# AV-SLAM: Autonomous Vehicle Simultaneous Localization and Mapping with Gravity Direction Initialization

# About Us

**Kaan Yilmaz**
kaan.yilmaz@volvocars.com
Chalmers University of Technology
Master program: Complex Adaptive Systems

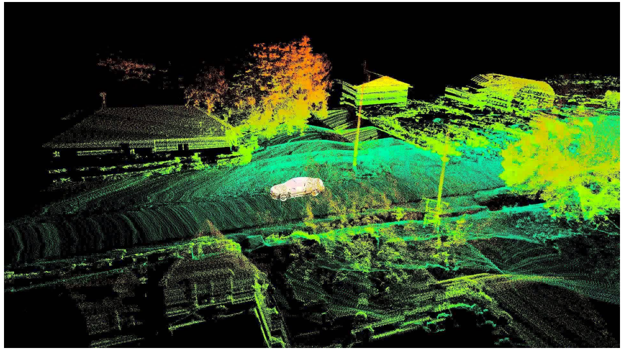
**Baris Suslu**
baris.suslu@volvocars.com
Chalmers University of Technology
Master program: System, Control and Mechatronics

**Sohini Roychowdhury**
Volvo Cars Technology USA, Mountain View

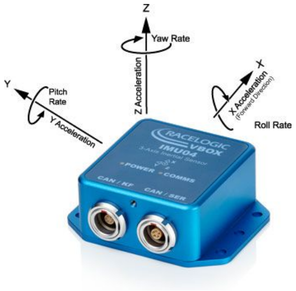
**L. Srikar Muppirisetty**
srikar.muppirisetty@volvocars.com
Volvo Car Corporation, SE-405 31 Göteborg, Sweden

# What is SLAM ?

- Create a map of the environment using sensors
- Localize the vehicle within the map

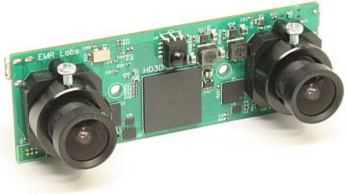


Inertial Measurement Unit (IMU)




Camera

Stereo Camera / RGB-D Camera




Lidar

# Challenges about SLAM

- **IMU initialization**

  If **IMU** is being used, then:

  - **Robust IMU initialization** for autonomous vehicle scenarios is essential.
  - Available methods have been tested only on UAV scenarios.

**>>> A gravity direction initialization method is proposed**

- **Sensor-failure**
  - The accuracy of sensors **can degrade** due to hardware wear.
  - Sensors may **stop working completely** because of environmental conditions.

**>>> Multiple localization algorithms are proposed to form a single SLAM which have fail-safe modes**

**MAIN PURPOSE:** Developing a **fail-safe** SLAM algorithm with accurate **gravity direction initialization**

# Proposed SLAM (AV-SLAM)

- Based on Mono-Camera, LIDAR and IMU
- Has 3 sensor setup modes (fail-safe):
    - IMU-Only Localization
    - Camera+LIDAR (RGBD-SLAM)
    - IMU+Camera+LIDAR (VI-SLAM)
- VI-SLAM features a gravity direction initialization algorithm (AGI)

