Handheld Shack Hartmann Wavefront Sensor

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Introduction

• Development of a compact Shack-Hartmann autorefractor.
• Assessment of refractive error (especially astigmatism) in a pediatric Native American population.
• Handheld Shack-Hartmann wavefront sensor
• Current efforts, analysis and tools.
Compact Shack-Hartmann

- Explored developing a *autorefractor* based on Shack-Hartmann technique.
- Ideal case would be a compact handheld device.
- Alternative techniques for analyzing Shack Hartmann patterns.
Traditional Shack-Hartmann Sensor

18 inches
SHAR - Shack Hartmann Autorefractor

- Illumination/Fogging Channel
  SLD source superimposed on fogging target in Badal configuration
- Alignment Channel
  provides live video of pupil
- Measurement Channel
  displaced Shack Hartmann sensor
Displaced SH Sensor

• Wavefront no longer measured at pupil plane, but instead at a location in front of the eye.
• Must compensate for this displacement. Similar to vertex adjustment for spectacles and contact lenses.
• Extreme errors will overfill CCD sensor or underfill lenslet array.
SH Grid Patterns

Spots stay uniformly spaced with defocus, but the relative spacing changes.
Grid becomes rectangular and skews as the cylinder axis is rotated.
Fourier Transforms

CCD Images

Fourier Transforms
Fourier Transforms

- One spot in Fourier space contains information about all of the spots from CCD space.
- In Fourier space, only two spots need to be analyzed to get sphere, cylinder and axis.
- Noise tends to have a much higher frequency than the spot pattern, so it gets pushed to the edge of the Fourier image. Central peaks are clean.
- Modulus of Fourier transform is independent of decentration of pupil.
Fourier Transforms

\[ W(x, y) = Ax^2 + Bxy + Cy^2 \]

\[ g(x, y) = \sum_{m,n} [\delta(x - \{(1 - 2Af)x_0 + fBmx_0\}) \cdot \delta(y - \{(1 - 2Cf)y_0 + fBnx_0\})]. \]

\[ G(\xi, \eta) = \text{comb}\left([1 - 2Af]x_0\xi - fBx_0\eta\right) \cdot \text{comb}\left([1 - 2Cf]y_0\eta - fBy_0\xi\right). \]
Fourier Transform Peaks

\[ A_{11} = \frac{1}{2f} - \frac{\eta_3}{2f \xi_0 (\eta_2 \xi_1 - \eta_1 \xi_2)} \]

\[ B_{11} = \frac{\xi_2}{f \xi_0 (\eta_2 \xi_1 - \eta_1 \xi_2)} = \frac{\eta_1}{f \xi_0 (\eta_2 \xi_1 - \eta_1 \xi_2)} \]

\[ C_{11} = \frac{1}{2f} - \frac{\xi_1}{2f \xi_0 (\eta_2 \xi_1 - \eta_1 \xi_2)} \]

\[ A_{34} = \frac{1}{2f} + \frac{\eta_3 - \eta_4}{2f \xi_0 (\eta_4 \xi_3 - \eta_3 \xi_4)} \]

\[ B_{34} = \frac{-\xi_3 + \xi_4}{f \xi_0 (\eta_4 \xi_3 - \eta_3 \xi_4)} = \frac{-\eta_3 - \eta_4}{f \xi_0 (\eta_4 \xi_3 - \eta_3 \xi_4)} \]

\[ C_{34} = \frac{1}{2f} + \frac{\xi_3 + \xi_4}{2f \xi_0 (\eta_4 \xi_3 - \eta_3 \xi_4)} \]
Fourier Transform Peaks

[Graph showing Fourier Transform Peaks with different angles and cycles/mm values]
Autorefractor Comparison

Autorefractor Comparison - STRAY LIGHT ARTIFACTS REMOVED

Subject

0.0 0.5 1.0 1.5 2.0 2.5

d(D)

Topcon  Humphrey  Shin-Nippon  SHAR 1/2 (Poly) - AVD
Handheld SH Wavefront Sensor

• Explored developing a handheld *wavefront sensor* based on Shack-Hartmann technique.
• Binocular open-view configuration.
• Live video and audio capture.
• Screening tool for early intervention to prevent amblyopia.
Amblyopia

• Developmental disorder of the visual system that is characterized by reduced vision in the absence of ocular causes.

