instead of an automatic process is one of the reasons why face recognition is selected as authentication method for biometric passports. The basic idea is simply to observe certain properties of the human face, such as the shape of the head or wrinkles and furrows and place landmarks on characterizing points. Beside the issues of the naturally ageing of the face, posing and external influences like lightning or camera properties, intentional alterations on the picture could be done to reduce or improve the acceptance level of the recognition system.

Since 2002, face recognition is used as identity confirmation in the electronic Machine Readable Travel Document (eMRTD) by the International Civil Aviation Organisation (ICAO) [Ri16]. This means every eMRTD issued by a governmental organisation contains an facial image which has to follow certain properties in order to support the machine based automatic verification [dI].

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In several countries, it is possible to provide own printed pictures to the issuing organisation. This practice leads to the possibility of processing the photo and therefore altering the biometric data set stored in the eMRTD. A feasible attack would also be an alteration in the way that another individual than the one which the passport is issued to is morphed into the photo. Of course these alterations form a potential attack vector on the Automated Border Control systems (ABC) . Automated border controls are automated self-service barriers which compare the photo stored in a biometric passport to a photo or video taken in the same moment. This process was selected by the ICAO as standard process for automated immigration checks which mainly takes place at airports [Ri16].

Especially morphing the biometric data from two subjects into one photo is a feasible alteration. If the alteration was successful, both subjects are recognized as the same person by the ABC.

To achieve this, the face of the issuing individual and an attacker has to be morphed together. The goal on this process is to provide a morphed photo to the issuing instance which is visually nearly identical with the issuer but automatically accepts both, the issuer and the attacker. Having reached this, both are able to show up at the ABC system and both will be accepted.

Morphing can be either done by an algorithm which is completely automatic or by manually setting the landmarks and performing the morphing automatically. In this work, we will compare both processes with respect to the acceptance rate of a face detection algorithm.

1.1 Related Works

Besides several works on the general topic of face detection [JRJ14] and recognition with different approaches (e.g. eigenfaces ([TP91]), neural networks ([RBK98], [La97]), there are two works directly addressing face morphing as base for an biometric attack. In [FFM14] an idea of the general topic with focus on manual morphing is given, whereas [RRB16] presents a scheme to detect morphed faces based on microtextures. Moreover, morphing techniques as part of visual effect in movies, like [Wo98], build up the technical background on the topic.

1.2 Outline

The rest of this paper is organized as follows: In section 2 we provide some details on the database we selected and ICAO compliance. The topic of morphing faces follows in section 3. Section 4 deals with the detection algorithm and gives some details on our test setup. The results of our research are presented in section 5 Finally, in section 6, we draw a conclusion, followed by further topics that could be issued in section 7.

2 Database and selection of test subjects

As test samples, a data set of 136 ICAO compliant pictures were given. The data set provided to us is part of the FaceDB database, which fulfils all parts of our requirements to biometric data sets. In order to get promising morph results, a subset of 10 pairs of photos were selected for manual morphing (3.3) whereas the automatic morphing algorithm (3.2) was applied on different data subsets. For manual morphing, only pairs with a visually high similarity are considered because the acceptance rate of the comparison algorithm is expected to be higher. In sum, 5 manual and 45 automatic morphs are issued in this paper. [3]

2.1 ICAO compliance

To fulfil ICAO compliance, a picture has to meet several properties. The whole face should be shown as well as the right and left half. The face, without the hair, should cover 70 - 80 % of the photo and should be in a centered positon without any rotations. The phote has to be sharp, clear and contrasty in all sections and should be illuminated homogeneously in all passages without reflexions. As background, a single coloured contrasty surface without shadows should be selected. The subject has to look directly into the camera. Especially if the subject wears glasses, reflections should be avoided and the eyes must not be covered by parts of the glasses. The pose should be neutral and the mouth has to be closed. The wearing of headpieces is forbidden but can be permitted e.g. because of religious reasons or long lasting head injuries[dI].

All photos used in this work are ICAO compliant or nearly ICAO compliant, with respect to the criteria mentioned above. Some of the pictures had the wrong format (the subject was too close to camera). These photos were reformatted to meet the standard with digital post production. It can be ruled out that the post production has any effect on the recognition algorithm.

3 Morphing of Faces

The main task during the morphing of two pictures is to detect characteristics and place landmarks as an instruction for the algorithm. This can be done completely automatic or with the support of a user. In this paper both ways are discussed.