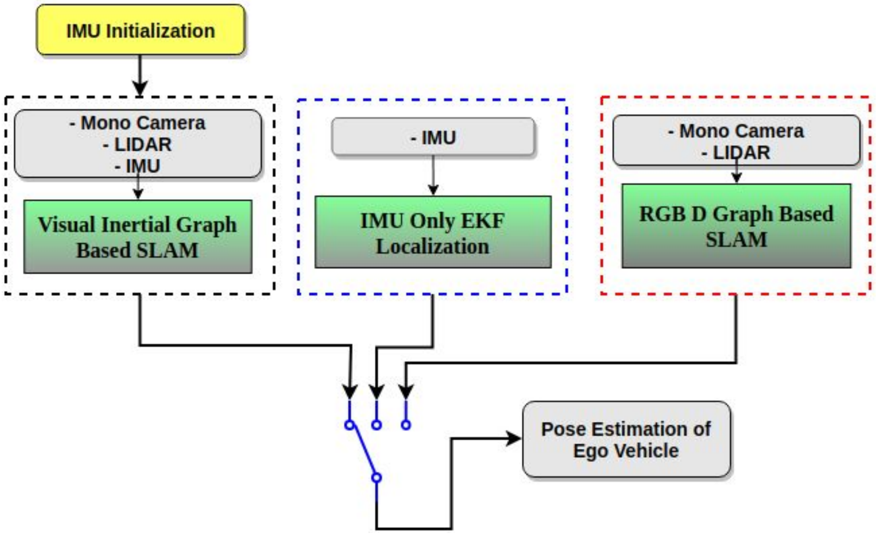



Figure 1: Overall architecture of AV-SLAM

# IMU-Only Localization

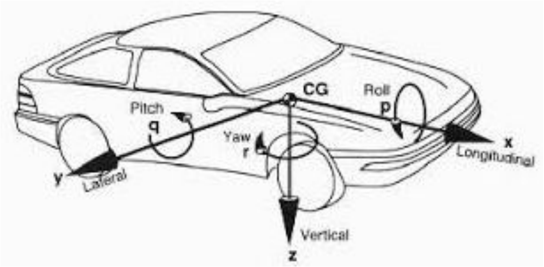
## Pseudo-Measurement Concept

**Extended Kalman Filter** consists of two steps;

- Prediction step
- Update step

In order to proceed the **update step**, **measurement** is needed.

It is assumed that while a car is travelling, its **lateral** and **upward** velocities are ‘zero’.




$$\boldsymbol{z} = \left[ {}^{\mathrm{IMU}}\mathbf{v}_t^{lat} ; {}^{\mathrm{IMU}}\mathbf{v}_t^{up} \right] = 0$$

Figure 2: Roll, pitch and yaw directions

# RGBD-SLAM

- Graph-SLAM that involves **Mono-Camera + LIDAR.**
- Scales of visual keypoints are estimated from LIDAR-interpolated depth image
- Create new 3D map points with unmatched ORB features
- Manage keyframes

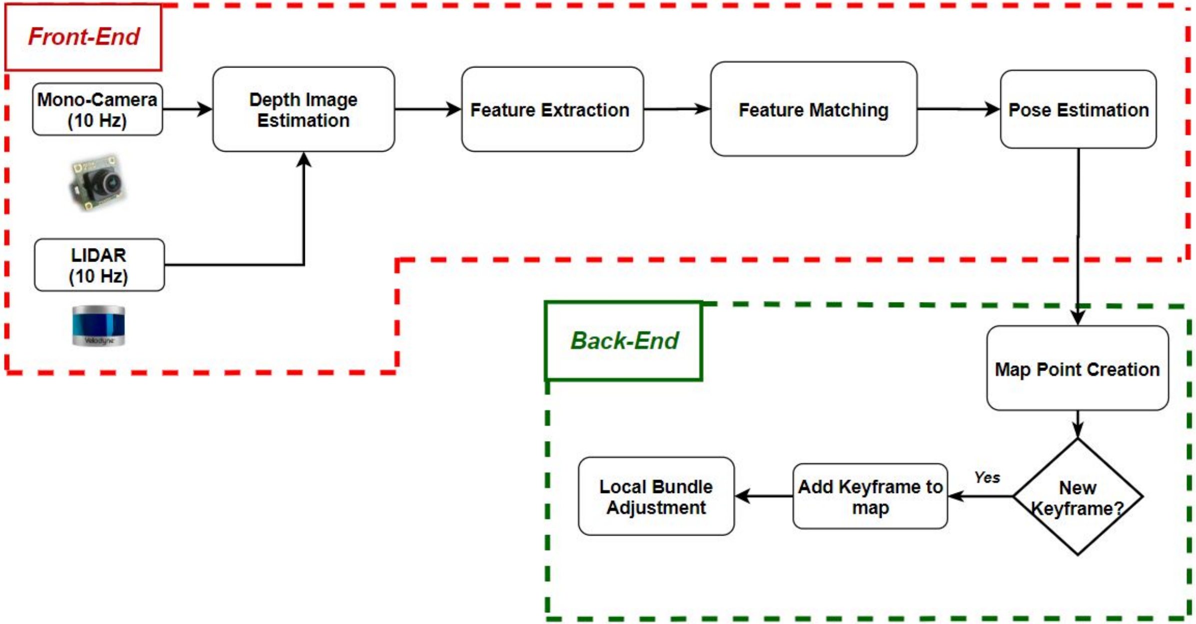



Figure 3: High-level architecture of RGBD-SLAM

# Visual-Inertial SLAM (VI-SLAM)

- Involves fusing RGBD-SLAM with IMU measurements
- Features a gravity direction initialization method

