Occlusions in 3D Face Recognition

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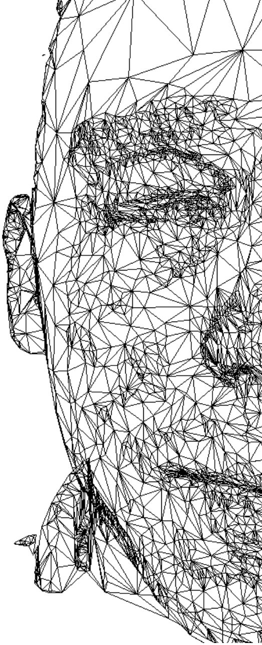


Outline

- Preliminaries
- Detection of occluded 3D faces
- Recognizing occluded 3D faces: a restoration approach
- Experimental Results on artificial and real occlusions
- Future Directions

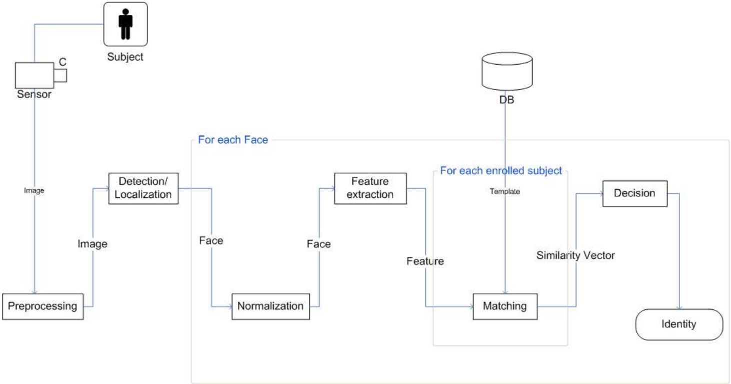
Why occlusions?

Authentication

Identification

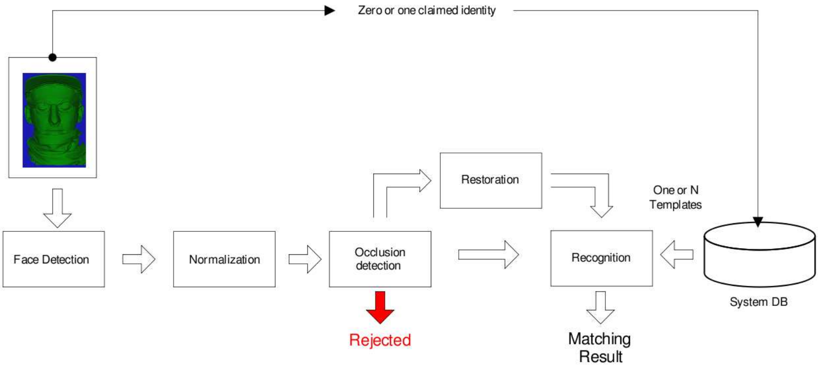
Occlusions in 3D

Requirements



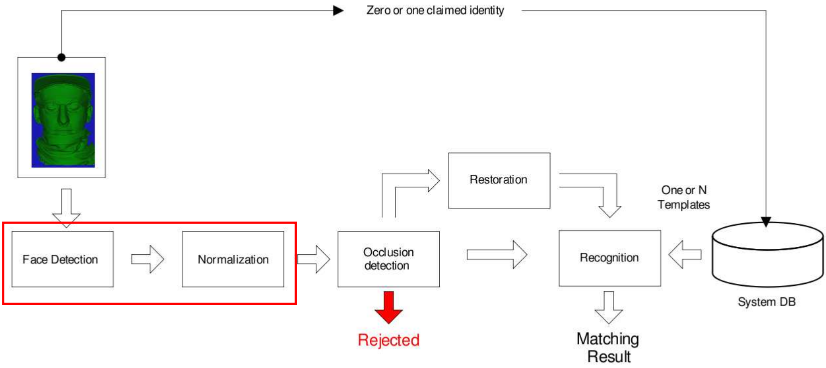
- Fully automatic
- Scalable
- *Is an holistic approach possible?*

System design choices



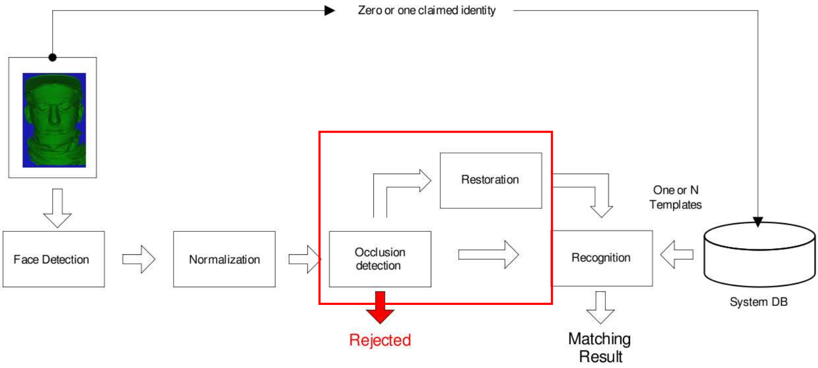
- Occlusion detection and restoration based pipeline.

System design choices



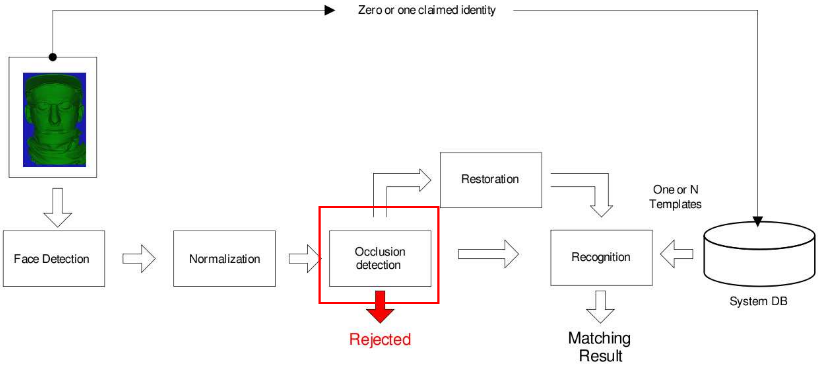
- Occlusion tolerant detection and *pre*-matching normalization.