[3] Note that manual morphing is a quite time consuming process and for this reason only a limited amount of manual morphes could be examined.

3.1 Basic idea

For every morph there were 15 images for automatic and 30 for manual created from 0% of Subject 1 to 100%, respectively the remaining % of Person 2. So as an example the 15 images for automatic are combined of:

- 1. Picture: Person 1 100% - Person 2 0%
- 2. Picture: Person 1 92,86% - Person 2 7,14%
- 3. Picture: Person 1 85,71% - Person 2 14,29%
- 4. Picture: Person 1 78,57% - Person 2 21,43%
- 5. Picture: Person 1 71,43% - Person 2 28,57%
- 6. Picture: Person 1 64,29% - Person 2 35,71%
- 7. Picture: Person 1 57,14% - Person 2 42,86%
- 8. Picture: Person 1 50,00% - Person 2 50,00%
- 9. Picture: Person 1 42,86% - Person 2 57,14%
- 10. Picture: Person 1 35,71% - Person 2 64,29%
- 11. Picture: Person 1 28,57% - Person 2 71,43%
- 12. Picture: Person 1 21,43% - Person 2 78,57%
- 13. Picture: Person 1 14,29% - Person 2 85,71%
- 14. Picture: Person 1 7,14% - Person 2 92,86%
- 15. Picture: Person 1 0% - Person 2 100%

3.2 Automatic morphing

To generate automatic face morphed images the software FantaMorph 5 was used in this paper. FantaMorph has the ability to create automaticaly morphed faces of to subjects. For this the software defines automatically the landmarks for both faces. These can be adjusted manually by the user afterwards, but in this paper this isn't used. Then the software generates a transition from face 1 to face 2 in a given number of steps, so called frames. For this paper a number of 15/30 steps is used. FantaMorph accepts a list of subjects to which it creates then a sequence to morph from one face to another. It doesn't morph every given subject with every given subject, only from subject 1 to subject 2 and then subejct 2 to subject 3 and so on. So it was not possible to create morphed faces of all subjects instead subsets were created and later on used.

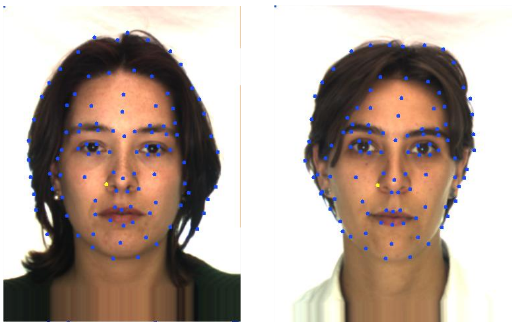
3.2.1 Results

The resulting morphed sets are 4 different subsets of morphs. The first is the subset of all men sequentially morphed, the second is all women sequentially morphed and the third is all men alternating women sequentially morphed, the last one is the set used from Budrhani. The number of resulting morphed images are:

- Subset 1: 1125 images
- Subset 2: 885 images
- Subset 3: 1800 images
- Subset 4: 225 images

For example in figure XXX is shown a morphed set of XXX and XXX with 15 steps. Picture 1 shows the Person 1 and the Picture 15 shows Person 2.

3.3 Manual morphing



(a) Subject 1 (b) Morph no. 5

Fig. 1: Example of two ICAO compliant photos with manually set and shifted landmarks.

In contrast to the automatic face morphing approach, manual morphing is discussed in this section.

To achieve morphes, the open source software GNU Image Manipulation Software (GIMP) (Version 2.8.16) with the GIMP Animation Package (GAP) (Version 2.6) was selected for this process. Morphing with GAP follows the simple approach of manually placing connected landmarks at characterizing points in both faces. In 1 two pictures with a setup of landmarks are shown. It can be observed, that the landmarks are placed at characterizing points in both faces, e.g. at the eye browns, lips and nose. The general shape of the face as well as the shape of the head including the hair is also respected. In the example the facial landmarks are close to each other whereas the landmarks describing the shape of the hair are farer apart.

The selection of characterizing points is based on findings from earlier works on the topic of automatic face recognition, to achieve an optimal morphing result compared with own estimation based on the individual appearance of the subjects. [JFR08, 60ff] [ALS16] . The algorithm shifts the landmarks from face one to face two. In addition to this the color of the skin is transmitted.