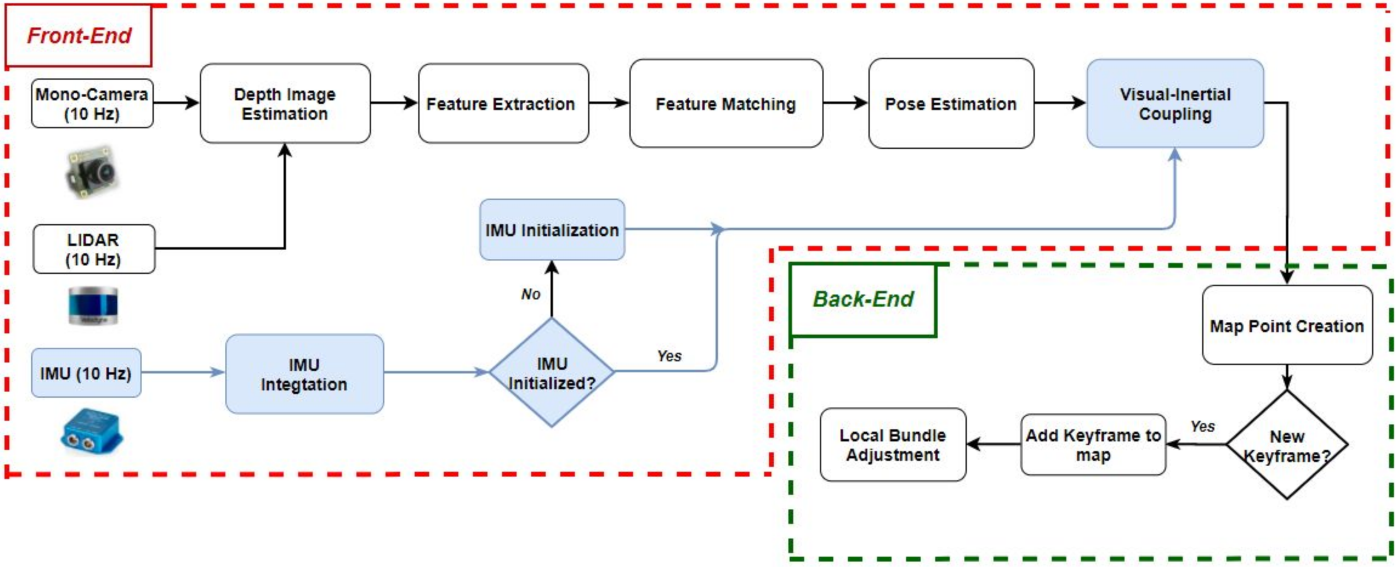



Figure 4: High-level architecture of VI-SLAM

# **VI-SLAM:** Fusing Visual and Inertial Pose Estimations

- Visual and IMU pose estimation are loosely coupled
- Equally weighting between Visual and IMU estimations

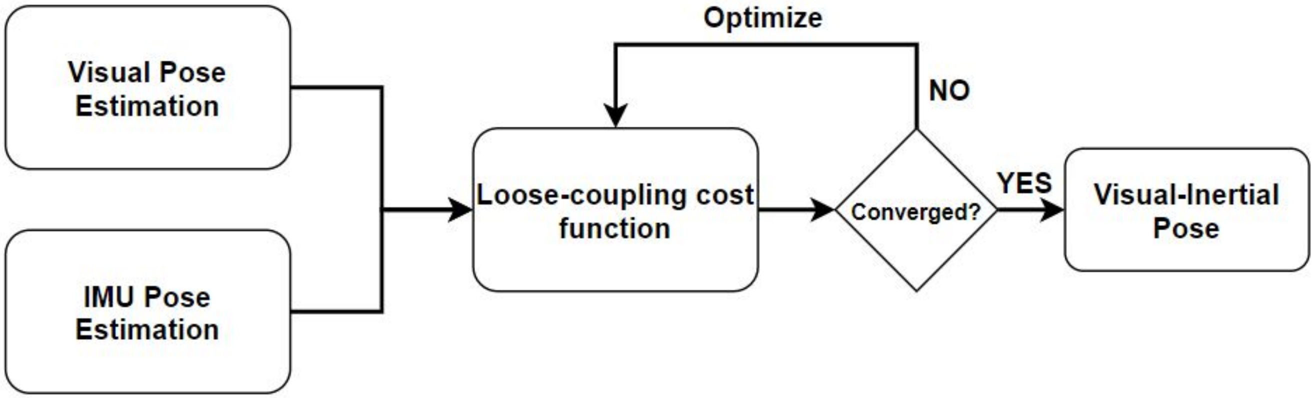



Figure 5: Coupling mechanism of VI-SLAM

# **VI-SLAM:** Proposed Gravity Direction Initialization (AGI)

1. Calculate roll and pitch angles using the estimated gravitational accelerations at each timestep.
2. The moving average of roll and pitch angles are calculated.

