S7797 Tobii Eye Tracked Foveated Rendering for VR and Desktop

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Eye tracking is hitting a tipping point.
About Tobii

- founded in 2001
- listed on Nasdaq Stockholm (April 2015)
- headquartered in Sweden, with offices in the US, China, Japan, South Korea, Germany, Norway and UK
- ~800 employees worldwide
- $117M Group revenue 2016
- 16 years in remote eye tracking, 9 years wearable eye tracking
- Heavy investment in R&D on all business units, VR, Smartphones and Desktop/Laptop eye tracking technology
- 3 industry leading business units:
  - Tobii Pro
  - Tobii Dynavox
  - Tobii Tech
Where VR is today

- Panel Resolution: 1200 x 1080
- Pixel Density: ~15 pixels/degree
- Field of View: ~90 degrees
- Depth of Focus: fixed at 2 m

What humans are capable of

- Panel Resolution: ~120 pixels/degree
- Pixel Density: ~220-320 degrees
- Field of View: variable
The human eye – anatomy perspective

- Center Vision
- Near peripheral
- Mid - Far

Images from Wikipedida "Peripheral vision"
An eye tracker consists of cameras, projectors and algorithms.

The projectors create a pattern of near-infrared light on the eyes.

The cameras take high-frame-rate images of the user’s eyes and the patterns.

The image processing algorithms find specific details in the user’s eyes and reflections patterns.

Based on these details, mathematical algorithms calculate the eyes’ position and gaze point, for instance on a computer monitor.
Foveated Rendering in VR

- Lens compensation warp in VR
- Nvidia VRWorks Multi-Res Shader
- 9 viewports
- Outer viewports lower resolution
- Reduced processing and bandwidth
- Reduced load == faster rendering

Images from developer.nvidia.com
Eye Tracked Foveated Rendering (ETFR)

- Extends Foveated Rendering to account for where the eye is actually looking.
- Allows for Foveated Rendering in both VR and PC.
- Increased refinement of the foveated area in VR.
- Greater potential for processing and bandwidth reduction.
- Improves the illusion of a high quality full screen rendering.
- Can increase apparent image quality in VR and PC.
Factors affecting ETFR

- Quality of the eye tracking
  - Precision and Accuracy
    - VR 0.5 degrees central vision 1.5 peripheral vision
    - Desktop 1.5 degrees over the full screen (Alienware 17)
  - Robustness
    - Work on all users – Tobii 98% of population (measured)

- Round trip system latency (from eye movement to visible changes)

- Quality of the tracking movement analysis

- Algorithm choices for shaping, sizing and moving the foveated area

- Visible artefacts
ETFR, latency and fps

• Low latency is important but less so than for “Presence”
  • Low motion-to-photon (< 20ms) latency is necessary for Presence.

• Vision is not primarily a mechanical process
  • Eyes do not process the world as a series of frames
  • ‘Time to awareness’ is the ultimate metric for ETFR.

• Foveated rendering can reduce motion to response latency.

• Round trip latency is still important though
  • Avoid adding unnecessary latency – fetch and apply the eye tracking data as late as possible.
  • Eye tracker (camera readout + algo + transport) worst case is currently 11ms.
  • Constantly working on hardware, firmware, drivers and SDK to reduce latency.
Excellent. What about ET Hz and Display Hz?

- The chart on the right gives a rough guide.
- In practice we currently see a 'sweet spot' with 90Hz tracking and 90Hz displays.
- No hard limit on latency for ETFR but in the 40-60ms range for saccades.
- More work is still needed.

Robin Thunström Master Thesis “Passive gaze-contingent techniques relation to system latency”
How does it work?

Foveated rendering is a two part process:

1. Logic for managing the foveated area.
2. Taking advantage of the foveation.
A simplified primer on eye tracking – eye movement

1. Fixation
2. Saccade
3. Smooth pursuit
Foveated region logic

- Allow the user some control!
- Simple direct use of the eye position can work with low enough latency.
- Determining the eye movement type can allow more refinement.
- Use light filtering during fixation and smooth pursuit.
- During saccades use immediate eye tracking data.
- Take account of warping in VR to limit the positioning.
Taking advantage of foveation

• Multi-viewport rendering
  • Tiled 3x3 as in Nvidia’s example.
  • Overlapping with a full low-res buffer.
  • Finer grained tiles.
• Mip clamping outside the foveal area.
• Shader complexity modification.
• LOD reduction in the periphery.
• Some combination of the above.
Complicating factors

• Existing high latency in the rendering pipe.

• Temporal effects can suffer due to the lack of a full-res history.

• Screen-space effects can emphasise the boundary between fovea and periphery.

• Tiled lighting and rendering can require extra code and produce boundary artefacts.

• Deferred rendering can require some complicated buffer management.

• Limited CPU availability.
Peripheral vision artefacts

Some artefacts in the peripheral vision can hurt the illusion:

- ‘Jaggies’ and Nyqvist frequency issues.
- Aberrant contrast and brightness changes.
- Boundary artefacts between the foveal and peripheral areas.

Solutions include:

- Increasing the size of the foveal region.
- Simple filtering.
- Contrast preserving or remapping filters.
- Differentiate between content types.
Implementation choices – a balancing act

• Performance? Quality? Latency? Difficulty?
• In VR, increased super-sampling in the foveated region can increase quality.
• Reducing rendering times and latency are likely to be equally important.
Experiment 1: Nvidia Multi-Res Shader

- SDK available
- DirectX example available
- Easy to change viewports at runtime
- 60% load reduction
Experiment 2: Lumberyard Game Engine

• Can we reduce Game/Game Engine processing time by applying foveation?
  • Screen space reflections
  • Tiled shading
  • Fog interleave
  • Depth of field
  • Motion vector apply

• Sort of. Currently down from 19ms to 13ms execution time (down 35%)

• Big coding exercise and we still need to do a color and contrast rebalance.
Without foveation
YOUR DEVICE IS BLIND
Explicit Selection – Gaze Assisted Grabbing
Explicit selection - teleportation
Explicit selection – Rapid selection
Implicit selection - Throwing
Positional Guidance (IPD)

Adjust Headset

Awesome!

Position the headset so the circles (your pupils) are in the center of the boxes to get the best VR experience!
Eye tracking and foveated rendering is practical today!
Understand how to use eye tracking
Add foveation to your render pipeline now!

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