For the test samples 100 - 125 landmarks were placed, depending on the face characteristics. The output contains a sequence of 30 photos which show different stages of the morphing procedure. 2e

3.3.1 Results

(a) Subject 1 (b) Morph no. 5 (c) Morph no. 15 (d) Morph no. 25 (e) Subject 2

Fig. 2: Example of two ICAO compliant photos (2a and 2e) and morphs at stage 5 (2b), 15 (2c) and 25 (2d)

In figure 2 a two subjects and three morphing stages (5, 15 and 25) are shown. The visual inspection of 2a shows biometric features of both subjects whereas (e) and 2d has more similarity to the closer subject but also covers features of the other subject. A manual post production of the morphs is not necessary because potential revealing details, like the interference of the clothes, glasses or hair is not considered by the algorithm.

4 Face detection

For our experiments a face detection and recognition is needed. All tests were made with the open source software OpenFace, which was initially released in 2015 and up to now appears to be quite active[ALS16].

4.1 Detection algorithm

As face detection algorithm the open source software OpenFace was selected. OpenFace is based on a neural network with is fully trained and has high confidence rates in the shipped version [BRM16]. Because OpenFaces main goal is to detect faces on arbitrary photos, The accuracy level is expected to be higher if it works on ICAO compliant data sets.

4.2 Process of work

Both of the two source photos and the sequence of 15/30 morphs is given as input to the OpenFace comparison algorithm. OpenFace computes the match rate of every morph to both of the two photos. The expected outcome of comparison algorithm is an almost equal match rate for morph no. 15 (for 30), where both pictures are represented to 50%. The closer the morph gets to one of the original pictures the higher the match rate and the lower to the other picture.

4.3 Distance and Threshold

OpenFace determines the similarity level of two subjects by computing the squared Euclidean distance between characterizing points in both faces. The lower the distance is the higher is the similarity of the two subjects. For determining if two pictures are from the same subject a threshold is determined with the property that distances lower than the threshold are seen as same subject and distances high as different ones. Facing this it is obvious, that subjects with a naturally given high similarity have a lower distance. The original threshold is at 0.999 which reveals different but very similar subject (e.g. twins) as different. Detection capabilities because of morphing are not known up to now. In subsection 5.2 we suggest a threshold for our approaches.

5 Results

Resulting from the work are the squared l2 euclidean distances calculated with the program OpenFace. The distance shows the similiarity to the given biometric references, it is a dissimilarity score. A lower distance means the compared two biometric references are more equal, when the distance is under a given threshold, these two biometric references are accepted to be the same biometric reference and so access is given. The resulting morphed photos were compared to diffrent photos of both biometric references, to get a independend distance. Which percentage of each biometric reference and the picture number is shown in 3.1.

5.1 Distances

5.1.1 Subset of 5 automatic generated morph sets

All resultingsquared l2 euclidean distances for the morphed photos of biometric references 01-m-002-27 to 01-m-003-24, 01-m-003-24 to 01-m-005-23, 01-m-004-23 to 01-m-005-23, 01-m-010-23 to 01-m-013-23 and 01-m-014-23 to 01-m-016-23 compared to the corresponding compare images are way too much data. So there is as an example of the morphed image 01-m-002-27 - 01-m-003-24:

Picture	01-m-002-28	01-m-002-29	01-m-002-30	01-m-003-25	01-m-003-26	01-m-003-27
1	0.11916	0.07499	0.19188	1.30874	1.16709	1.31322
2	0.13701	0.06885	0.18756	1.25716	1.10248	1.25841
3	0.17384	0.06523	0.19060	1.17656	1.01354	1.17311
4	0.22901	0.07982	0.21253	1.08009	0.90457	1.06856
5	0.31766	0.12439	0.24763	0.89989	0.70834	0.88006
6	0.39700	0.16766	0.30990	0.83492	0.62518	0.81035
7	0.50975	0.24823	0.40167	0.72848	0.51501	0.70676
8	0.67400	0.39087	0.53792	0.60985	0.39251	0.59632
9	0.74737	0.46525	0.58010	0.52552	0.32146	0.50314
10	0.94108	0.62628	0.74969	0.40924	0.21060	0.37129
11	1.05918	0.76321	0.86483	0.32472	0.13804	0.28219
12	1.21209	0.90143	0.99503	0.25177	0.08833	0.20977
13	1.25246	0.97993	1.05583	0.19876	0.05832	0.17236
14	1.34758	1.07654	1.14637	0.19252	0.04679	0.16232
15	1.37122	1.13813	1.18339	0.14941	0.05522	0.13605

Also shown in figure 3.

