

# CSE 190: Virtual Reality Technologies

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LECTURE #13: HIGH-END HEAD-MOUNTED DISPLAYS



# Announcements

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Project 2 late deadline this Sunday, May 17<sup>th</sup> at 11:59pm

Project 3 has been released

- Discussion recording on Canvas

Project 3 due Sunday, May 31<sup>st</sup> 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: Step Into the Game



Developer kit for the Oculus Rift - the first truly immersive virtual reality headset for video games.

Pre-order Rift!

Created by

Oculus

9,522 backers pledged \$2,437,429 to help bring this project to life.

# Oculus Rift DK1

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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

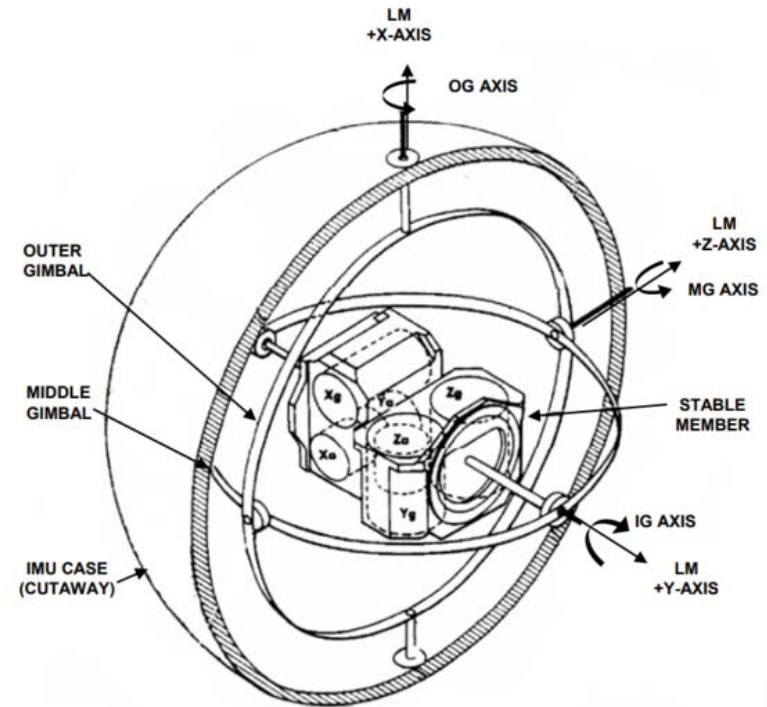
- gravitational force
- angular rate
- magnetic field (optional)

## 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

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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

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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

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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

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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

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# Face Foam

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# Infrared LEDs

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# Separate lens/display assemblies

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# CV1 Lens

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Asymmetric

Hybrid Fresnel lens

Focus varies along vertical axis of lens

→ Push lens higher or lower to focus





# Lenses: DK2 vs. CV1

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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

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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

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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

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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

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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

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Release date: May 21, 2019

LCD display

1280 x 1440 pixels per eye

80 Hz refresh rate

Internal speakers + headphone jack



# Valve Index

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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

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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

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## 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 <small>Not to scale, obviously.</small>									Image <small>Not to scale, obviously.</small>
Horizontal Pixels / eye	1440	1280	1440	1440	1440	1080	2160	1440	Horizontal Pixels / eye
Vertical Pixels	1600	1440	1600	1700	1600	1200	2160	1600	Vertical Pixels
Display Tech	OLED	LCD	LCD	LCD	OLED	OLED	LCD	OLED	Display Tech
Subpixel Type	Pentile Grid	Vertical Linear Grid	Horizontal? Linear Grid	Diagonal Grid	Pentile Grid	Pentile Grid	Vertical Linear Grid	Pentile Grid	Subpixel Type
Panel Count	Dual	Single	Dual, 10° angled	Dual	Dual	Dual	Dual	Dual	Panel Count
Refresh Rate (Hz)	72	80	144/120/90 Adjustable	90	90	90	90	90	Refresh Rate (Hz)
Persistence (ms)	~2	~1	0.33	?	~2	~2	?	?	Persistence (ms)
"Marketed" FOV (°)	110	110	130	110	110	110	114	110	"Marketed" FOV (°)
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...
Calculated Pixels/Deg.	13.09	11.64	11.08	13.09	13.09	9.82	18.95	13.09	Calculated Pixels/Deg.
Lens Diameter (mm)	45	45	50	?	?	?	?	?	Lens Diameter (mm)
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)
Adjustable Depth	No	Yes	Yes	No	Yes	Yes	No	No	Adjustable Depth
Tracking System	Oculus Insight	Oculus Insight	Lighthouse v2	Cosmos Inside Out	Lighthouse v2	Lighthouse v1	WMR Inside Out	WMR Inside Out	Tracking System
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
Subj. Trk. Resolution	Millimeters?	Millimeters?	Sub-millimeter	Millimeters?	Sub-millimeter	~1mm?	Millimeters?	Millimeters?	Subj. Trk. Resolution
Tracking Scale	Room-scale	Room-scale	Room-scale	Room-scale	Room-scale	Room-scale	Room-scale	Room-scale	Tracking Scale
Subj. Trk. Noise/Jitter	Minimal Noise	Minimal Noise	Negligible Noise	Minimal Noise	Negligible Noise	Negligible Noise	Minimal Noise	Minimal Noise	Subj. Trk. Noise/Jitter
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...
Subj. Latency on PC	Apparent, but less than Vive Wireless	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Subj. Latency on PC
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
Wireless/Standalone?	Standalone	No	No	Wireless Addon	Wireless Addon	Wireless Addon	No	No	Wireless/Standalone?
Headset Weight (g)	571	561	809	702	550	468	498	590	Headset Weight (g)
Audio Jack	3.5mm (27)	3.5mm	3.5mm	3.5mm	None	3.5mm	3.5mm	None	Audio Jack
Speaker/Headphone	Spatial Speakers	Spatial Speakers	Index Off-Ear Spatial	On-Ear	On-Ear, Removable	None	On-Ear, Removable	Harmon 3D spatial	Speaker/Headphone
Speaker Subj. Quality	Not very immersive	Not very immersive	Very good	Better than Vive Pro?	Low Bass	?	?	Good	Speaker Subj. Quality
Mic Type	Microphone	Microphone	Microphone	Microphone	Microphone	Microphone	Two Integrated Mics	Microphone	Mic Type
Mic Quality	?	Good	Very good, full depth	Compressed and pops	?	?	?	?	Mic Quality
Controller Type	Oculus Controllers	Oculus Controllers	Index "Knuckles"	Cosmos Controllers	Vive Wand v2	Vive Wand v1	WMR Controllers	WMR Controllers	Controller Type
Weight+battery (g)	129	129	197	212	203	203	171	171	Weight+battery (g)
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
Occlusion Resistance	Occlusion-Resistant	Occlusion-Resistant	Almost Occlusion Free	Significant Occlusion	Almost Occlusion Free	Almost Occlusion Free	Some Occlusion	Some Occlusion	Occlusion Resistance
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
Trigger	Yes	Yes	Yes	Yes, 2 With Bumper	Yes	Yes	Yes	Yes	Trigger
Grip	Button	Button	Capacitive 5-finger	Button	Button	Button	Button	Button	Grip
Mini-Joystick	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Mini-Joystick
Trackpad	No	No	Yes	No	Yes	Yes	Yes	Yes	Trackpad
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://en.wikipedia.org/wiki/Comparison_of_virtual_reality_headsets)

