Robust Facial Landmark Localization for Automotive Applications

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The best or nothing.
Motivation

Driver observation as enabler for many safety and comfort functions:

- Attention detection
- Tiredness-/Micro sleep detection
- Ensure takeover readiness
- Hazard recognition

- Facial landmarks
- Head pose and
- Gaze estimation

- Gesture and Gaze based user interaction
- Intention detection

* Murphy-Chutorian, E., Trivedi, M, ** Daimler Intern

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Face Modelling – State of the art

Template based Models

Active Shape Models

Active Appearance Models

* : Cristinacce, Cootes - Facial Feature Detection and Tracking with Automatic Template Selection
** : Cootes, Baldock, Graham - An introduction to active shape models
Deployment Scenario: Automotive Applications

Challenges for driver monitoring:
- Deep shadows
- Major and quickly-varying changes in illumination
- Partly occlusion of facial parts
- Direct sunlight, reflections and overexposure

→ Problems for traditional AAMs
Active Appearance Model (AAM) - Basics

Method for localization and description of well-defined objects

**Appearance Model:**
- Linear model to describe the texture

**Consists of:**
- Mean face $A_0(x)$ in frontal view
- “Appearance Images“ $A_i(x)$: texture components, principle components of a PCA

\[
A(x) = A_0(x) + \sum_{i=1}^{m} A_i(x) \lambda_i
\]

**Shape Model:**
- Linear model to describe the object geometry

**Consists of:**
- Base mesh configuration $s_0(x)$ in frontal view
- Shape vectors $s_i(x)$: Shape components, principle components of a PCA

\[
s(x) = s_0(x) + \sum_{i=1}^{n} s_i(x)p_i
\]
Active Appearance Model (AAM) - Matching

**Assumption:** Initial guess available

1. Initial guess
2. Warping face onto frontal view
3. Calculate difference image $r(p)$
4. Calculate parameter optimization $\Delta p$
5. Adjust shape mesh

Face with initial guess → Warped face onto frontal view

Mean face $A_0(x)$ → Difference calculation

$\Delta p = -Rr(p)$ → Face with optimized shape model → Difference image $r(p)$
AAM – Novel Method for facial landmark localization

MCT AAM

- Illumination invariant features
- Parameter constraints
- Occlusion detection and handling
Modified Census Transformation (MCT)

Properties:

- Local operator with a size of 3x3 pixels
- Illumination invariant
- Invariant regarding different camera characteristics

Example:

\[
A^* = \begin{bmatrix}
126 & 127 & 87 \\
124 & 125 & 96 \\
123 & 126 & 59 \\
\end{bmatrix}
\]

Mean: \( \bar{A}^* = 110.33 \)

Processing of MCT features:

\[
\begin{bmatrix}
126 & 127 & 87 \\
124 & 125 & 96 \\
123 & 126 & 59 \\
\end{bmatrix} \Rightarrow \begin{bmatrix}
1 & 1 & 0 \\
1 & 1 & 0 \\
1 & 1 & 0 \\
\end{bmatrix} \Rightarrow \{1,1,0,1,0,1,1,0\} \Rightarrow \text{MCT}\{A^*\} = 438
\]
Novel MCT AAM - Matching

Initial guess

Warping face onto frontal view

Process MCT transformation

Calculate difference image $r(p)$

Calculate Parameter optimization $\Delta p$

Adjust shape mesh

Face with initial guess

Warped face onto frontal view

MCT transformed frontal view

Difference calculation

Face with optimized shape model

Difference image $r(p)$

Mean MCT face $A_0(x)$
Novel MCT AAM – Parameter Optimization and Constraints

**Shape Parameter $p$ :**
- 4 global shape parameter rotation (Roll), translation, scaling
- 13 local shape parameter rotation (Yaw, Pitch), inter- und intra variability

**Optimization of the shape parameters:**
- AAMs requires a good initial guess
  ➔ Coarse-to-Fine: Global-to-local optimization

Variation of the shape parameter

Parameter constraints

→ Limit parameter range to 98% of all variations over the training set

*: Murphy-Chutorian, E., Trivedi, M

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Novel MCT AAM – Initial Guess Generation

Initial guess estimation based on detected ROIs for the face, eyes and mouth

1. Face detected?
   - Yes
     - Calculate initial guess + AAM Matching
     - Error < Max. Error?
       - Yes
         - Matching successful
       - No
         - Reject image
   - No
     - Reject image

2. Eye detection
3. Mouth detection

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Novel MCT AAM

Increasing robustness concerning external influences:

• Local parameter limitation based on preceding parameter
• Detection and deactivation of occluded triangle patches

Head pose estimation

• LMS approach with Candide-3-Model as reference 3D face model

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Novel MCT AAM – Example Sequences

Pitch: $21^\circ$  Yaw: $24^\circ$  Roll: $-14^\circ$
Evaluation

Evaluation method:

- Leave-one-out cross evaluation
- Sequences of 42 test drives with different probands
- Error-Metric: **Point-to-Point distance**

Evaluation Results:

<table>
<thead>
<tr>
<th></th>
<th>Point-to-Point distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand annotation process</td>
<td>3.16 pixel</td>
</tr>
<tr>
<td>ICAAM*</td>
<td>Did not converge</td>
</tr>
<tr>
<td>IntraFace** (pre-trained)</td>
<td>5.29 pixel</td>
</tr>
<tr>
<td><strong>Novel MCT AAM</strong></td>
<td>3.51 pixel</td>
</tr>
</tbody>
</table>

* Luca Vezzaro, MathWorks File Exchange, 2011
** X. Xiong and F. De la Torre, CVPR 2013
Summary

Computational speed: 10-12 fps with MATLAB-Implementation (Core i7-960 1st Generation)

Input:
- Raw images

MCT AAM Framework

Initial guess generation
- Viola-Jones detector
- ROIs: face, eyes, mouth

AAM using MCT features
- Global and local parameter constraints
- Quality criterion for matching result
- Intelligent stopping criterion
- Occlusion detection and handling

Head-pose estimation
- Candide-3 face model
- Least mean squares

Output:
- Positions of facial landmarks
- Head-pose (yaw-, pitch-, roll-angle)
- Quality criterion for matching result
Many Thanks
for your attention!

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