The results of the 01-m-002-27 to 01-m-003-24, 01-m-003-24 to 01-m-005-23, 01-m-004-23 to 01-m-005-23, 01-m-010-23 to 01-m-013-23 and 01-m-014-23 to 01-m-016-23 morphs are shown in figure 4.

For better recognizability the mean value of all the diffrent squared l2 euclidean distances is calculated for biometric reference 1 and biometric reference 2. The result is shwon in figure 5. The distance graphs crosses by (9.04, 0.49), so the best distance for both biometric references is with picture 9 with distances of 0.48 and 0.49. Picture 9 with 42.86% of biometric reference 1 and 57.14% of biometric reference 2 so it not the middle of all 15 pictures, this could be the cause of the different distances of the biometric references to their own compare images.

OpenFace uses normally a threshold of 0.99, which allows nearly all morphs from picture 5 to 10 to be successful acknowledged as shown in figure 4. Only in 3 cases there is the distance way too high to work properly. The compare pictures are 01-m-016-24.jpg, 01-m-016-25.jpg and 01-m-016-26.jpg which are all from the same biometric reference, so this morph with this biometric reference is not working, this could be the cause of the different distances to the own compare images. As a result in 4 out of 5 cases it is possible to morph two biometric references to be successful acknowledged, this makes a success chance of 80%.

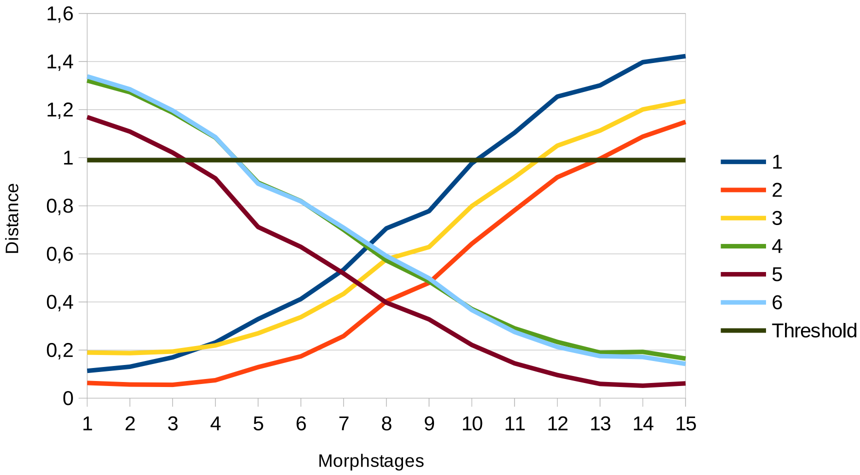


Fig. 3: Squared l2 euclidean distances (y axis) of morphs from 01-m-002-27 to 01-m-003-24 (with 15 steps ont he x axis) comparing to 01-m-002-28.jpg, 01-m-002-29.jpg, 01-m-002-30.jpg, 01-m-003-25.jpg, 01-m-003-26.jpg and 01-m-003-27.jpg

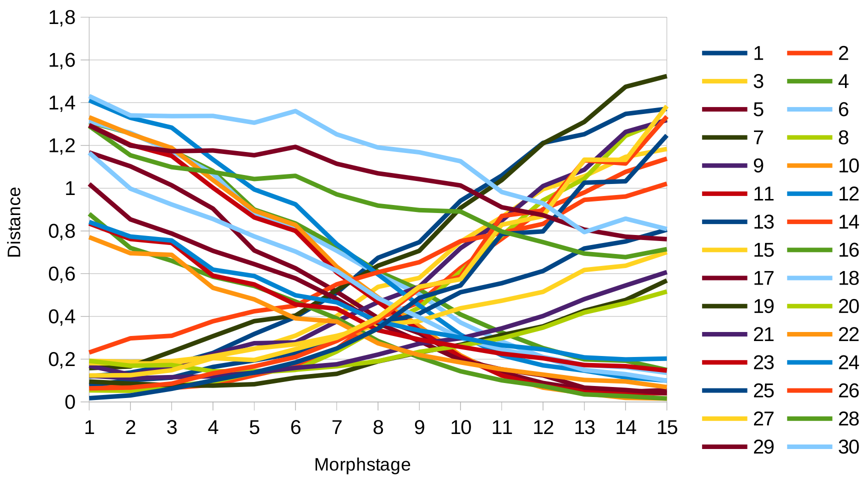


Fig. 4: Squared l2 euclidean distances (y axis) of morphs from 01-m-002-27 to 01-m-003-24, 01-m-003-24 to 01-m-005-23, 01-m-004-23 to 01-m-005-23, 01-m-010-23 to 01-m-013-23 and 01-m-014-23 to 01-m-016-23 (with 15 steps on the x axis) comparing to the corresponding compare photos

