CSE 190: Virtual Reality Technologies

LECTURE #13: HIGH-END HEAD-MOUNTED DISPLAYS

Announcements

Project 2 late deadline this Sunday, May 17th at 11:59pm

Project 3 has been released

- Discussion recording on Canvas

Project 3 due Sunday, May 31st at 11:59pm

Today's VR app presentations:

- Arren Jake De Manuel: Bigscreen
- Arun Sugumar: RUN VR
- Cynthia Butarbutar: Trail World

Oculus DK1 Kickstarter in 2012

Launch video:

- https://www.youtube.com/watch?v=DhcOMOWRMnA

Oculus Rift DK1

Funded through Kickstarter with $2.4M

Released March 2013

Single LCD display with 1280 x 800 pixels

110 degrees FOV

60 Hz refresh rate

Head orientation tracking only (3 DOF)

- Fast, custom IMU

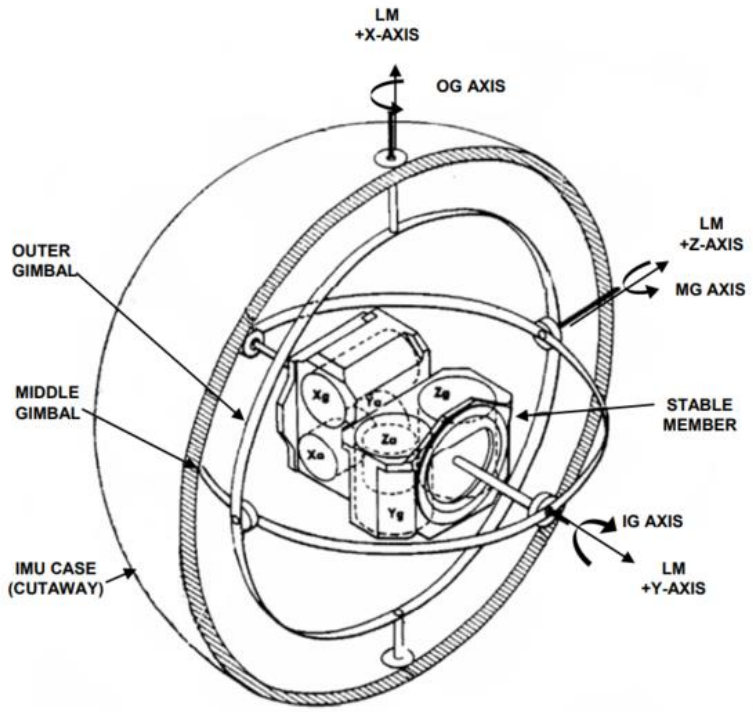
No tracked controllers available

Inertial Measurement Unit (IMU)

Measures
- gravitational force
- angular rate
- magnetic field (optional)

Consists of
- 3 accelerometers
- 3 gyroscopes
- magnetometer

IMUs also used in
- aircraft, spacecraft, satellites
- smart phones
- fitness trackers
- remote controls
- game controllers



Oculus Rift DK2

Released July 2014

Single OLED display (same as Samsung Galaxy Note 3)

1920 x 1080 pixels

Field of view: 95 x 105 degrees

75 Hz refresh rate

Same IMU as DK1

6 DOF tracking with IMU and camera for head location tracking

No tracked controllers available

Sony Playstation VR

Released October 13, 2016

Sold for Play Station 4

Single OLED display

960 x 1080 pixels per eye

100 degrees field of view

90 or 120 Hz refresh rate

Fixed IPD

Headphone jack

Innovative head strap

External camera for tracking

6 DOF tracking with visible light in different colors

Uses Sony Move controllers

HTC Vive

Released April 5, 2016

2 OLED displays

1200 x 1080 pixels per eye

110 x 113 degrees field of view

90 Hz refresh rate

Adjustable eye distance (IPD)

Integrated camera

Headphone jack

Includes two controllers

6 DOF tracking with 2 Lighthouses

Oculus Rift CV1

Released March 28, 2016

2 OLED displays

1200 x 1080 pixels per eye

94 x 93 degrees field of view

90 Hz refresh rate

Adjustable eye distance (IPD)