System design choices



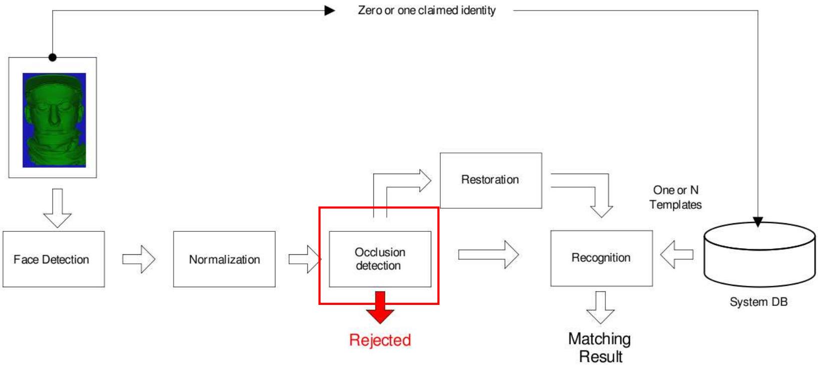
- Holistic approach through occlusion detection and restoration.

System design choices



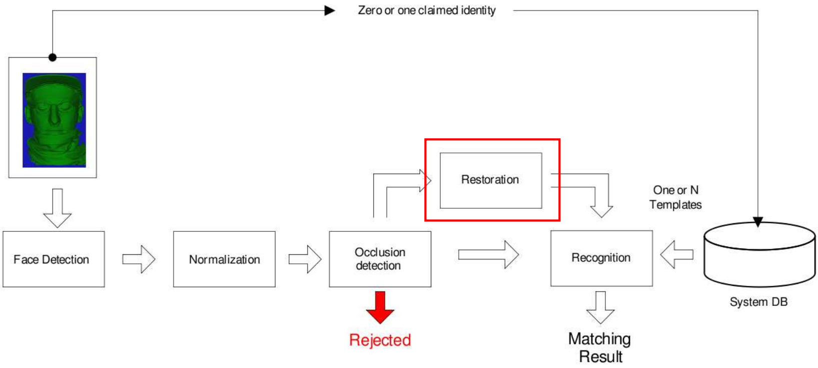
- Faces are analyzed in order to detect occlusions.

System design choices



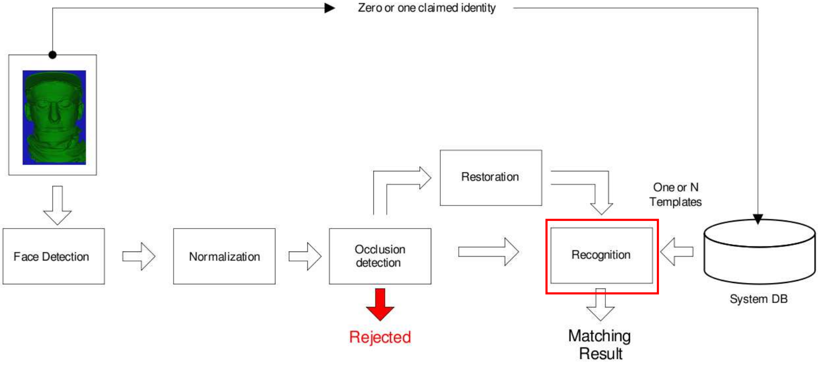
- If occlusions are too large the acquisition may be eventually rejected.

System design choices



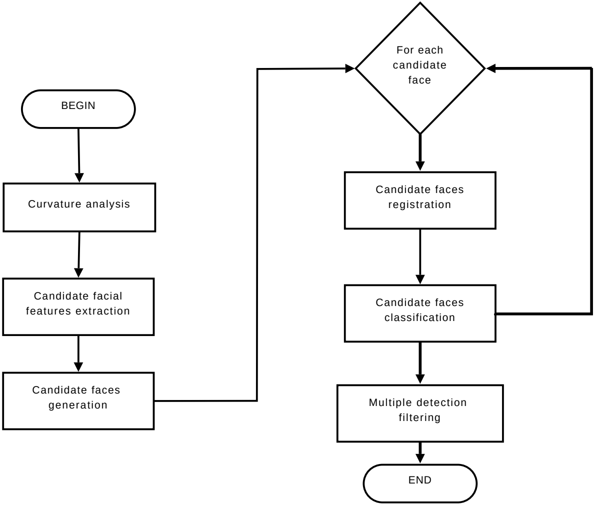
- Occlusions are cleared and the missing facial surface is reconstructed.

System design choices



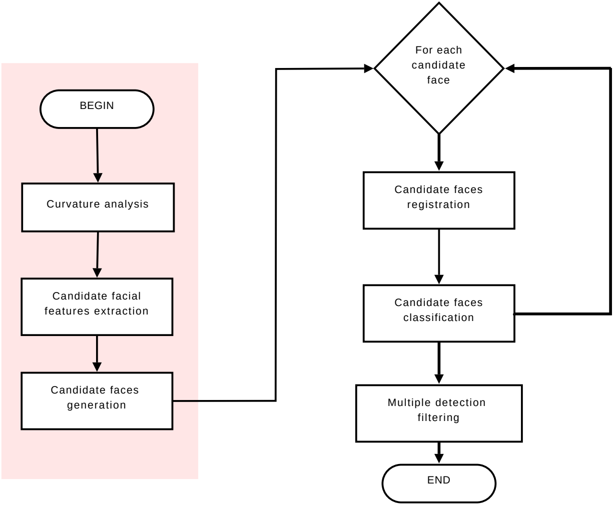
- *Any state* of the art recognition strategy may be applied.

Occlusion Tolerant 3D Face Detector



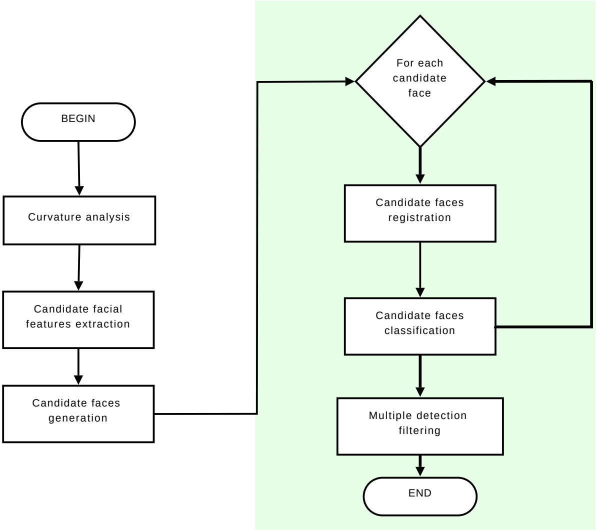
- Hypothesis generation and test structure.

