# Visual-inertial tracking for Monado

## Leveraging research systems for XR tracking

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# Hello!

**I'm Mateo de Mayo**

- Started with Collabora in the XR team on July 2021.

- Six month Internship on visual-inertial tracking for Monado.

- Also the thesis for my computer science degree (@FaMAF UNC).

- You can find me online as @mateosss or @mateodemayo.

- Links: Blog, FDO GitLab, GitHub, YouTube, Twitter, Discord.

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# Context for VI tracking

**What do I mean with visual-inertial tracking?**

- Tracking: knowing the **pose** of some real world entity.

- Focus on tracking the viewer, specifically a VR headset.

- External sensors were mainstream (e.g., Constellation, Lighthouse)

- Now "inside-out" tracking is the norm.

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# Sensors and terminology

- **Cameras**: high latency, low frequency, exteroceptive measurements (cf. visual system).

- **IMU**: low latency, high frequency, proprioceptive measurements (cf. vestibular system).

- **Sensor fusion:** Kalman filters vs non-linear optimization. Read *"Why filter?"*.

- **Terminology:** SLAM, VI-SLAM, VIO, SfM.

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# Internship project

- **Previous trackers in Monado:** PSVR, PSMV, 3DoF, T265, Lighthouse.

- But no inside-out tracking component to support all of the newer headsets.

- **"Simple" plan:** Leverage this active research field.

- Easier said than done: too many, biased papers, brittle systems.

- Research software can be problematic.

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# Things to look for in a VI system

1) Sensor setup versatility.
2) Permissive license.
3) Active maintainers.
4) Software quality.
5) Performance.
6) Tracking quality.

- **Integrated systems:** Kimera-VIO, ORB-SLAM3 and Basalt
- **Honorable mentions:** HybVIO, OpenVINS, DM-VIO, OKVIS2, SVO Pro
- See the xrtslam-docs repository.

# Basalt - The "clear" winner

- Some preliminary comparisson metrics can be found in this blogpost.
- Note: be careful when reading metrics for SLAM systems.

**The good**
- Significantly faster times.
- The trajectory feels smoother than ORB-SLAM3 (see this blogpost).
- Vladyslav Usenko and Nikolaus Demmel were super helpful and responseful.
- Few external dependencies.

**The bad**
- Few external dependencies.
- It is not a full (realtime) SLAM pipeline; i.e., it drifts over time (see #69).
- It had (and still has some) problems with non overlapping cameras (see #62).
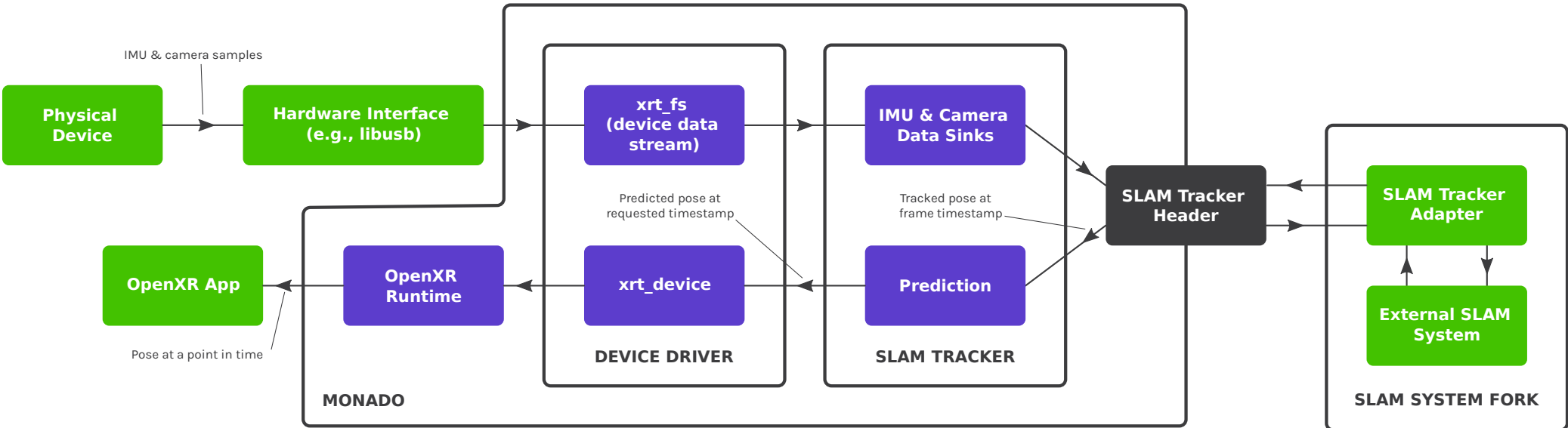- Only stereo-imu setup supported natively (see #88 and #25).