**Gravity direction** ← Converged values of roll and pitch angles

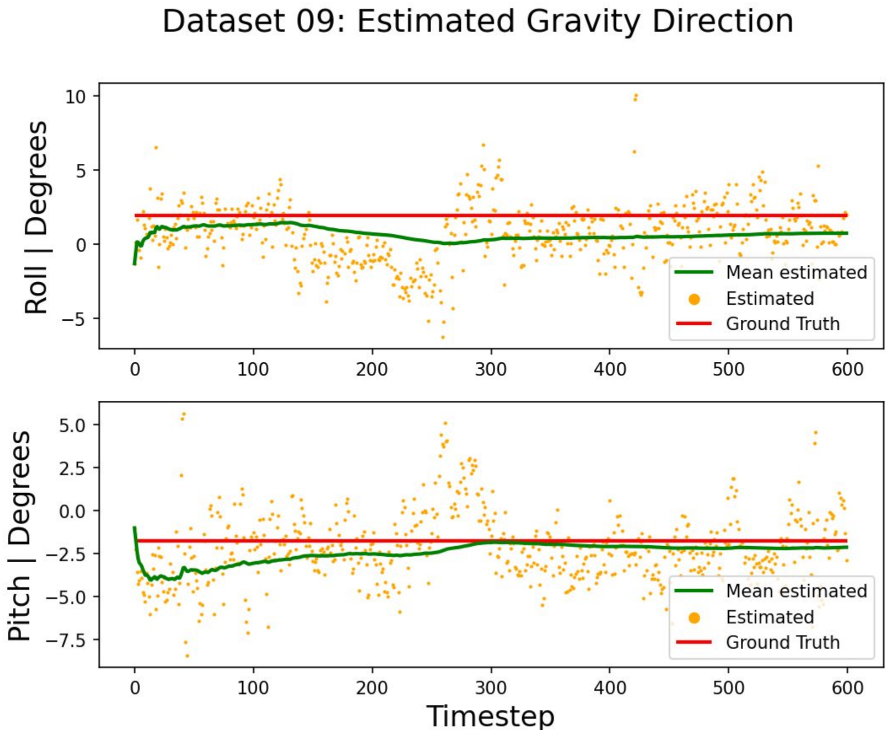



Figure 8: Convergence plot of gravity direction initialization

# Results: Translational RPE Comparison

Table 1: Percentage Translational RPE of proposed and state-of-the-art SLAM algorithms on KITTI sequences

| Seq No | % $RPE_{trans}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | IMU-Only (Proposed) | RGBD-SLAM (Proposed) | VI-SLAM (Proposed) | LOAM | ORB-SLAM2 | Cube-SLAM | PL-SLAM |
| 00 | 362 | 1.62 | 2.03 | 0.78 | **0.7** | 1.97 | 2.38 |
| 01 | 14.0 | 31.1 | 32.1 | 1.43 | **1.39** | - | 3.23 |
| 02 | 91.5 | 1.25 | 1.19 | 0.92 | **0.76** | 2.48 | 2.2 |
| 04 | 2.23 | 0.9 | 1.16 | 0.71 | **0.55** | 1.12 | 1.57 |
| 05 | 24.2 | 1.53 | 1.31 | 0.57 | **0.37** | 1.64 | 1.67 |
| 06 | 6.65 | 1.69 | 1.36 | 0.65 | **0.43** | 2.26 | 2.02 |
| 07 | 3.95 | 2.01 | 1.21 | 0.63 | **0.45** | 1.63 | 1.57 |
| 08 | 22.7 | 1.78 | 1.3 | 1.12 | **1.06** | 2.05 | 2.42 |
| 09 | 11.1 | 1.05 | **0.65** | 0.77 | 0.83 | 1.66 | 1.49 |
| 10 | 11.9 | 1.04 | 0.75 | 0.79 | **0.55** | 1.46 | 1.61 |