Occlusion Tolerant 3D Face Detector



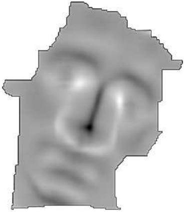
- Hypothesis generation.

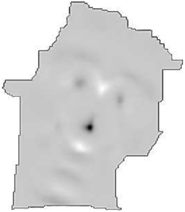
Occlusion Tolerant 3D Face Detector



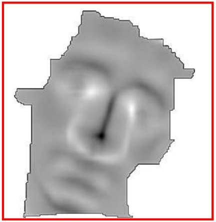
- Hypothesis test.

Curvature Analysis

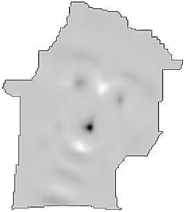




Curvature Analysis

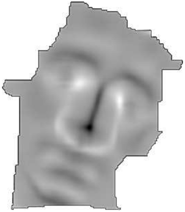


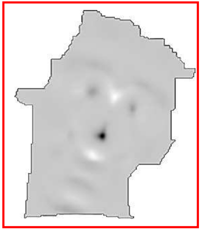
Mean Curvature



$$H(x_0, y_0) = \frac{(1+f_y^2)f_{xx} - 2f_x f_y f_{xy} + (1+f_x^2)f_{yy}}{2(1+f_x^2+f_y^2)^{\frac{3}{2}}}$$

Curvature Analysis

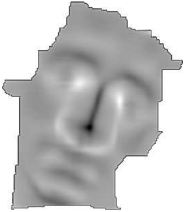


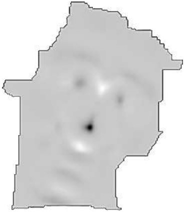


Gaussian Curvature

$$K(x_0, y_0) = \frac{f_{xx} f_{yy} - f_{xy}^2}{(1+f_x^2+f_y^2)^2}$$

Curvature Analysis

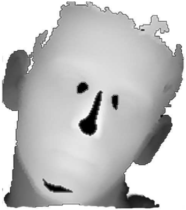


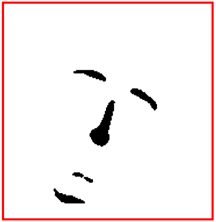


HK Classification

	$K < 0$	$K = 0$	$K > 0$
$H < 0$	*Hyperbolic concave*	Cylindrical concave	*Elliptical concave*
$H = 0$	Hyperbolic symmetric	Planar	Impossible
$H > 0$	*Hyperbolic convex*	Cylindrical convex	*Elliptical convex*

Candidate Features Extraction



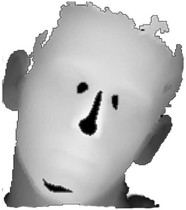


Candidate Features Extraction

Candidate Noses

Positive Mean regions;

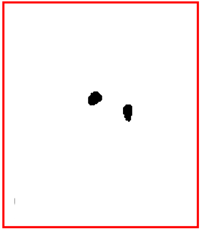
$$H(u,v) > T_h$$



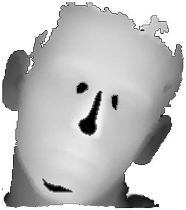
Candidate Features Extraction

Elliptical concave regions;

$$|K(u,v)| > T_k$$



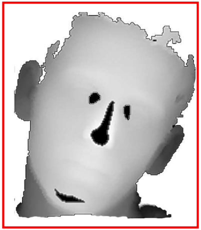
Candidate Eyes



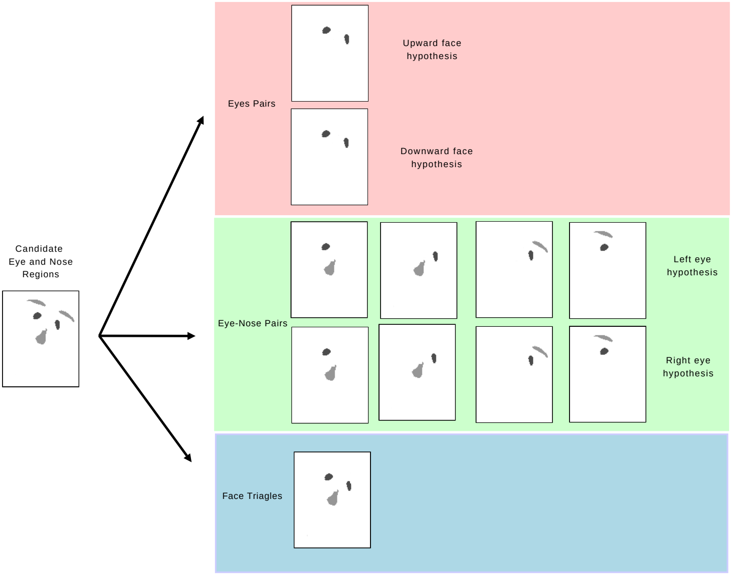
Candidate Features Extraction

Final candidate filtering

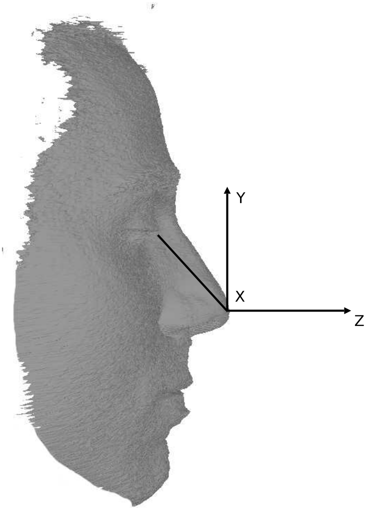
Region size, shape, average curvature etc.