Integrated headphones

Infrared LEDs on HMD and controllers

6 DOF tracking with infrared cameras (“sensors”)

Initial Oculus Rift kit

Oculus Touch Controllers

Oculus Rift CV1 Teardown

Oculus Rift: Ear Phones

Face Foam

Infrared LEDs

Separate lens/display assemblies

CV1 Lens

Asymmetric

Hybrid Fresnel lens

Focus varies along vertical axis of lens

→ Push lens higher or lower to focus

Lenses: DK2 vs. CV1

Circular vs. Asymmetric

Microsoft Mixed Reality

First devices released October 17, 2017

Virtual Reality HMDs

- No augmented reality, despite the name

Specifications by Microsoft

Dual 6 DOF controllers with infrared LEDs

Inside-out 6 DOF HMD tracking with two cameras

HMDs built by:

- Samsung, Dell, HP, Lenovo, Acer, Asus

HTC Vive Pro

Released April 5, 2018

Built-in stereo cameras for AR

1440 x 1600 pixels per eye

90Hz refresh rate

110 degrees FOV

Integrated headphones

New design with sizing dial

2 cameras

Tracking space up to 10 x 10 meters with new Lighthouses 2.0 (released April 23, 2018)

HTC Vive Focus Plus

Released April 15, 2019

Standalone VR HMD

OLED display

1440 x 1600 pixels per eye

75 Hz refresh rate

110 degrees FOV

IPD adjustment

Qualcomm Snapdragon 835

Built-in headphones

Inside-out 6 DOF tracking

Includes 2 controllers

HP Reverb

Released May 6, 2019

Windows Mixed Reality headset

2160 x 2160 pixels per eye

114 degrees field of view

90 Hz refresh rate

6 DOF inside out tracking

Same controllers as other Mixed Reality systems

Oculus Quest

Release date: May 21, 2019

Standalone VR HMD
- Inside-out 6 DOF tracking

OLED display

1440 x 1600 pixels per eye

72 Hz refresh rate

100 degrees FOV

Adjustable IPD

Qualcomm Snapdragon 835

Built-in headphones

Includes 2 controllers

Oculus Rift S

Release date: May 21, 2019

LCD display

1280 x 1440 pixels per eye

80 Hz refresh rate

Internal speakers + headphone jack

Valve Index

Release date: July 1, 2019

1440 x 1600 pixels per eye

LCD display

120 Hz refresh rate (144 Hz experimental mode)

Integrated speakers

Lighthouse base stations 2.0

New Index (“Knuckle”) controllers: sense finger positions, allow open hands

Vive Cosmos

Released October 2019

Inside-out tracking with 6 cameras

Price: $700

1440 x 1700 pixels per eye

90Hz refresh rate

110 degrees FOV

Built-in stereo headphones

Adjustable IPD

Includes controllers

Issues with VR HMDs

High-End (PC-Based) VR:

- Most drivers for Windows only, Mac and Linux lacking support
- User can get tangled up in cables (except for wireless HMDs)
- Cumbersome camera calibration (even with inside-out systems)

Low-End (Smart Phone-Based) VR:

- Most apps only have orientation tracking
  - Position tracking possible with Apple's ARKit and Google's ARCore, but rarely used for VR
- Hand-held controllers not standardized and usually not supported

Both:

- More powerful GPUs needed for more visual realism
- Most VR HMDs don't allow view of environment
- Wearing an HMD is socially awkward (looks weird, can't see other people)
- AR is coming, but technology lagging behind VR