<https://www.youtube.com/watch?v=Gokb7v317Zw>

<https://www.youtube.com/watch?v=kMNx00SaJ0w>

[https://www.youtube.com/watch?v=Ev\\_2VDOEAAY](https://www.youtube.com/watch?v=Ev_2VDOEAAY)

<https://www.youtube.com/watch?v=rEQIBs1IWI>

Color legend

Lesser than average

Average

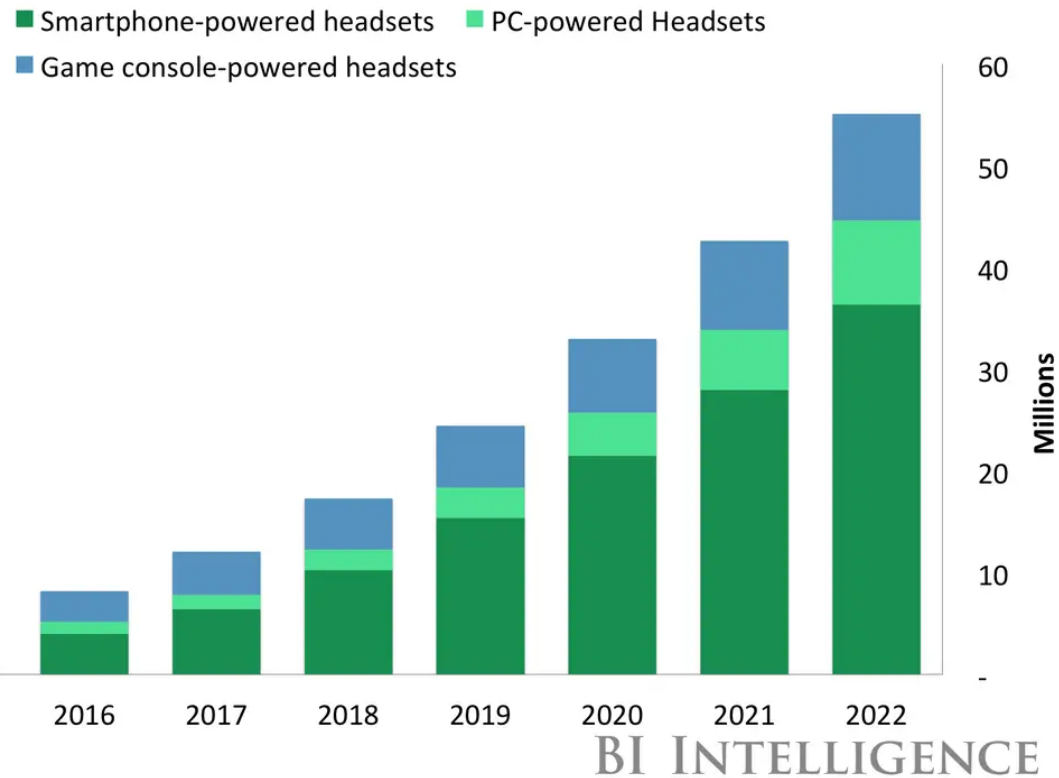
Better than average

Leading/Unique

# HMD Sales Forecast

## FORECAST: Global VR Headset Shipments

*By Category*



Source: BI Intelligence Estimates