Candidate faces generation

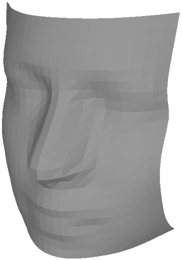


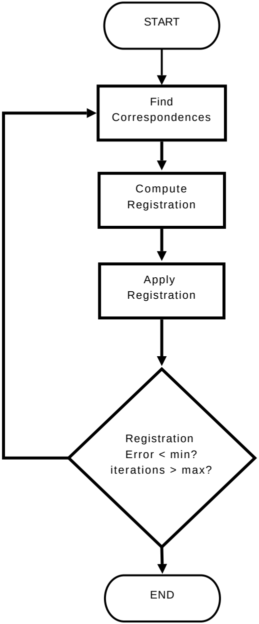
Candidate faces rough registration



Candidate faces fine registration

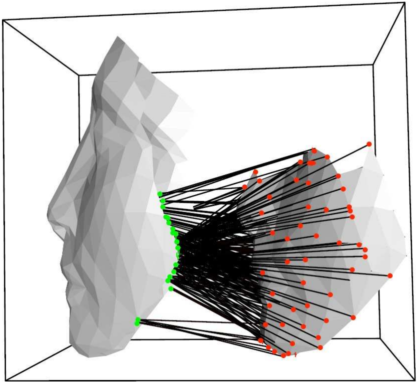
- Global registration through ICP with a mean reference face

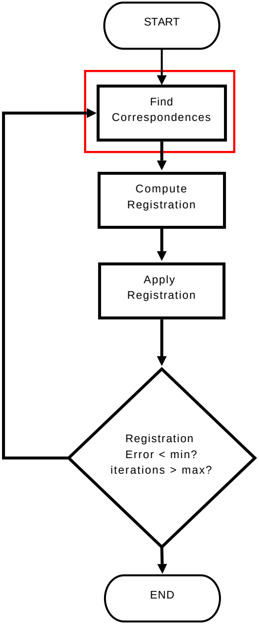




Candidate faces fine registration

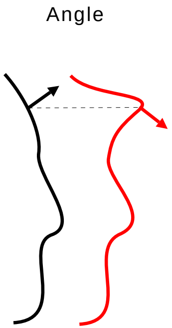
- Global registration through ICP with a mean reference face
- Projective matcher

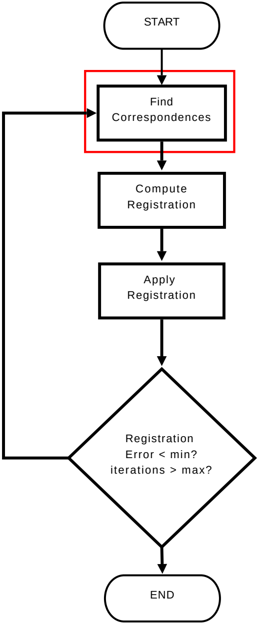




Candidate faces fine registration

- Global registration through ICP with a mean reference face
- Projective matcher
- Geometric correspondences rejector





Candidate faces classification

Standard PCA classification

Candidate faces classification

Standard PCA classification

 $\simeq$  $+\, y_1 \times$  $+\, y_2 \times$  $+ \cdots +\, y_n \times$ 

Candidate faces classification

Standard PCA classification

 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$  $=$ 

Candidate faces classification

Standard PCA classification

 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$  $=$ 

$D.F.F.S. = \|$  $-$  $\|$

Candidate faces classification

Standard PCA classification

 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$  $=$ 

$D.F.F.S. = \|$  $-$  $\| \ll \|$  $-$  $\|$

Candidate faces classification

Standard PCA classification

- Missing data?

Candidate faces classification

Standard PCA classification

 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$  $=$ 

$D.F.F.S. = \|$  $-$  $\| \ll \|$  $-$  $\|$

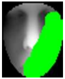
- Missing data?
- Occlusions?

Candidate faces classification

Gappy PCA

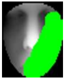
Candidate faces classification

Gappy PCA



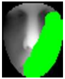
Candidate faces classification

Gappy PCA

 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$ 

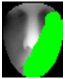
Candidate faces classification

Gappy PCA

 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$  $=$ 

Candidate faces classification

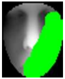
Gappy PCA

 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$  $=$ 

$\min \|$  $-$  $\|_{mask}$

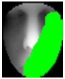
Candidate faces classification

Gappy PCA

 $\simeq$  $+\ y_1 \times$  $+\ y_2 \times$  $+ \cdots +\ y_n \times$  $=$ 

$\min \|$  $-$  $\|_{mask} = D.F.F.S.$

Candidate faces classification
Gappy PCA

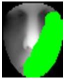
 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$  $=$ 

$\min \|$  $-$  $\|_{mask} = D.F.F.S.$

- Closed form for GPCA projection; *really fast.*

Candidate faces classification

Gappy PCA

 $\simeq$  $+ y_1 \times$  $+ y_2 \times$  $+ \cdots + y_n \times$  $=$ 

$\min \|$  $-$  $\|_{mask} = D.F.F.S.$

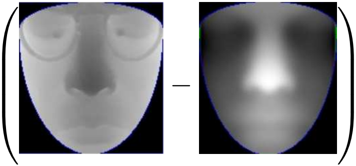
- Closed form for GPCA projection; *really fast.*
- Occlusions?