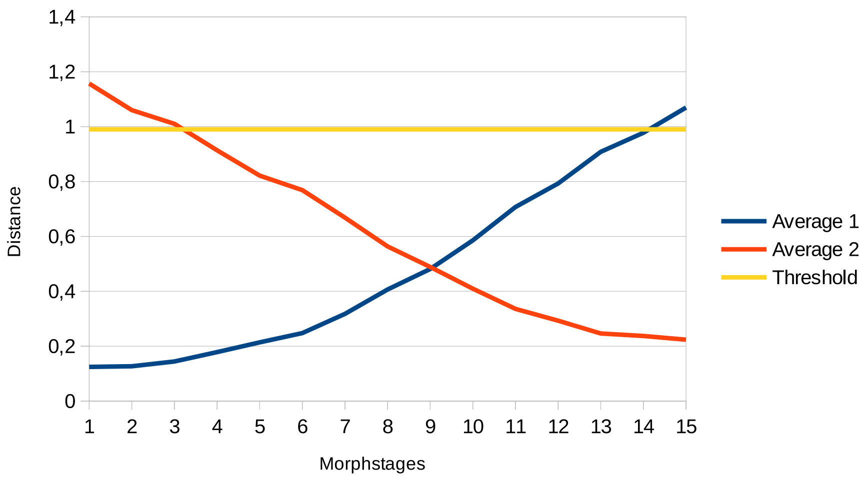


Fig. 5: Mean squared l2 euclidean distances (y axis) of morphs from 01-m-002-27 to 01-m-003-24, 01-m-003-24 to 01-m-005-23, 01-m-004-23 to 01-m-005-23, 01-m-010-23 to 01-m-013-23 and 01-m-014-23 to 01-m-016-23 (with 15 steps on the x axis) comparing to the corresponding compare photos

5.1.2 Subset of 39 automatic generated morph sets

Now 39 automatic generated sets of morphed biometric references were used. The used biometric references are:

- 01-m-002 - 01-m-003
- 01-m-003 - 01-m-004
- 01-m-004 - 01-m-005
- 01-m-013 - 01-m-014
- 01-m-016 - 01-m-017
- 01-m-019 - 01-m-020
- 01-m-020 - 01-m-021
- 01-m-021 - 01-m-022
- 01-m-022 - 01-m-023
- 01-m-025 - 01-m-026
- 01-m-026 - 01-m-027
- 01-m-030 - 01-m-031
- 01-m-031 - 01-m-032
- 01-m-032 - 01-m-033
- 01-m-037 - 01-m-038
- 01-m-038 - 01-m-039
- 01-m-039 - 01-m-040
- 01-m-040 - 01-m-041
- 01-m-041 - 01-m-042
- 01-m-042 - 01-m-043
- 01-m-043 - 01-m-044
- 01-m-044 - 01-m-045
- 01-m-045 - 01-m-046
- 01-m-046 - 01-m-047
- 01-m-047 - 01-m-048
- 01-m-048 - 01-m-049
- 01-m-051 - 01-m-052
- 01-m-052 - 01-m-053
- 01-m-053 - 01-m-054
- 01-m-054 - 01-m-055
- 01-m-055 - 01-m-056
- 01-m-059 - 01-m-060
- 01-m-060 - 01-m-061
- 01-m-065 - 01-m-066
- 01-m-066 - 01-m-067
- 01-m-069 - 01-m-070
- 01-m-072 - 01-m-073
- 01-m-073 - 01-m-074
- 01-m-074 - 01-m-075

With these sets again the squared l2 euclidean distances are computed to the associated compare images of the two biometric references. The resulting distances are shown in figure 6. To decrease the amount of information the mean values for both biometric references were computed and are shown in figure 7. The distance graphs crosses by (7.93, 0.6), so the best distance for both biometric references is with picture 8 with distances of 0.6 and 0.59. Picture 8 is the exact middle of all 15 pictures with 50% of biometric reference 1 and 50% of biometric reference 2.