Comparison

PC-Based Full Set VR Comparison

	Name	Oculus Quest	Oculus Rift S	Valve Index	HTC Vive Cosmos	HTC Vive Pro	HTC Vive	HP Reverb	Samsung Odyssey+	Name
	Image Not to scale, obviously.									Image Not to scale, obviously.
DISPLAY	Horizontal Pixels / eye	1440	1280	1440	1440	1440	1080	2160	1440	Horizontal Pixels / eye
DISPLAY	Vertical Pixels	1600	1440	1600	1700	1600	1200	2160	1600	Vertical Pixels
DISPLAY	Display Tech	OLED	LCD	LCD	LCD	OLED	OLED	LCD	OLED	Display Tech
DISPLAY	Subpixel Type	Pentile Grid	Vertical Linear Grid	Horizontal? Linear Grid	Diagonal Grid	Pentile Grid	Pentile Grid	Vertical Linear Grid	Pentile Grid	Subpixel Type
DISPLAY	Panel Count	Dual	Single	Dual, 10° angled	Dual	Dual	Dual	Dual	Dual	Panel Count
DISPLAY	Refresh Rate (Hz)	72	80	144/120/90 Adjustable	90	90	90	90	90	Refresh Rate (Hz)
DISPLAY	Persistence (ms)	~2	~1	0.33	?	~2	~2	?	?	Persistence (ms)
OPTICS	"Marketed" FOV (°)	110	110	130	110	110	110	114	110	"Marketed" FOV (°)
OPTICS	Some says FOV is…	as narrow as OG Vive	wider than Quest	the widest of all listed here	?	?	?	narrow, nearing 90?	?	Some says FOV is…
OPTICS	Calculated Pixels/Deg.	13.09	11.64	11.08	13.09	13.09	9.82	18.95	13.09	Calculated Pixels/Deg.
OPTICS	Lens Diameter (mm)	45	45	50	?	?	?	?	?	Lens Diameter (mm)
OPTICS	HW IPD Range (mm)	58-72	63.5 Fixed	58-70	60-72	60-72	60-72	63 fixed	60-72	HW IPD Range (mm)
OPTICS	Adjustable Depth	No	Yes	Yes	No	Yes	Yes	No	No	Adjustable Depth
IMMERSION	Tracking System	Oculus Insight	Oculus Insight	Lighthouse v2	Cosmos Inside Out	Lighthouse v2	Lighthouse v1	WMR Inside Out	WMR Inside Out	Tracking System
IMMERSION	Tracking Tech	4 IR Cameras	5 IR Cameras	2+ IR Laser Base Stations	6 Visible Cameras	2+ IR Laser Base Stations	2+ IR Laser Base Stations	2 IR Cameras	2 IR Cameras	Tracking Tech
IMMERSION	Subj. Trk. Resolution	Milimiters?	Milimiters?	Sub-milimiter	Milimiters?	Sub-milimiter	~1mm?	Milimiters?	Milimiters?	Subj. Trk. Resolution
IMMERSION	Tracking Scale	Room-scale	Room-scale	Room-scale	Room-scale	Room-scale	Room-scale	Room-scale	Room-scale	Tracking Scale
IMMERSION	Subj. Trk. Noise/Jitter	Minimal Noise	Minimal Noise	Negligible Noise	Minimal Noise	Negligible Noise	Negligible Noise	Minimal Noise	Minimal Noise	Subj. Trk. Noise/Jitter
IMMERSION	Tracking sensitive to…	?	?	Mirrors	Dim Lighting, Plain Rooms	Mirrors	Mirrors	Some fluorescent & cheap LED room light	Some fluorescent & cheap LED room light	Tracking sensitive to…
IMMERSION	Subj. Latency on PC	Apparent, but less than Vive Wireless	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Subj. Latency on PC
IMMERSION	PC Link	USBC3.2G1 Compressed	USB3.0 + DP1.2	USB3.0 + DP1.2	USB3.0 + DP1.2	USBC3.0 + DP1.2	2xUSB3.0 + HDMI1.4	USB3 + DP1.4	USB3 + HDMI?	PC Link
IMMERSION	Wireless/Standalone?	Standalone	No	No	Wireless Addon	Wireless Addon	Wireless Addon	No	No	Wireless/Standalone?
IMMERSION	Headset Weight (g)	571	561	809	702	550	468	498	590	Headset Weight (g)
AUDIO	Audio Jack	3.5mm (2?)	3.5mm	3.5mm	3.5mm	None	3.5mm	3.5mm	None	Audio Jack
AUDIO	Speaker/Headphone	Spatial Speakers	Spatial Speakers	Index Off-Ear Spatial	On-Ear	On-Ear, Removable	None	On-Ear, Removable	Harmon 3D spatial	Speaker/Headphone
AUDIO	Speaker Subj. Quality	Not very immersive	Not very immersive	Very good	Better than Vive Pro?	Low Bass	-	?	Good	Speaker Subj. Quality
AUDIO	Mic Type	Microphone	Microphone	Microphone	Microphone	Microphone	Microphone	Two Integrated Mics	Microphone	Mic Type
AUDIO	Mic Quality	?	Good	Very good, full depth	Compressed and pops	?	?	?	?	Mic Quality
CONTROLLERS	Controller Type	Oculus Controllers	Oculus Controllers	Index "Knuckles"	Cosmos Controllers	Vive Wand v2	Vive Wand v1	WMR Controllers	WMR Controllers	Controller Type
CONTROLLERS	Weight+battery (g)	129	129	197	212	203	203	171	171	Weight+battery (g)
CONTROLLERS	Subjective Trk. Quality	Minimal Jitter	Minimal Jitter	Almost Jitter Free	Noticeable Jitter	Almost Jitter Free	Almost Jitter Free	Minimal Jitter	Minimal Jitter	Subjective Trk. Quality
CONTROLLERS	Occlusion Resistance	Occlusion-Resistant	Occlusion-Resistant	Almost Occlusion Free	Significant Occlusion	Almost Occlusion Free	Almost Occlusion Free	Some Occlusion	Some Occlusion	Occlusion Resistance
CONTROLLERS	Tracking Field	Front, Up, Side, Below	Front, Up, Side, Below	All-Around	Front, Up, Side, Below	All-Around	All-Around	Front, Side, Below	Front, Side, Below	Tracking Field
CONTROLLERS	Trigger	Yes	Yes	Yes	Yes, 2 With Bumper	Yes	Yes	Yes	Yes	Trigger
CONTROLLERS	Grip	Button	Button	Capacitive 5-finger	Button	Button	Button	Button	Button	Grip
CONTROLLERS	Mini-Joystick	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Mini-Joystick
CONTROLLERS	Trackpad	No	No	Yes	No	Yes	Yes	Yes	Yes	Trackpad
CONTROLLERS	Dedicated XY/AB Button	XY Left, AB Right	XY Left, AB Right	AB Left, AB Right	XY Left, AB Right	None	None	On Trackpad Press	On Trackpad Press	Dedicated XY/AB Button
	Headset Price (USD)	-	-	500	-	750	-	-	-	Headset Price (USD)
	Full Set Price (USD)	400	400	1000	760	1100	-	640	320	Full Set Price (USD)
	Worldwide Availability	Amazon Official	Amazon Official	Elite 31 Countries only :(	Amazon Official	Amazon Official	Discontinued	Amazon Official	Amazon Unofficial?	Worldwide Availability