Candidate faces classification

Rough occlusion detection

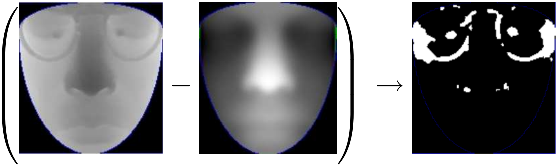
Candidate faces classification

Rough occlusion detection



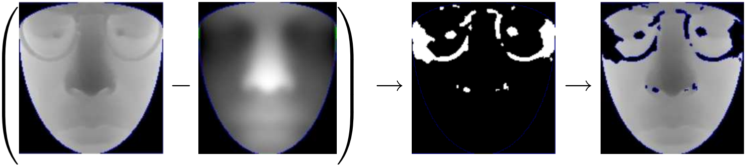
Candidate faces classification

Rough occlusion detection



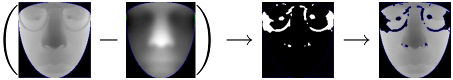
Candidate faces classification

Rough occlusion detection



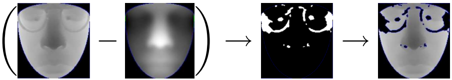
Candidate faces classification

Summary



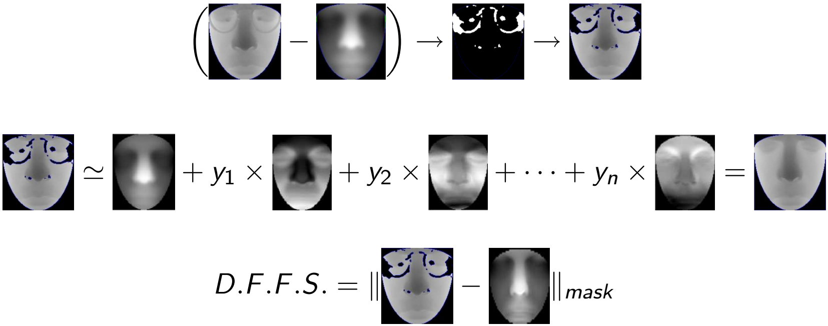
Candidate faces classification

Summary



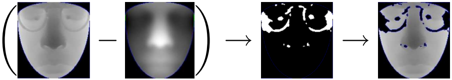
Candidate faces classification

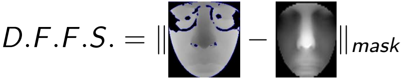
Summary



Candidate faces classification

Summary

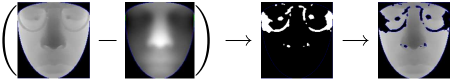


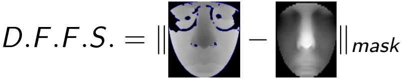


- if $D.F.F.S. < \tau \rightarrow$ *candidate is a face*

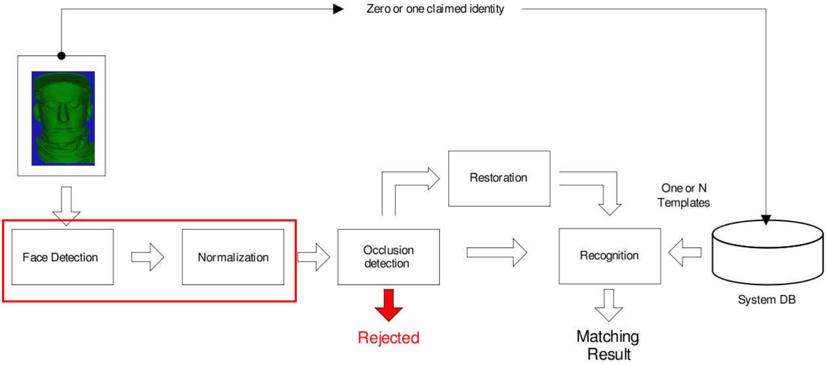
Candidate faces classification

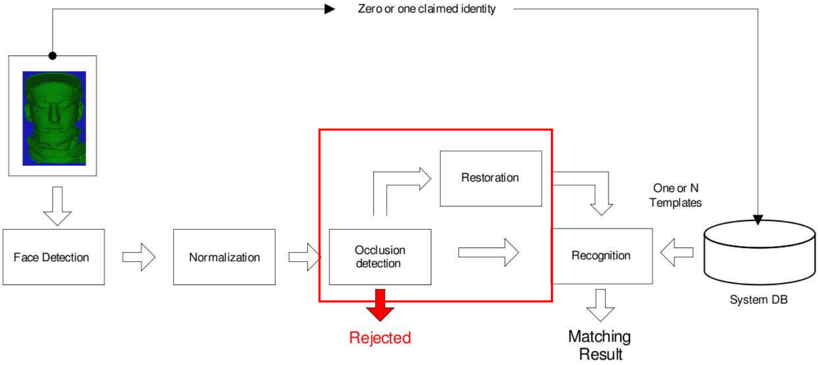
Summary





- if $D.F.F.S. < \tau \rightarrow$ *candidate is a face*
- If the occluded area is large the candidate may be rejected


Zero or one claimed identity
Restoration
One or N
Templates
Face Detection
Normalization
Occlusion
detection
Recognition
System DB
Rejected
Matching
Result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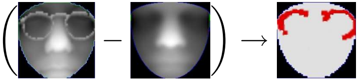
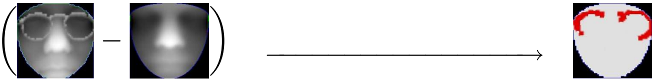
Occlusion Detection and Face Restoration



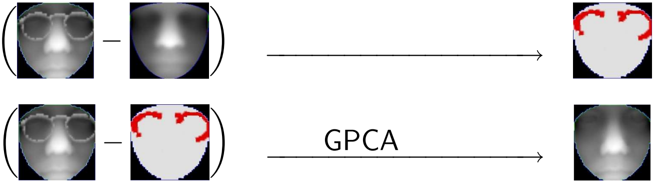
- Need a more precise detection of occluded pixels and reconstruction of the face for maximizing recognition performances

Occlusion Detection and Face Restoration



- a “large” threshold τ is used to discriminate occluded pixels

Occlusion Detection and Face Restoration

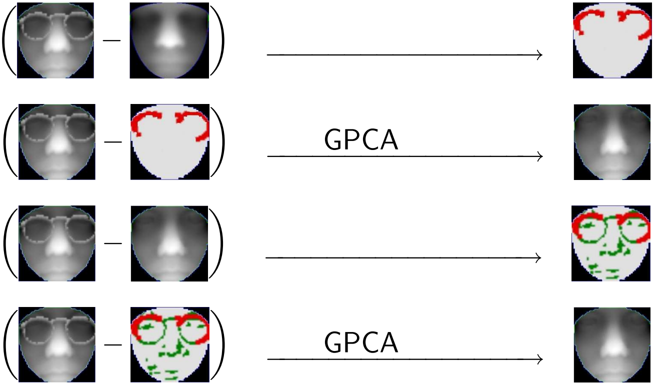


- a first reconstruction is generated through GPCA projection

Occlusion Detection and Face Restoration

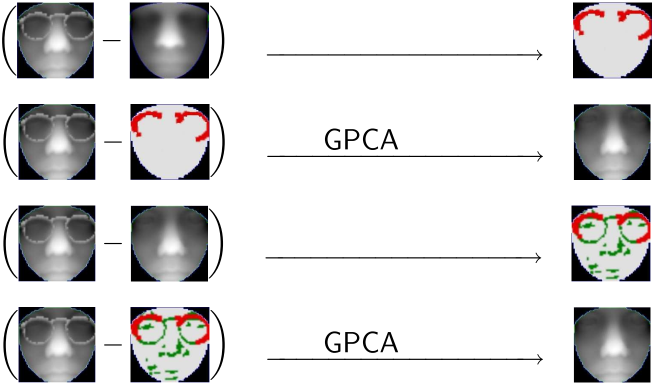
- a smaller threshold τ_2 is used. Morphological operators are also applied