• Caused by poor visual input (abnormal visual experience) during early development.
Astigmatism

- One cause of poor visual input is uncorrected astigmatism.
- Condition of the cornea or lens in which there is unequal curvature across meridians.
- When uncorrected, individuals with astigmatism cannot bring stimuli of all stimulus orientations into focus at once.
Meridonal Amblyopia

- Astigmatism associated with a specific pattern of visual deficits termed *meridional amblyopia*
  - Orientation that is most out of focus when astigmatism is uncorrected associated with best-corrected visual deficits
  - Mitchell, Freeman, et al....

- Recent studies have reported deficits across stimulus orientation for some forms of astigmatism
  - “Astigmatism-Related Amblyopia”
Treatment

- In the absence of unilateral amblyopia and/or strabismus, most common treatment for astigmatism-related amblyopia is optical correction of refractive error.

- Previous research has suggested that there is a sensitive period for treatment of astigmatism-related amblyopia.
Tohono O’odham Nation

- “Desert People”
- Members: 26,000
  - 11,400 on reservation
  - 1,800 on traditional lands in Mexico
- 2nd largest reservation
  - 2.7 Million Acres
### ASTIGMATISM AMONG NATIVE AMERICAN CHILDREN

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Tribe</th>
<th>Grades</th>
<th>Prevalence</th>
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<tbody>
<tr>
<td>Abraham</td>
<td>520</td>
<td>Navajo</td>
<td>PK-6</td>
<td>51% (&gt;1 D)</td>
</tr>
<tr>
<td>Boniuk</td>
<td>212</td>
<td>Sioux</td>
<td>PK-4</td>
<td>44% (&gt;1 D)</td>
</tr>
<tr>
<td>Hamilton</td>
<td>499</td>
<td>Cheyenne</td>
<td>PK-12</td>
<td>33% (&gt;1 D)</td>
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<tr>
<td>Levy</td>
<td>358</td>
<td>Pueblo</td>
<td>1-9</td>
<td>62% (&gt;1 D)</td>
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<tr>
<td>Maples</td>
<td>1,106</td>
<td>Navajo</td>
<td>K-12</td>
<td>27% (&gt;2 D)</td>
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<tr>
<td>Mohindra</td>
<td>382</td>
<td>Zuni</td>
<td>1,2</td>
<td>45% (&gt;1 D)</td>
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<tr>
<td>Mohindra</td>
<td>337</td>
<td>Navajo</td>
<td>1,2</td>
<td>37% (&gt;1 D)</td>
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<tr>
<td>Tyszko</td>
<td>250</td>
<td>Tohono O’odham</td>
<td>PK</td>
<td>44% (&gt;1 D)</td>
</tr>
<tr>
<td>Wick</td>
<td>378</td>
<td>Sioux</td>
<td>1-5</td>
<td>40% (&gt;1 D)</td>
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</tbody>
</table>
Tohono O’Odham Vision Screening Program

- Phase I (1997-2001)
  - Preschool children

- Phase II (2000-2005)
  - K-2nd grade
  - 4-6th grade

- Phase III (2005-2010)
  - 6 months through 1st grade
Mean Letter Acuity
Baseline vs. Outcome

- Astigmats poorer than non-astigmats at baseline (about 2 lines)
- Greater improvement over time for astigmats than non-astigmats
- Astigmats remain poorer than non-astigmats at 1 year
- Younger showed more improvement over time, but no effect of time x group x cohort

Significant: Time, Cohort, Group, Cohort, Time x group, Time x cohort
Percentage of Children Classified as “Amblyopes”: Baseline vs. Follow-up

- Smaller % of non-astigmats than astigmats classified as "amblyopes" at:
  - Baseline
  - 1 Month
  - 1 Year

(all Ps < 0.01)
Questions for Current Phase

• Both age groups responded to treatment, but can eyeglass treatment *eliminate* astigmatism-related amblyopia?
  – Is there further improvement after 1 year?
  – Can discrimination learning be used to enhance effects of eyeglass treatment

• Screening and Prevention:
  – Astigmatism-related amblyopia present by 3 years
  – At what age does it first develop?
  – At what age should glasses be prescribed?
Welch Allen Suresight
PEWE
(Pediatric Evaluation of Wavefront Error)
Gaze Angle Error

![Graph showing Gaze Angle Error](image)
Summary

• Examined alternative configurations for Shack Hartmann wavefront sensors.
• Examined Fourier transform techniques for analyzing grid pattern.
• Currently testing pediatric binocular version
Acknowledgments

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  – Tohono O’Odham Nation
  – Parents
  – Children

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