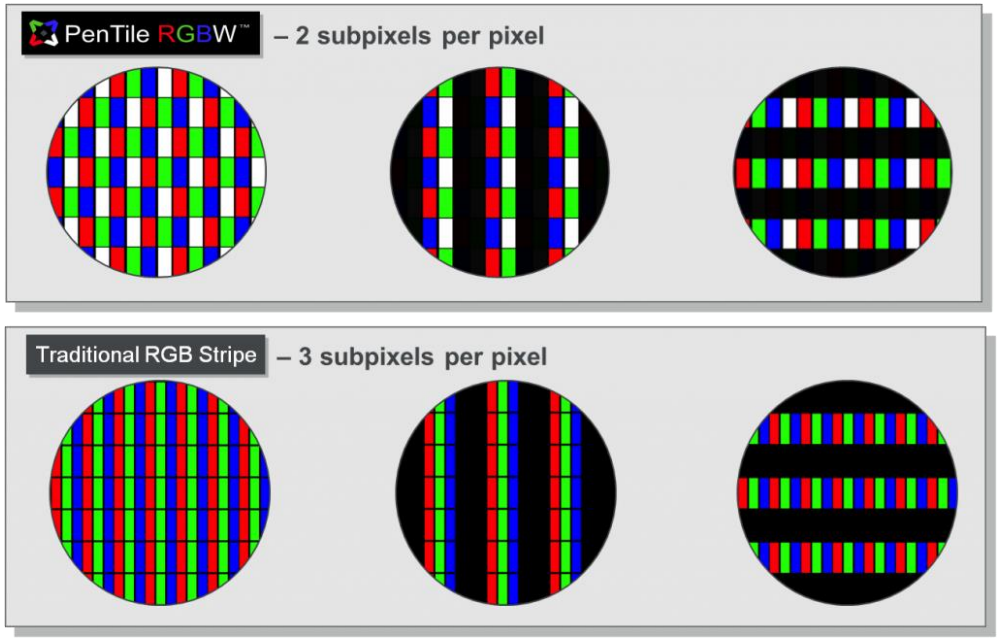
Only lists some of the most popular currently available fullset PC-Powered VR Systems, except the HTC Vive for baseline comparison since that's the one I have experienced before.
Some fields contains subjective measurement. This entire table can be said as subjective, from a point of view of someone new to PC VR and am looking to buy my first. Take all this info with a massive block of salt.
What I consider better might not what everyone consider better. **Weight does not necessarily correlate with comfort**, you will need Center of Mass measurement for that
I decide not to include Pimax range, since those are not sold in full-set, and again, my goal with this table is to find which system to buy as my first