Occlusion Detection and Face Restoration



- a new projection with the refined mask is generated

Occlusion Detection and Face Restoration



- If the occluded area is large the face may be rejected

Experimental Results

Dataset Requirements:

- large number of subjects
- different occlusion types (object type, location, size of occluded area)

Ground truth needed for an in-depth analysis:

- occluded/non-occluded regions, *pixel precision*
- landmarks, *even if occluded*
- original, *non-occluded surface*

Experimental Results

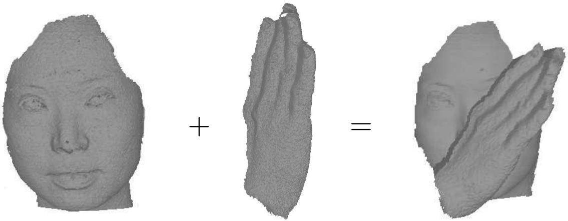
Dataset Requirements:

- large number of subjects
- different occlusion types (object type, location, size of occluded area)

Ground truth needed for an in-depth analysis:

- occluded/non-occluded regions, *pixel precision*
- landmarks, *even if occluded*
- original, *non-occluded surface*

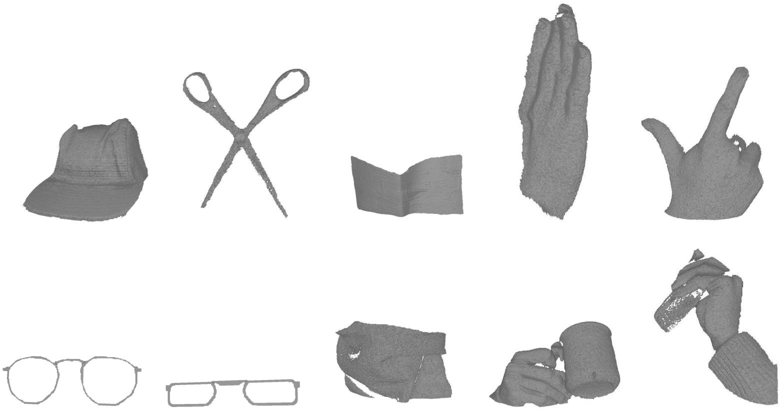
Artificial Occlusions Generation



- Random or semi-random position and orientation of the object

Artificial Occlusions Generation

Occluding objects

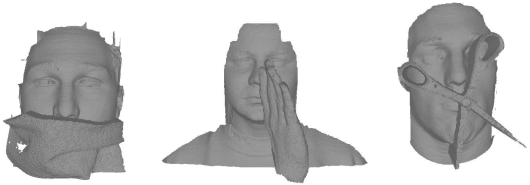


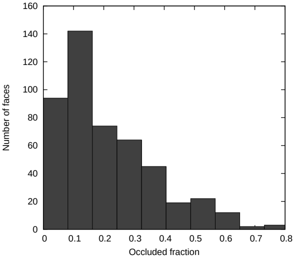
Artificial Occlusions Generation

The Artificially Occluded UND Dataset

UND Dataset:

- 277 subjects (male/female, different races)
- 953 acquisitions (frontal, neutral expression, 2D+3D)
- facial features annotation





Face Detection Results

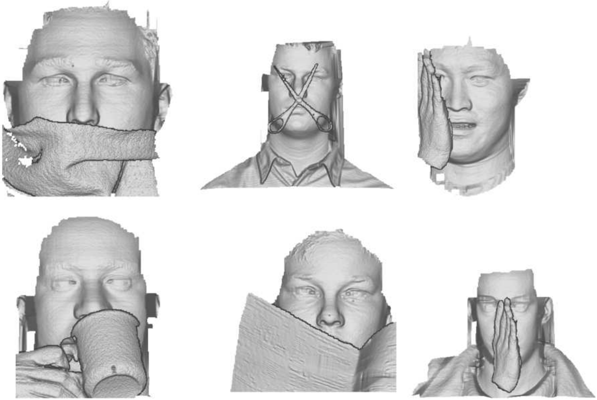
Artificially occluded UND Dataset

Test Set	Classifier	Total Faces	False Positives	False Negatives	Detected Faces
UND (non-occluded)	PCA	951	3	1	950 (99.9%)
	GPCA	951	18	0	951 (100%)
UND (artificially occluded)	PCA	951	165	483	468 (49.2%)
	GPCA	951	135	104	847 (89.8%)

Object Type	Total Faces	False Positives	False Negatives	Detected Faces
hand with cup	91	5	3	88 (96.7%)
eyeglasses	184	4	0	184 (100.0%)
free hands	181	46	41	140 (77.3%)
newspaper	77	20	18	59 (76.6%)
hand with phone	97	1	0	97 (100.0%)
scarf	123	42	29	94 (76.4%)
scissors	109	9	7	102 (93.6%)
hat	89	8	6	83 (93.6%)
all	951	135	104	847 (89.8%)

