In Situ 3D Visualization with Deployable and Head-Worn Displays

See-through

ODALab
(Optical Diagnostics and Applications Lab)

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CREOL & FPCE
College of Optics and Photonics

Affiliates Day
April 21, 2006
Science Fiction Sets Expectations of Where we Aim to Be Going!

Outline

Historical Note on See-through Head-worn Displays (HWD)

Early Results in Optical Superimposition and Depth Perception
   The foundation for a vision

Emerging Technologies in HWDs

Emerging Technologies in Biophotonics

Application to 3D Medical Visualization for Assisted Surgery
Overview of System Engineering

3D Visualization Framework

- Tracking apparatus for head, body movements, and real objects
- Custom designed algorithms for merging real and virtual objects
- Graphical rendering of virtual objects
- Head-worn displays
- Human perception quantification

HWD Engineering Architecture

- Optical design concept
- Detailed optical design
- Optics fabrication
- Assembly and testing of integrated system

Optomechanical design conducted off site in partnerships
Historical note
First graphics-driven HWD was developed by Ivan Sutherland in the 1960s.
One Early Question We Addressed

Assuming rapid tracking and optimal graphics rendering, can we create the relative correct depth perception of real and virtual objects?
First results in dynamic optical superimposition on an optical bench system

Featured in Scientific American, April 2002
Baillot et al., Presence 2000; Argotti et al., Computers & Graphics 2002
US Patent 6,708,142 2004, UCF Tech Transfer 2005
Veridicality of Perceived Depth
Average data for 3 observers

ΔPSE (m)

0.10

0.05

0.00

-0.05

-0.10

0.60 0.80 1.00 1.20 1.40
Distance in Depth (m)

Rolland et al., 95 J. Presence
Next,

Breakthroughs in HWD designs were needed

Specifically in the development

- light weight and
- large field of view (≥ 40°)

Head Worn Displays
Eyepiece versus Projection HMDs

**Eyepiece Optics**
- **Advantage**
  - Simple/Robust
  - Color
- **Disadvantage/Challenge**
  - Optical weight scales with FOV
  - Distortion (electronic comp)
  - Illumination limited (miniature display)

**Projection Optics**
- **Advantage**
  - Simple/Robust
  - Color
  - Optics size does not scale with FOV
  - Lightweight
  - Distortion free
  - Lower aberrations than eyepiece design
- **Challenge**
  - Illumination limited by microdisplays
  - Screen type and location
Deployable Technology
1st Generation HMPD with VGA LCD microdisplays
Hua and Rolland, 2002

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Felix Hamza-Lup, LINK Foundation Fellow 03, PhD. 2004
42° FOV HMPD
Lightweight 595 grams - 2nd Generation HMPD using 800x600 OLED

Collaboration with Nvis Corporation and the US ARMY
under SBIR phase II Industry/Academia program 2004-2005
Stereoacuity for Howard-Dolman & Virtual-Dolman

Cali Fidopiastis, LINK Foundation Fellow 04
Out the Window Simulation
3rd Generation HMPD using 1280x1040 LCOS microdisplay

M-HMPD - Fabric-free, Mobile
Ricardo Martins

See-through 42° FOV

US Patent 6,963,454 & 6,999,239 B1, 05&06
Optical Design and Fabrication with OLED

42° Diag., 2 arcmin Res. - fabrication done with Optimax Corp.

![Graph showing modulation transfer function (MTF) and diffraction limits with wavelength and weight specifications.](image-url)

<table>
<thead>
<tr>
<th>DIFFRACTION LIMIT</th>
<th>WAVELENGTH</th>
<th>WEIGHT</th>
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<tr>
<td>0.0 FIELD (0.00°)</td>
<td>656.3 NM</td>
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<td>-0.3 FIELD (-6.30°)</td>
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<tr>
<td>-1.0 FIELD (-21.00°)</td>
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DEFOCUSING 0.00000
ET-HMPD  (Eyetracking Integration)
Costin Curatu, William Price Award 06, Optical Engineering

Vaisse/Rolland US Patent 6,433,760 B1 2002 ; UCF Tech Transfer 05 ;
Eyeglass Display
Ozan Cakmakci, Kidger Memorial Award 05, Optical System Design

[Diagram of eyeglass system with Microdisplay, ASP+DOE, Exit pupil, Mirror, and QVGA, VGA resolutions]

[Graph showing Diffraction MTF across spatial frequencies]

WAVELENGTH WEIGHT
608.9 NM 1
513.9 NM 1
DEFOCUSING 0.000

SPATIAL FREQUENCY (CYCLES/MM)

40 cycles/mm
Emerging Technologies in Biophotonics
Optical Coherence Tomography

- 2D and 3D imaging in
  - transparent tissue (e.g. eye)
  - highly scattering tissue (e.g. skin)
- Non-invasive imaging with non-ionizing NIR radiation
- Axial resolution from $1 \, \mu m$ up to $\sim 20 \, \mu m$
- Depth penetration of up to 3 mm in highly scattering tissue
- Measuring of the optical properties of tissues (e.g. reflectivity, scattering)
- Catheter/endoscope imaging of internal organs
- Processing, storage and transmission of electronic data

Fujimoto, 2000
Imaging System combining Fourier domain OCT and 2-photon fluorescence spectroscopy

Lee and Rolland, 2006

Fourier domain OCT; 5 microns resolution
Biophotonics Instrumentation for Microscopy Imaging

Catheter Design for Endoscopy OCT Imaging

Electrical wire for micromotor drive voltage

MEMS mirror

Micromotor

Optical Fiber

Axicon lens

Current focus is application to lung imaging
Task-based Optimization and Assessment Framework for OCT is under Development

Purpose:
Hardware optimization of the imaging system based on diagnosis tasks

Classification tasks
images from ensemble belongs to class 0 ($H_0$) or 1 ($H_1$)

• Can a tumor be detected? Often binary response: Yes or No

Estimation tasks

• Quantifying the strength of a layer or size of a lesion

Rolland et al, JOSA A 2005
ROC and AUC

ROC: Receiver Operating Characteristics

\[ \text{SNR}_t = \frac{\langle t \rangle_2 - \langle t \rangle_1}{\sqrt{\frac{1}{2} \sigma_1^2 + \frac{1}{2} \sigma_2^2}}. \]

AUC = 1 is perfect,
AUC = 0.5 is worthless system

Originally devised for radar signal detection
RESULTS: SIGNAL-DETECTION
Ceyhun Akcay, Ph.D 2005

- $n = 1.4$ (skin)
- $4 \mu s$ photodetector integration time
- $v_m = 0.154$ m/sec

Collaboration with Newport Corporation

Akcay, et al., Applied Optics 2005
A Driving Application:
Guiding Surgical Procedures
In Situ OCT Imaging and 3D Visualization Towards Treatment of Emphysema

Imaging

Augmented Reality Visualization

Bronchoscope
Oesophagus (gullet)
Trachea (windpipe)
Collar bone
Right lung
Left bronchus
Left lung
Creation of Deformable Model

Anand Santhanam, LINK Foundation Fellow 05
Santhanam et al., IEEE Computer Based Medical Systems 2006

4D-CT data

Extraction of 3D deformable model
Using Inverse Dynamics

PV data

Normalized pressure

Subject data
Inhalation (proposed method)
Exhalation (proposed method)
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Cali Fidopiastis (IST, HCI)
Ricardo Martins (IST, Eng.)
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