# Basalt pipeline

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# Dataflow



**Physical Device** → **Hardware Interface (e.g., libusb)**

IMU & camera samples

**xrt_fs (device data stream)** → **IMU & Camera Data Sinks**

Predicted pose at requested timestamp

Tracked pose at frame timestamp

**xrt_device** — **Prediction**

**DEVICE DRIVER**

**SLAM TRACKER**

**SLAM Tracker Header**

**SLAM Tracker Adapter**

**External SLAM System**

**SLAM SYSTEM FORK**

**OpenXR App** ← **OpenXR Runtime**

Pose at a point in time

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# Interface: `slam_tracker.hpp`

```cpp
1  class slam_tracker {
2  public:
3    // (1) Constructor and start/stop methods
4    slam_tracker(string config_file);
5    void start();
6    void stop();
7
8    // (2) Main interface methods
9    void push_imu_sample(timestamp t, vec3 accelerometer, vec3 gyroscope);
10   void push_frame(timestamp t, cv::Mat frame, bool is_left);
11   bool try_dequeue_pose(timestamp &t, vec3 &position, quat &rotation);
12
13   // (3) Optional dynamic features
14   bool supports_feature(int feature_id);
15   void* use_feature(int feature_id, void* params);
16
17 private:
18   // (4) Pointer to implementation
19   void* impl;
20 }
```

- Many projects have switchable SLAM systems: ILLIXR, SLAMBench, GSLAM.
- A standard would be good.
- But It's probably to soon to standardize. This interface already has issues.

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# Drivers that support it

- RealSense (D455).

- WMR (Odyssey+).

- Rift S (Thanks to @thaytan).

- Vive (Valve Index).

- DepthAI (North Star).

- EuRoC.

# Show time

# Videos

- RealSense D455 - Monado with Basalt
- Samsung Odyssey+ - Monado with Basalt
- Samsung Odyssey+ - Monado with Basalt and HT
- Valve Index - Monado with Basalt

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# Consideration for new devices

- Use the EuRoC recorder/player first.
- Calibration data (converting from factory or recalibrate).
- Shutter type: global vs rolling
- Exposure and gain adjustment (`aeg` module)
- Camera and IMU frequencies.
- Unified IMU measurements.
- Hardware clock sync: cam-to-cam, cam-to-imu
- Hardware to host clock sync (hw2mono).
- Coordinate spaces (IMU input, SLAM output, calibration data).
- IMU-to-eyes transform.

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# Contributions

- Pinhole radial-tangential 8 camera model for WMR (link).

  - Weird camera model from WMR almost identical to OpenCV's

  - Problem: Model is not injective, metric_radius field provided from factory

  - While the MR was open, people from Kitware released this paper addressing the issue for a simpler model.

- Average depth guess for stereo matching (link).

  - Basalt uses optical flow for stereo matching.

  - Initial guess was the same pixel, so non-overlapping cameras couldn't work.

  - Improves feature count although some issues are present on EuRoC.

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# Conclusions and future work

- These are among the first headsets working on a totally open source software stack.

- A lot of work remains to get closer to commercial solutions.

- Fix rough edges. Documentation, crashes, etc.

- Keep improving Basalt.

- While sporadically integrating new systems that look good.

- Tools for metrics are in place (xrtslam-metrics using evo).

- We need metrics designed for XR.

- Custom XR datasets with lighthouses; plan to publish for the community.

- Midterm future: Handle dynamic objects, synthetic datasets, joint HT optimizer, online calibration.

- The infrastructure plumbing is now there to keep iterating on.

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# Thank you!

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