Sources (not comprehensive):
Each headset's respective official pages
https://uploadvr.com/data-suggests-oculus-rift-s-ipd-range-best-for-around-half-of-adults/
https://www.tomshardware.com/reviews/htc-vive-cosmos-vr-headset,6367.html
https://www.roadtovr.com/valve-index-hands-on-preview-valve-vr-headset/
https://www.blurbusters.com/best-vr-guide-2019-compare-popular-virtual-reality-headsets/
https://en.wikipedia.org/wiki/Comparison_of_virtual_reality_headsets
https://www.youtube.com/watch?v=Gokb7v3I7Zw
https://www.youtube.com/watch?v=kMNX0OSaJ0w
https://www.youtube.com/watch?v=Ev_2VDOEAAY
https://www.youtube.com/watch?v=rEOjBsj1iWI

Color legend
Lesser than average
Average
Better than average
Leading/Unique

PenTile Displays

A display technology from Samsung that uses clusters of **five** (penta) **subpixels**. Originally developed by Clairvoyante, PenTile uses fewer subpixels, and subsequently less power, for the total number of pixels on screen than the conventional RGB subpixel method. [Wikipedia]



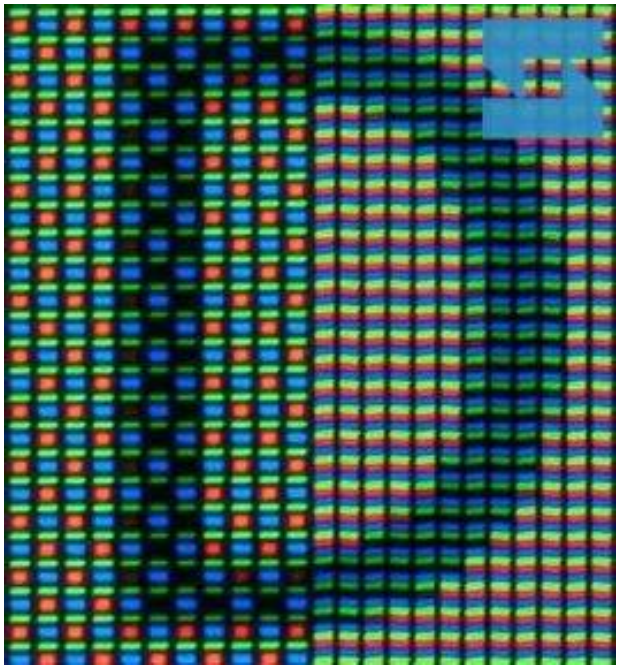
AMOLED Displays

AMOLED = Active-Matrix Organic Light-Emitting Diode

AMOLED screens don't need a backlight, as each pixel is able to produce **its own light** when it needs to. This makes **blacks look amazing** when viewing a picture or video, because the pixels do not have a to provide light at all, rather than LCD displays where the backlight bleeds through and you get a dark grey color where there should be black.

AMOLED drawbacks:

- more expensive to produce
- not as sharp as LCD displays when looking up close
  - AMOLED uses a different subpixel arrangement than LCD displays, which makes individual pixels more noticeable (see picture)



AMOLED LCD

HMD Sales Forecast