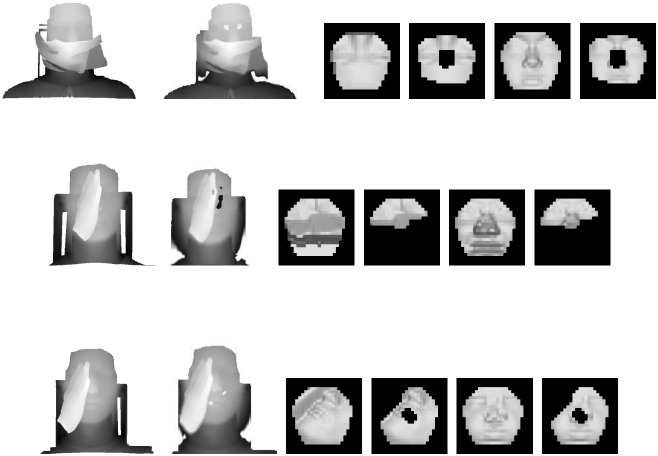
Face Detection Results

Successes



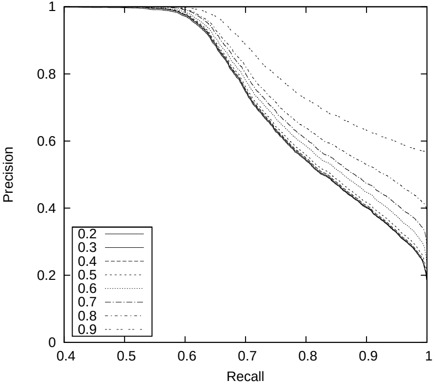
Face Detection Results

Failures



Face Detection Results

Detector Precision vs Recall



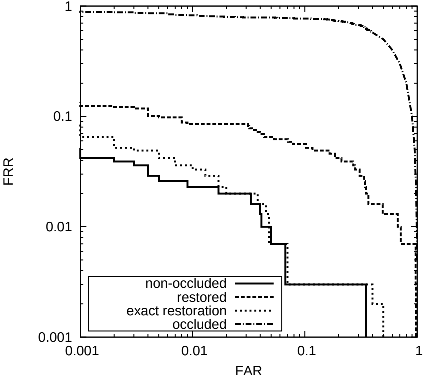
- Precision vs Recall varying the minimum valid area fraction threshold

Face Recognition Results

Artificially occluded UND Dataset

- Fisherfaces recognition approach; Manual normalization
- Training: 474 images; 3 x subject (*non-occluded*)
- Test: 477 remaining images (*occluded*)

Set	EER	IR
non occluded	0.020	99.35%
occluded	0.488	27.45%
restored	0.062	96.08%
exact restoration	0.022	99.35%



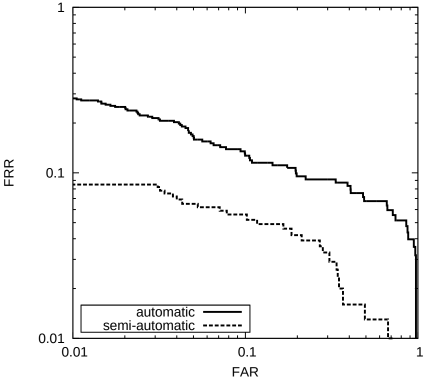
Face Recognition Results

Artificially occluded UND Dataset

- Full Automatic Pipeline: face detection, occlusion detection and restoration
- Fisherfaces recognition approach;
- Same training and test sets

- EER drops from 0.062 to 0.115
- IR drops from 96.08% to 81%

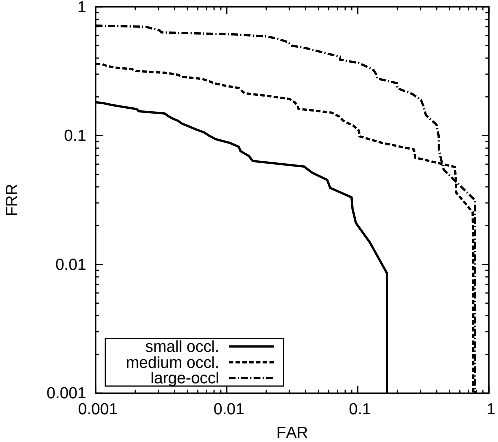
Occlusion type	Manual normalization	Automatic normalization
Cup	100%	81%
Scissors	100%	100%
Eyeglasses	100%	100%
Hat	100%	63.16%
Hand	97.18%	96.49%
Phone	100%	93.75%
Newspaper	92%	87.5%
Scarf	95.92%	46.34%



Face Recognition Results

Artificially occluded UND Dataset

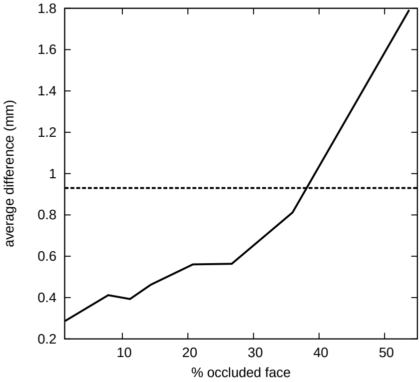
subset	from %	to %
small	0%	20%
medium	20%	40%
large	40%	82%



Restoration Accuracy

Artificially occluded UND Dataset

- Average absolute difference between depth of corresponding points for each pair of restored and original faces.



- Average absolute z difference between the pixels of pairs of non-occluded acquisitions of the same subject: 0.93 mm.
- GPCA is able to precisely reconstruct faces even if occluded up to 40%.

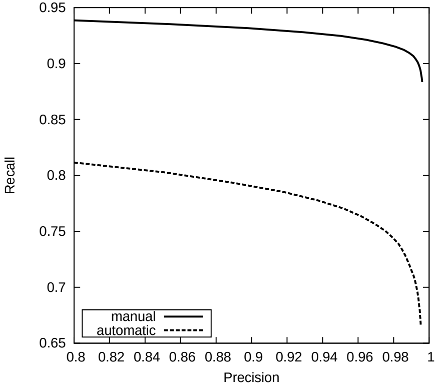
Occlusion Detection Accuracy

Artificially occluded UND Dataset

- Occlusion detection performances evaluated at the pixel level

$$precision = \frac{tp}{tp + fp}$$

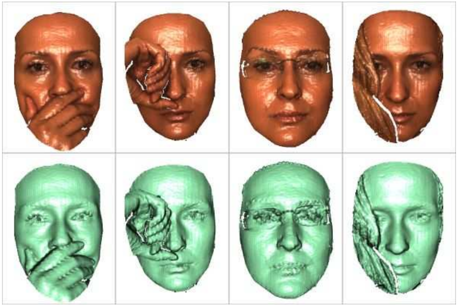
$$recall = \frac{tp}{tp + fn}$$



Face Recognition Results

Bosphorus Database

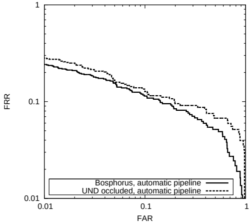
- 105 subjects; 4652 acquisitions, 381 occluded.
- Occluding objects:
  - mouth with hand
  - one eye with hand
  - eyeglasses (not sunglasses, normal eyeglasses)
  - hair

