On-device motion tracking for immersive mobile VR

Qualcomm Technologies, Inc.
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Taking the lead in XR

Building on our mobile VR/AR innovation and leadership
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XR technologies and use cases evolve from mobile

VR usage primarily comes from console/TV/PC, but it’s also moving towards AR
VR will provide the ultimate level of immersion

Creating physical presence in real or imagined worlds: Intuitive interactions required

Visuals
So vibrant that they are eventually indistinguishable from the real world

Sounds
So accurate that they are true to life

Interactions
So intuitive that they become second nature
Immersive virtual reality has extreme requirements

Achieving full immersion at low power to enable a comfortable, sleek form factor

- **Extreme pixel quantity and quality**
  - Screen is very close to the eyes

- **Spherical view**
  - Look anywhere with a full 360° spherical view

- **Stereoscopic display**
  - Humans see in 3D

- **High resolution audio**
  - Up to human hearing capabilities

- **3D audio**
  - Realistic 3D, positional, surround audio that is accurate to the real world

- **Minimal latency**
  - Minimized system latency to remove perceptible lag

- **Precise motion tracking**
  - Accurate on-device motion tracking

- **Natural user interfaces**
  - Seamlessly interact with VR using natural movements, free from wires
3-DoF vs. 6-DoF

3 degrees of freedom (3-DoF)

- “In which direction am I looking”
- Detect rotational head movement
- Look around the virtual world from a fixed point

6 degrees of freedom (6-DoF)

- “Where am I and in which direction am I looking”
- Detect rotational movement and translational movement
- Move in the virtual world like you move in the real world
6-DoF allows developers to bring the user into their story

3 degrees of freedom (3-DoF)
- Can only watch

6 degrees of freedom (6-DoF)
- Full immersion
- Can become part of the story
- Can now interact and change the story
6-DoF motion tracking evolution

2014

Outside-in
External sensors, markers, cameras, or lasers to be set up throughout the room.

Monocular fisheye camera
Inside-out solution requiring no room setup

Today’s discussion

Stereo fisheye camera
More accurate motion tracking for immersive interactions

Room-scale VR
Object detection, boundary augmentation, and safety

2017

Future

World VR
Limitless movement and robust safety
Conventional 6-DoF: “Outside-in” tracking

External sensors determine the user’s position and orientation
Mobile 6-DoF: “Inside-out” tracking
Visual inertial odometry (VIO) for rapid and accurate 6-DoF pose
Mobile 6-DoF: “Inside-out” tracking

Visual inertial odometry (VIO) for rapid and accurate 6-DoF pose

Mono or stereo camera data
Captured from tracking camera image sensor at ~30 fps

Accelerometer & gyroscope data
Sampled from external sensors at 800 / 1000 Hz

“VIO” subsystem on Qualcomm® Snapdragon™ Mobile Platform

- Camera feature processing
- Inertial data processing
- Qualcomm® Hexagon™ DSP algorithms
  - Camera and inertial sensor data fusion
  - Continuous localization
  - Accurate, high-rate “pose” generation & prediction

6-DoF position & orientation
(aka “6-DoF pose”)

Qualcomm Hexagon is a product of Qualcomm Technologies, Inc.
Minimizing motion to photon (MTP) latency is crucial.

~15-16 ms MTP latency on Snapdragon 835 Mobile Platform shows our mobile VR leadership.
Low latency mobile 6-DoF inside-out tracking

Many workloads must run efficiently for an immersive VR experience

Motion detection
- Sensor sampling
- Sensor fusion

Visual processing
- View generation
- Render / decode

Display
- Image correction
- Quality enhancement and display

Total time (motion to photon latency) for all steps above must be less than 20 milliseconds
Stereo VIO for rapid, robust and accurate 6-DoF pose
Sensor fusion of stereo camera features and high rate IMU data

Benefits of stereo over monocular 6-DoF
- Instant accurate scene depth
- Faster initialization
- Better performance with quick and rotational motions
- Improved tolerance to camera occlusion

Stereo wide-angle lenses
6-DoF key performance indicators (KPI)

KPI definitions
- Jitter: Defines the frame to frame changes in VIO pose when stationary.
- Absolute error: Defines the total instantaneous error in translation and rotation in VIO pose for the video sequence.
- Relative error: Defines frame to frame rotation and translation error in VIO pose.

