Challenges in Head Pose Estimation of Drivers in Naturalistic Recordings Using Existing Tools

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Head Pose Estimation

• The position and orientation of the head find useful application in multiple interactive environment

• Human computer interaction

• Non-verbal communication

• Visual attention

• In a vehicle setting

• Visual attention of driver
Motivations

• Head Pose estimation in a controlled environment with limited head motion is a solved (almost) problem

• Additional challenges in driving environment
  • Wide variation in lighting
  • High head rotations
  • Occlusion

• Questions
  • What are the factors that affect the performance of Head Pose Estimation (HPE) algorithms?
  • What are the conditions where,
    • most algorithms work?
    • most algorithms fail?
Objective

• Use a reference head poses in a naturalistic driving dataset to study factors affecting head pose estimation
  • Glasses
  • Illumination
  • Head rotation

• Isolate frames which are easiest to process and the ones that are the most challenging
  • Ideal Scenario – Frames that always give good estimate
  • Challenging – Frames that always fail estimation
Outline

• Tools and Dataset
• Factors affecting Head Pose Estimation
• Ideal Scenarios and Challenging Scenarios
• Conclusions and Future Work
Tools analyzed

- We analyse 3 state-of-the-art head pose estimation tools
  - IntraFace [Xiong et al., 2013]
    Supervised Gradient Descent (SGD) to track non-linear features associated with each landmarks
  - OpenFace [Baltrusaitis et al., 2016]
    Conditional Local Neural Fields (CLNF) which learns the landmark shape and appearance variations
  - Zface [Jeni et al., 2015]
    Iteratively build a 3D mesh from the 2D landmarks to register a dense model
Database

• Collected naturalistic driving data in the UTDrive platform
• Dash Cameras record the road and driver’s face
  • Blackvue dr650gw 2 channel
    • Rear camera records the face
    • Front camera records the road
• Data Collected with 16 subjects (10 males and 6 females)
  ~ 6 hours of naturalistic driving
AprilTags for Head Pose Estimation

- AprilTags [Olson, 2011]: 2D barcodes that can be robustly detected in an image
- Headband designed with 17 AprilTags
- Used to establish reference head position and orientation

Performance of AprilTag system

- Accuracy of AprilTag based detection
- Rendered the band on a head in virtual environment
- Studied the performance in various quality of rendering and adding external effects like illumination

<table>
<thead>
<tr>
<th>Data condition</th>
<th>Median angle error</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Quality render (3840 x 2160)</td>
<td>0.89°</td>
</tr>
<tr>
<td>Medium Quality render (960 x 540p)</td>
<td>1.26°</td>
</tr>
<tr>
<td>Data with added illumination</td>
<td>2.69°</td>
</tr>
</tbody>
</table>
Affect of Headband on HPE

• Head band occludes a part of forehead which can confuse HPE

• 7 subject collected without headband for comparison

• Frames missed by each algorithm

<table>
<thead>
<tr>
<th>Affect of Headband on HPE</th>
<th>From AprilTag</th>
<th>IntraFace</th>
<th>OpenFace</th>
<th>Zface</th>
</tr>
</thead>
<tbody>
<tr>
<td>With AprilTag</td>
<td>5.3 %</td>
<td>27.3 %</td>
<td>24.1 %</td>
<td>21.9 %</td>
</tr>
<tr>
<td>Without AprilTag</td>
<td>-</td>
<td>19.0 %</td>
<td>21.8 %</td>
<td>8.9 %</td>
</tr>
</tbody>
</table>
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Factors affecting Head Pose Estimation

- We study factors that effects Head Pose Estimation in driving environment
  - Glasses
  - Illumination
  - Head Rotation
Occlusion due to glasses

- Glasses occlude the face affecting performance of HPE
- Percentage of the total frames that failed detection by each algorithm

<table>
<thead>
<tr>
<th>Method</th>
<th>No Glasses</th>
<th>Glasses with thick frame</th>
<th>Glasses with Normal frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntraFace</td>
<td>15.40%</td>
<td>67.70%</td>
<td>18.50%</td>
</tr>
<tr>
<td>OpenFace</td>
<td>12.10%</td>
<td>67.50%</td>
<td>13.70%</td>
</tr>
<tr>
<td>Zface</td>
<td>8.80%</td>
<td>64.10%</td>
<td>13.80%</td>
</tr>
</tbody>
</table>

![Images showing face detection with and without glasses]
Effect of Illumination

• Both high and low illumination affects the quality of image
  • We study the effect of saturation of the face image
  • Partial or total saturation of face image
• Performance depends on the third quartile of the face image
  • Third Quartile of the intensity (Q3) is high when part of the face is saturated
Effect of head rotation

- Face detection and head pose estimation affected by high head rotation
  - Most tools only work for frontal and semi-frontal faces

- Naturalistic driving scenario
  - Distribution of head poses
    - Bright – High frequency
    - Dark – Low frequency
  - Most of the time head pose is frontal
  - The robustness is more crucial when head pose is non-frontal
Percentage of Frames Missed by the HPEs at Different Angles

• Analysis of percentage of face missed by HPE at different angles
  - Bright pixels – most frames not detected by HPE
  - Dark pixels – few frames not detected by HPE
Difference in Angle between estimates from AprilTags and HPEs

- Difference in estimation for the frames detected by each Algorithm
- Bright Pixels – Large difference in angular estimation
- Dark Pixels – Small difference in angular estimation
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Ideal Scenarios (IS) and Challenging Scenarios (CS)

• We extract two types of frames from the database
  • Ideal Scenarios (IS): Frames successfully detected and estimation error less than 10°
  • Challenging Scenarios (CS): Frames that failed detection by all the three HPEs

• Helps in design of more robust algorithms that work for challenging cases
Ideal Scenarios

- Distribution of Ideal frames at different rotation angles and illumination

- IntraFace ✔
- OpenFace ✔
- ZFace ✔
Challenging Scenarios

- Distribution of Challenging frames at different rotation angles and illumination
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Conclusions and Future Work

• Open access face processing tools have limited reliability in naturalistic driving environment
• Reliable estimation of head pose can be useful in designing smart systems in car

Future Work
• A more robust reference system with minimal obtrusion
• Investigate and evaluate other modalities such as depth sensing cameras
• Extend the database with more subjects under varying conditions
Thank you!

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