Analyzing the Relationship Between Head Pose and Gaze to Model Driver Visual Attention

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Drivers’ Visual Attention

• Primary driving related task
  • Mirror checking actions (Li and Busso, 2016)
  • Lane change
  • Turns and cross sections

• Secondary tasks
  • Mobile Phones and In-vehicle entertainment unit
  • Co-passengers in the car
  • Billboards and other distractions from the environment
Motivations

• Gaze detection is a challenging problem in car environment

• It is often approximated by head pose [Lee et al., 2011]

• Coarse direction of driver’s gaze is enough for most in-vehicle applications [Tawari & Trivedi, 2014; Doshi & Trivedi, 2009]

• Goal of this study is to analyze the relationship between gaze and head pose
Objective

• Questions
  • How well can we estimate the head pose in a real world driving environment?
  • How well does the head pose of the driver predict his/her gaze (visual attention)?
  • How much does the head pose varies when the driver is looking at a certain direction?

Head Pose Estimation  Gaze Detection
Outline

• Data collection
• Performance of head pose estimation
• Gaze estimation using linear regression
• Study of eye movement bias
• Conclusion
Data Collection

- To relate the facial image to ground truth gaze locations

- UTDrive platform

- Dash Cameras used instead of the on-board equipment
  - (Blackvue dr650gw 2 channel)
  - 2 channel camera
  - with WiFi, GPS and accelerometer
Experimental Setup

- Rear camera → Face
- Front camera → Road
- Markers placed at the windshield (1-13), mirrors (14-16), side windows (17-18), speedometer panel (19), radio (20), and gear (21)
- Data collected with 16 subjects (10 males, 6 females) in three phases.
Phase 1
(Natural Gaze – Parked Vehicle)

- Collected in a parked car
- Subject asked to look at each point multiple times
- Natural variability in head pose without the constraint of driving task
- The driver familiarizes to the core task
Phase 2
(Natural Gaze - Driving)

- Collected when the subject is driving the car
- Subject asked to look at points
- Data collected in a straight road with minimum maneuvering task
Phase 3
(Controlled Gaze – Parked Vehicle)

• Direct head pose toward markers
  • Head pose ≈ gaze
  • No bias due to eye movement
• Difficult to achieve naturally
  • Used a glass frame with laser mounted at the center
• Subjects point at the target marks with the beam
AprilTags for Head Pose Estimation

• Head pose estimation challenging in driving environment
• AprilTags (Olson, 2011): 2D barcodes that can be robustly detected in an image
• Headband designed with 17 AprilTags
• Useful for robust detection of head pose across conditions
Outline

• Data collection

• **Performance of head pose estimation**
  - Question 1: How well can we estimate the head pose in a real world driving environment?
  - Gaze estimation using linear regression
  - Study of eye movement bias
  - Conclusion
Performance of Head pose Estimation Algorithm

- Head Pose estimation challenging in driving environment
  - Wide variation in lighting
  - High head rotations
  - Occlusion

- We Study a state-of-the-art head pose estimation algorithm (HPA) (Baltrusaitis et al. 2013)
  - Representative performance with respect to other good head pose estimation algorithms
Performance of Head Pose Estimation Algorithm (HPA)

- Analysis performed on all the frames when the subject was driving
- Frames detected by the HPA compared to the AprilTag

<table>
<thead>
<tr>
<th>HPA AprilTag</th>
<th>Face detected</th>
<th>Face not detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tag detected</td>
<td>73.2%</td>
<td>21.51%</td>
</tr>
<tr>
<td>Tag not detected</td>
<td>2.25%</td>
<td>3.03%</td>
</tr>
<tr>
<td></td>
<td>75.45%</td>
<td>24.54%</td>
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Percentage of Frames Missed by the HPA at Different Angles

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75.45% 24.54%
Mean Absolute Angle Difference between AprilTags and HPA

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Outline

- Data collection
- Performance of head pose estimation
- Gaze estimation using linear regression
  - Question 2: How well does the head pose of the driver predict his/her gaze (visual attention)?
- Study of eye movement bias
- Conclusion
Linear Regression Model for Gaze Estimation

• Investigate the linear relationship between head pose and gaze location

• Model Trained
  - $x_0 = a_0 + a_1 x + a_2 y + a_3 z + a_4 \alpha + a_5 \beta + a_6 \gamma$

• Driver independent partition
  - 10 training, 6 testing
Linear Regression (Contd.)

- R-squared value

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<tr>
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<th>Phase 1 (Natural-Parked)</th>
<th>Phase 2 (Natural-Driving)</th>
<th>Phase 3 Controlled*</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Train</td>
<td>Test</td>
<td>Train</td>
</tr>
<tr>
<td>$x_0$</td>
<td>0.78</td>
<td>0.77</td>
<td>0.69</td>
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<tr>
<td>$y_0$</td>
<td>0.36</td>
<td>0.12</td>
<td>0.36</td>
</tr>
<tr>
<td>$z_0$</td>
<td>0.25</td>
<td>0.10</td>
<td>0.24</td>
</tr>
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</table>

* Head Pose $\approx$ Gaze

- High correlation in Horizontal direction $\Rightarrow$ But deterministic prediction of gaze not possible
- Low $R^2$ values of $y$ $\Rightarrow$ Low predictability in pitch direction
- High values in Phase III $\Rightarrow$ No eye movement therefore more predictability

**Phase 1** (Natural-Parked)  **Phase 2** (Natural-Driving)  **Phase 3** Controlled*
Outline

• Data collection

• Performance of head pose estimation

• Gaze estimation using linear regression

• Study of eye movement bias
  
  • Question 3: How much does the head pose varies when the driver is looking at a certain direction?

• Conclusion
Study of Eye Movement Bias

- Projected the head direction on the windshield
- Ellipse representing the standard deviation of the head pose
- Distance between the ellipse and the gaze point is the average bias due to the eye movement

Phase 1 (Parked)  Phase 2 (Driving)
Study of Eye Movement Bias (cont.)

- Observations
  - More variance (hence less predictability) when driving
  - More variance when looking away from the front.
  - The bias increases as the direction moves away from the frontal pose
Conclusions

• How well can we estimate the head pose in a real world driving environment?
  • At high yaw angles detection rate goes down
  • At high pitch angles the difference between the angles goes up

• How well does the head pose of the driver predict his/her gaze (visual attention)?
  • While there is strong correlation (horizontal direction) a deterministic model may not be possible

• How much does the head pose varies when the driver is looking at a certain direction?
  • Variation in head pose and the bias due to eye movement increases when looking further away from the front.
Thank you!

Questions?

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