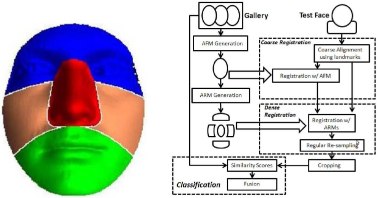


Face Recognition Results

Bosphorus Database

Method	Occlusion Type			
	Eye	Mouth	Eyeglasses	Hair
Alyuz et al.[1] (semi-auto)	93.62%	93.62%	97.87%	89.66%
Proposed approach (auto)	91.18%	74.75%	94.23%	90.47%





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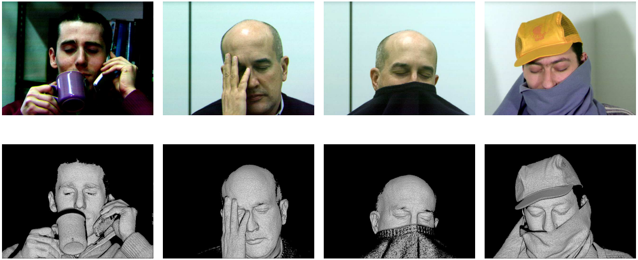
[1] N. Alyuz, B. Gokberk, L. Akarun, 3D Face Recognition System for Expression and Occlusion Invariance, IEEE 2nd International Conference on Biometrics: Theory, Applications, and Systems (IEEE BTAS), Washington, DC, USA, September 2008.

UMB-DB Database

The University of Milano-Bicocca 3D face Database

- 143 subjects
- 1461 acquisitions; 9 - 12 per subject
- 4 facial expressions
- 578 occluded acquisitions
- 6+ occluding objects



UMB-DB Database

Face Detection Preliminary Results

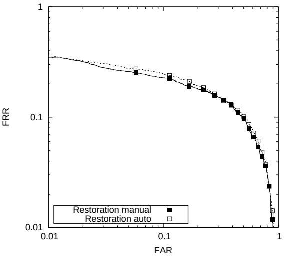
Total Faces	False Positives	False Negatives	Detected Faces
1473	56	52	1421 (96.5%)

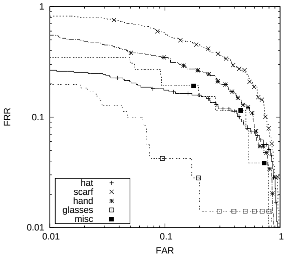
Acquisition type	Number of faces	Detected Faces
Neutrals	441	437 (99.1%)
Non-neutral	442	431 (97.5%)
Occluded	578	553 (95.7%)
Scarf	151	141 (93.4%)
Glasses	75	71 (94.7%)
Hair	33	30 (90.9%)
Hand	165	150 (90.9%)
Hat	183	179 (97.8%)
Misc	28	26 (92.85%)

UMB-DB Database

Face Recognition Preliminary Results

Normalization	Test set	EER	IR
Manual	All cases	0.186	71.0%
Automatic	All cases	0.195	69.6%
Automatic	Neutral	0.019	98.0%
Automatic	Occlusions	0.238	56.5%





Conclusions

- Main contributions:
  - a fully automatic occlusion tolerant 3D face recognition pipeline
  - occlusion tolerant face detector
  - occlusion detector
  - face restoration module

Conclusions

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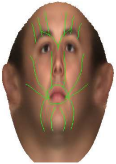
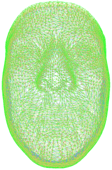
  - a fully automatic occlusion tolerant 3D face recognition pipeline
  - occlusion tolerant face detector
  - occlusion detector
  - face restoration module
- Considerations:
  - there is enough information to recognize faces even with 40% of the occluded area
  - face detection and normalization is *crucial*

Conclusions

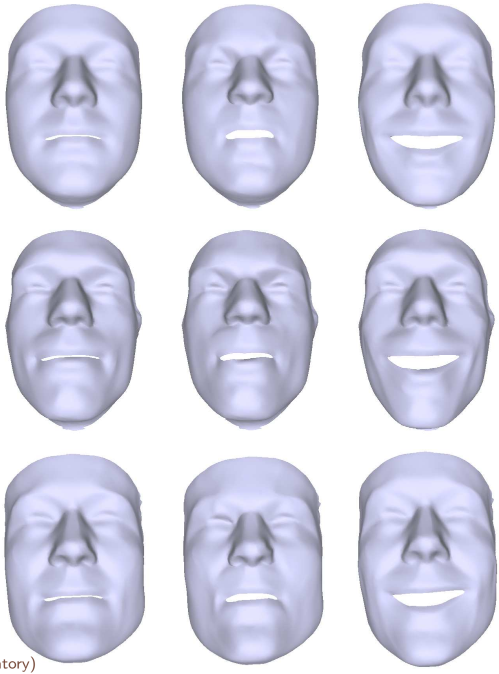
- Main contributions:
  - a fully automatic occlusion tolerant 3D face recognition pipeline
  - occlusion tolerant face detector
  - occlusion detector
  - face restoration module
- Considerations:
  - there is enough information to recognize faces even with 40% of the occluded area
  - face detection and normalization is *crucial*
- Work in progress & Future work
  - use of other surface features and 2D data in order to improve occlusion detection, normalization and restoration
  - embed face detection, normalization, occlusion detection and face restoration in an iterative schema
  - explore facial expressions
  - artificial generation of datasets with facial expressions and occlusions

Facile

A system for artificial face datasets generation

- Given a face 3D textured model with neutral facial expression, the current version of facile is able to:
  - simulate facial expressions through a physical simulator based on a mass-spring system and synthetic muscles.
  - render images of the morphed faces from different viewpoints and with different lighting conditions
- Features:
  - facial expressions are defined by the user on a mean face specifying muscle contractions
  - facial expressions are automatically transferred on novel faces
  - a dense annotation of facial feature points is automatically generated
  - ready to be used with synthetic faces generated through morphable models or morphing techniques



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Thresholds

- Histogram of the distribution of the pixel by pixel difference between training faces and the mean face