# Results: Gravity Direction Initialization

- Abs. error <1 degree in datasets 02, 07, 08, 09 and 10
- Low std deviation across multiple runs
- Sampling: 10Hz
- Compared with VINS-Mono's method and a baseline method (Roll and pitch are initialized to 0 deg)

Table 2: Absolute error of gravity direction initialization methods

| Seq No | Roll - Abs Error (deg) | | | Pitch - Abs Error (deg) | | |
|---|---|---|---|---|---|---|
| | Baseline | AGI (Proposed) | VINS-Mono | Baseline | AGI (Proposed) | VINS-Mono |
| 00 | 2.41 | $0.8 \pm 0.03$ | $\mathbf{0.57 \pm 0.1}$ | 1.27 | $2.38 \pm 0.05$ | $\mathbf{1.06} \pm 0.02$ |
| 01 | **0.73** | $1.07 \pm 0.95$ | $9.6 \pm 0.06$ | **3.01** | $6.78 \pm 0.45$ | $4.44 \pm 0.03$ |
| 02 | 0.9 | $0.68 \pm 0.01$ | $\mathbf{0.19 \pm 0.01}$ | 0.23 | $0.34 \pm 0.05$ | $\mathbf{0.19} \pm 0.08$ |
| 04 | **2.44** | $3.22 \pm 0.06$ | - | **0.66** | $1.3 \pm 0.08$ | - |
| 05 | **1.87** | $3.85 \pm 0.01$ | - | 1.22 | $\mathbf{0.09 \pm 0.02}$ | - |
| 06 | **2.65** | $5.3 \pm 0.01$ | $5.42 \pm 0.02$ | **0.55** | $1.38 \pm 0.22$ | $0.93 \pm 0.01$ |
| 07 | 1.29 | $\mathbf{0.38 \pm 0.06}$ | $3.35 \pm 0.2$ | **0.64** | $0.93 \pm 0.06$ | $0.73 \pm 0.01$ |
| 08 | 2.95 | $\mathbf{0.49 \pm 0.14}$ | $8.52 \pm 0.3$ | 1.37 | $\mathbf{0.52 \pm 0.04}$ | $1.5 \pm 0.02$ |
| 09 | 1.92 | $1.46 \pm 0.05$ | $\mathbf{0.94 \pm 0.05}$ | 1.76 | $\mathbf{0.1 \pm 0.01}$ | $1.83 \pm 0.01$ |
| 10 | 1.4 | $\mathbf{0.82 \pm 0.03}$ | - | 3.22 | $\mathbf{0.33 \pm 0.05}$ | - |

Table 3: Timesteps required to initialize gravity direction

| Seq No | #Timesteps to Initialization | |
|---|---|---|
| | AGI (Proposed) | VINS-Mono |
| 00 | $\mathbf{169 \pm 48}$ | $741 \pm 2$ |
| 01 | $599 \pm 62$ | $\mathbf{170 \pm 3}$ |
| 02 | $\mathbf{343 \pm 2}$ | $\mathbf{186 \pm 60}$ |
| 04 | $\mathbf{243 \pm 38}$ | - |
| 05 | $\mathbf{279 \pm 28}$ | - |
| 06 | $202 \pm 29$ | $\mathbf{78 \pm 8}$ |
| 07 | $211 \pm 22$ | $\mathbf{125 \pm 2}$ |
| 08 | $174 \pm 23$ | $\mathbf{154 \pm 4}$ |
| 09 | $325 \pm 0$ | $\mathbf{177 \pm 1}$ |
| 10 | $\mathbf{211 \pm 0}$ | - |

# Conclusion

**We developed:**

- A SLAM algorithm comprising of 3 localization algorithms
- Ability to work when IMU fails or when Camera and LIDAR fail
- A gravity direction initialization method and tested it on raw KITTI datasets

1. AV-SLAM ensures relative translation error of <**2.03%** for low to medium speed ego-vehicle scenarios (speed <**38km/h**) when all sensors are available
2. The proposed SLAM framework with AGI method without loop closure modules outperforms state-of-the-art methods with loop closure modules on some datasets.
3. The proposed VI-SLAM with AGI algorithm provides fast, accurate and repeatable initialization on some datasets.

# QUESTIONS & ANSWERS