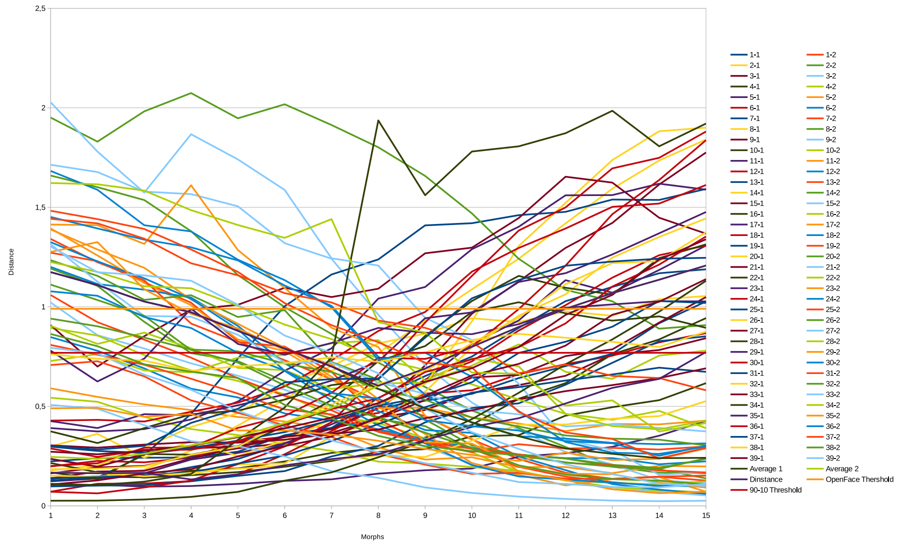


Fig. 6: Squared l2 euclidean distances (y axis) of the subset of 39 morphs (with 15 steps on the x axis) comparing to the corresponding compare photos

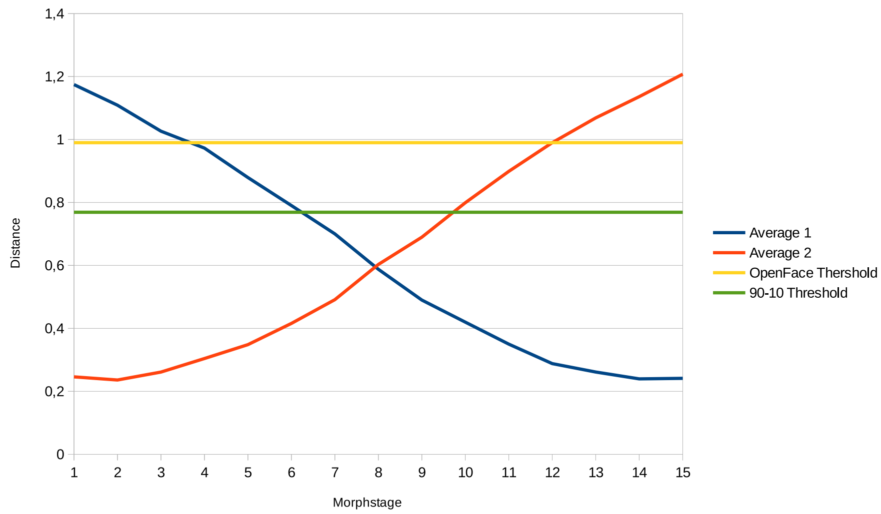


Fig. 7: Mean squared l2 euclidean distances (y axis) of the subset of 39 morphs (with 15 steps on the x axis) comparing to the corresponding compare photos

5.1.3 Subset of 8 manual generated morph sets

Finally 8 sets of morphed biometric references were created and the distances to the comparing images was calculated. As a speciality in this set a morph of a woman and a man. The biometric references for the manual morphing are:

- 01-m-002-27 - 01-m-003-24
- 01-m-003-24 - 01-m-005-23
- 01-m-004-23 - 01-m-005-23
- 01-m-010-23 - 01-m-013-23
- 01-m-014-23 - 01-m-016-23
- 01-m-017-23 - 01-m-019-23
- 01-m-020-23 - 01-w-002-23
- 01-w-036-23 - 01-w-037-23

For this subset the squared l2 euclidean distances to the associated compare images of the two biometric references is also computed. The resulting distances are shown in figure 8. To decrease the amount of information the mean values for both biometric references were computed and are shown in figure 9.