KPIs are captured for:
- Different environments (seated, standing)
- Lighting (low: 5-35 lux, high: 180-350 lux)
- Features (low, high)
- Head motions (slow, fast)
Developing 6-DoF content

Some key things to consider

Scale and space
- Issue: Untethered mobile allows for limitless movement, but available space could change between runs of app
- **DO** consider limits to amount of full body movement
- **DO** provide movement alternatives

Tracking
- Issue: Device cameras can become occluded or environment can be too dark
- **DO** fade to black or fixed image in event of lost head tracking to avoid nauseating jumps and judder
- **DON'T** fall back to tracking only orientation (3-DoF). Jumps in position or seeing virtual world respond differently to movement can be uncomfortable for users

Storytelling
- Issue: Users may not be looking or positioned in desired location to advance story
- **DO** use audio and visual cues to guide user focus
- **DON'T** take over control of virtual camera in order to force focus on story element
We are accelerating the adoption of XR

Designed to make it easy to create premium mobile VR and AR experiences

Snapdragon Mobile VR Platform
Purpose built silicon for superior Mobile VR & AR

Snapdragon VR SDK
Access to advanced features to optimize applications and simplify development

Snapdragon Mobile VR HMD
Reference design to build and optimize applications

HMD Accelerator Program
Accelerating the development of standalone head-mounted displays

LTE/5G
5G will be required to take XR experiences to the next level

Ecosystem Collaboration
Advancing XR content development and technology advancements
Commercialize VR HMDs quickly with few resource constraints

HMD Accelerator Program

**Commercialization**
Allow OEMs to quickly design and manufacture standalone VR HMDs

**High quality**
Provide means for OEMs to track performance, monitor KPIs and promote them

**Scale & harmonization**
Standardizes a platform for the whole value chain to build on top and garner critical scale for VR to flourish
Snapdragon 835 VR Development Kit

Advanced VR features designed to optimize applications and simplify development

**System on Chip (SoC)**
Snapdragon 835 mobile platform

**Display**
AMOLED WQHD
~2MPix per eye

**Memory**
DRAM: 4GB LPDDR4
Flash: 64GB UFS

**Connectivity**
Wireless: Wi-Fi, Bluetooth
Other: USB3.1 type C (power)

**Audio**
Integrated WCD9335 CODEC

**I/O**
3-DoF controller support

**Cameras & Other Sensors**
Six degrees of freedom (6-DoF) motion tracking:
- Two monochromatic, one mega pixel (1280x800) global shutter cameras & fisheye lens
- Inertial measurement unit with fast interface to Snapdragon 835 integrated sensor core

**Eye Tracking:**
- Two monochromatic VGA global shutter cameras

**Six degrees of freedom (6-DoF) motion tracking:**
- Two monochromatic, one mega pixel (1280x800) global shutter cameras & fisheye lens
- Inertial measurement unit with fast interface to Snapdragon 835 integrated sensor core
Snapdragon VR SDK
Access to advanced VR features to optimize applications and simplify development

- **DSP sensor fusion**
  Access to the latest and predictive head pose

- **Stereoscopic rendering**
  Generate left and right eye view

- **Asynchronous time warp**
  Warp image based on the latest head pose just prior to scan out

- **Chromatic aberration correction**
  Correct color distortion based on lens characteristics

- **Lens distortion correction**
  Barrel warp image based on lens characteristics

- **Single buffer rendering**
  Render directly to the display buffer for immediate display scan out

- **VR layering**
  Generate UI menus and text so that they render correctly in a virtual world

- **Power & thermal management**
  Qualcomm® Symphony System Manager provides CPU, GPU, and DSP power, thermal, and performance management

- **APIs optimized for VR**

**Benefits**

- Simplified development
- Optimized VR performance
- Power and thermal efficiency
Actively working with XR device manufacturers

XR products based on Snapdragon Mobile VR Platform

VR HMD
- Baofeng Matrix
- Coocaa Wondergate G1
- iQiyi Adventure
- ASUS Zenfone AR
- Google Pixel
- Google Pixel XL
- Lenovo Phab 2 Pro
- Pico Neo
- WhaleyVR
- ODG R8/R9
- ZTE Axon
- Moto Z
- Samsung Galaxy S8
- Samsung Galaxy S8 Edge

20+ Devices launched

20+ Devices in development
Snapdragon Mobile VR Development Kit

- Snapdragon VR SDK
- Snapdragon VR HMD

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