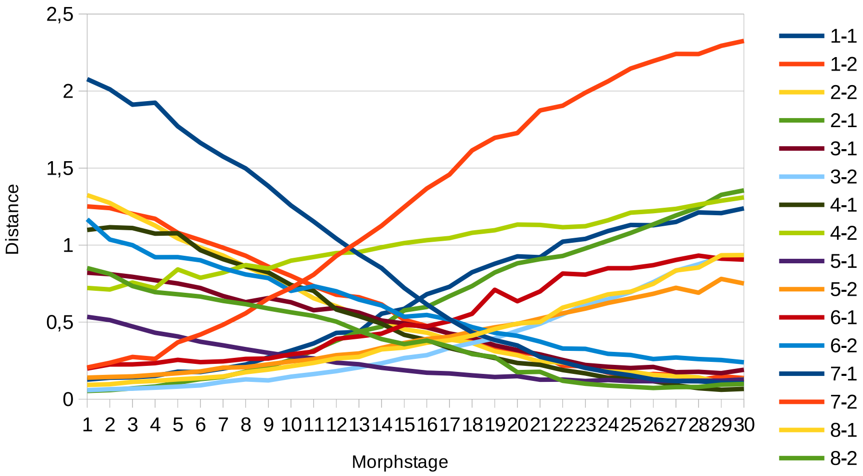


Fig. 8: Squared l2 euclidean distances (y axis) comparing to the corresponding compare photos of the subset of 8 manual morphs (with 30 steps on the x axis)

5.2 Threshold

As a result a threshold is computed to get a 10% biometric false acceptance of an impostor (false match rate (FMR)) and a 90% chance to non-match a morphed image.

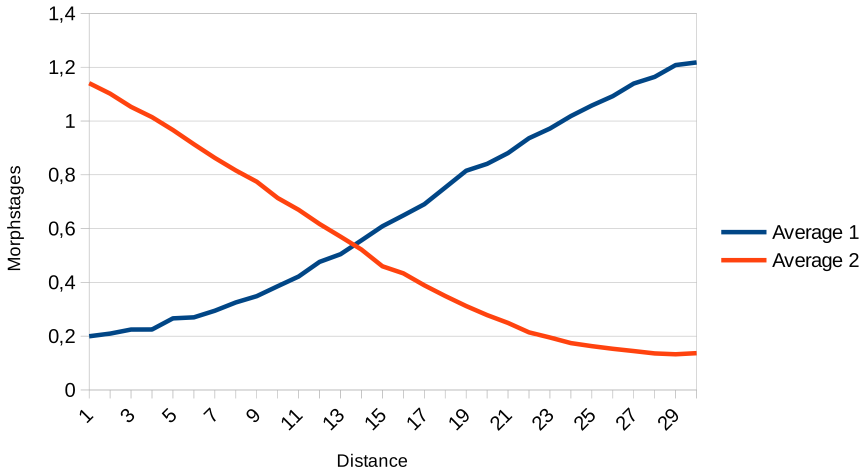


Fig. 9: Mean squared l2 euclidean distances (y axis) comparing to the corresponding compare photos of the subset of 8 manual morphs (with 30 steps on the x axis)

5.2.1 Automatic morphing (Subset of 39 automatic generated morph sets)

For the calculation of the threshold of the automatic generated morphs the subset of 39 of section 5.1.2 is used, it's bigger than the subset of 5 automatic generated morph sets from section 5.1.1 so the used mean values are more representative. Used for the calculation are the squared l2 euclidean distances of section 5.1.2. The resulting threshold for this subset is 0.76891524. In contrast to the distances it is shown in figure 10.

5.2.2 Manual morphing (Subset of 8 manual generated morph sets)

For the calculation of the threshold of the manual generated morphs the subset of 8 of section 5.1.3 is used and the calculated distances from the same section. The resulting threshold for this subset is 0.7172467154. In contrast to the distances it is shown in figure 11.

5.2.3 Comparison threshold of manual and automatic

The two tresholds of the automatic morphing from subsubsection 5.2.1 0.76891524 and the manual morphing in subsubsection 5.2.2 0.7172467154 are close to another. They differ only about 0.05, which is not much. The threshold of the manual morphing is lower than the automatic threshold, this could mean that the images of the manual morphing are better,

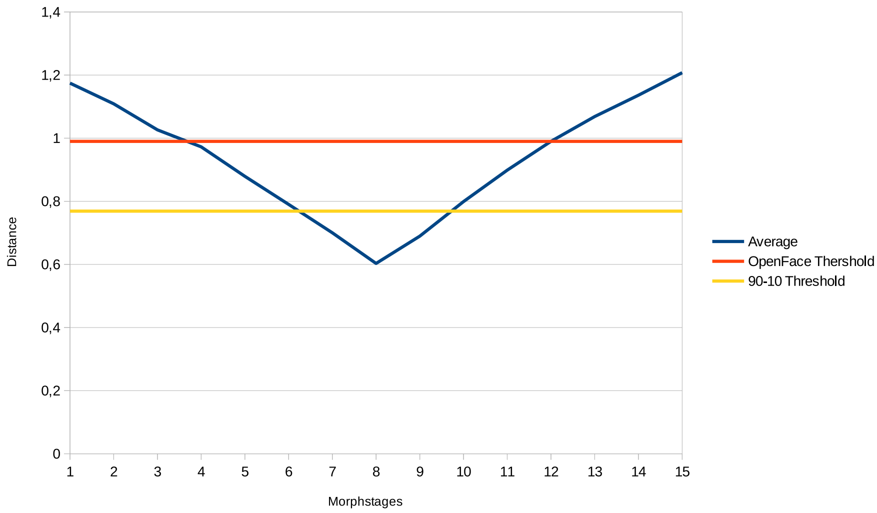


Fig. 10: Squared l2 euclidean distances (y axis) of the 39 morphed subset (with 15 steps on the x axis) compared to the corresponding compare photos, in contrast to the calculated threshold of 0.76891524

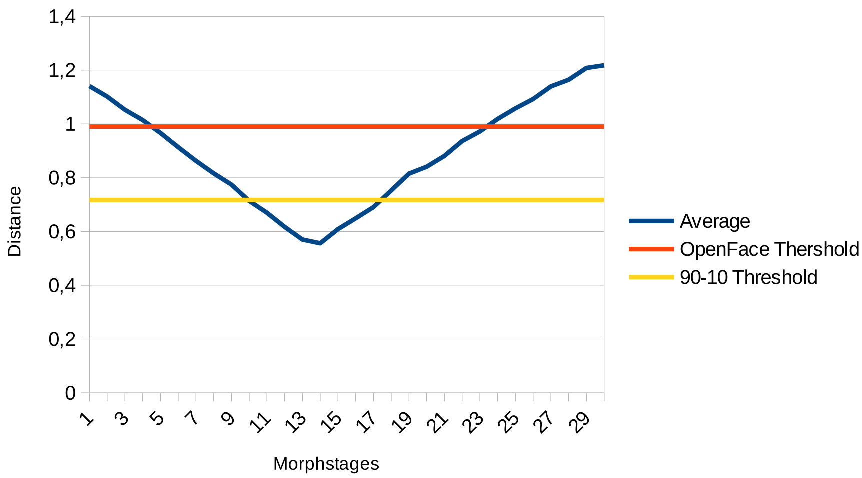


Fig. 11: Squared l2 euclidean distances (y axis) of the 8 manual morphed subset (with 30 steps on the x axis) compared to the corresponding compare photos, in contrast to the calculated threshold of 0.7172467154

but such a low difference could also be possible through lower the distances because of the input biometric reference variations.

As a result the threshold of OpenFace should be set to 0.71 to fight off morphing attacks, in fact the biometric false rejection rate in the biometric system is acceptable.

Compared to [FFM14] which is based on [BRM16] (threshold of 0.999) we were able to show that a 90-10 threshold is already achieved at a much lower distance.

6 Conclusion

In our work we were able to show that it is feasible to attack automated border controls by morphing the ICAO compliant photos of two subjects together. The ABC recognizes both of them as one person. Moreover we found out that with the suggested threshold of OpenFace (0,999), there is a huge number of morphs which are detected as both of the two subjects. Because of this we suggested a new threshold of $0,71$. Another interesting fact is that manual morphing does not lead to much better results than automatic morphing in general but has a much higher standard deviation. Facing this, automatic morphing with a sanity check of the match rates could be an approach for generating a huge number of morphs in little time. In contrast to this manual morphing has a quite promising standard deviation, especially if two similar subjects are morphed. It should be noticed that it takes about 40 minutes to achieve one high quality manual morph with GIMP GAP but in the case of visual inspection they are much harder to reveal.

7 Further topics

In this paper we focussed on the capabilities of morphing visually similar subjects together. The selection of “visual similarity“ is based on our own personal estimations. An approach to achieve even smaller distances of morphs could be to compare a subject to many other subjects with OpenFace and then morph the two closest togehter.

Another possibility would be to hide two subjects in a morph with the approach of morphing tree photos together.

Sooner or later all subjects and passports are visually inspected by a border control officer, so a morph should hold against this verification, too. An interesting question is, until which level humans are able to reveal morphed pictures.

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