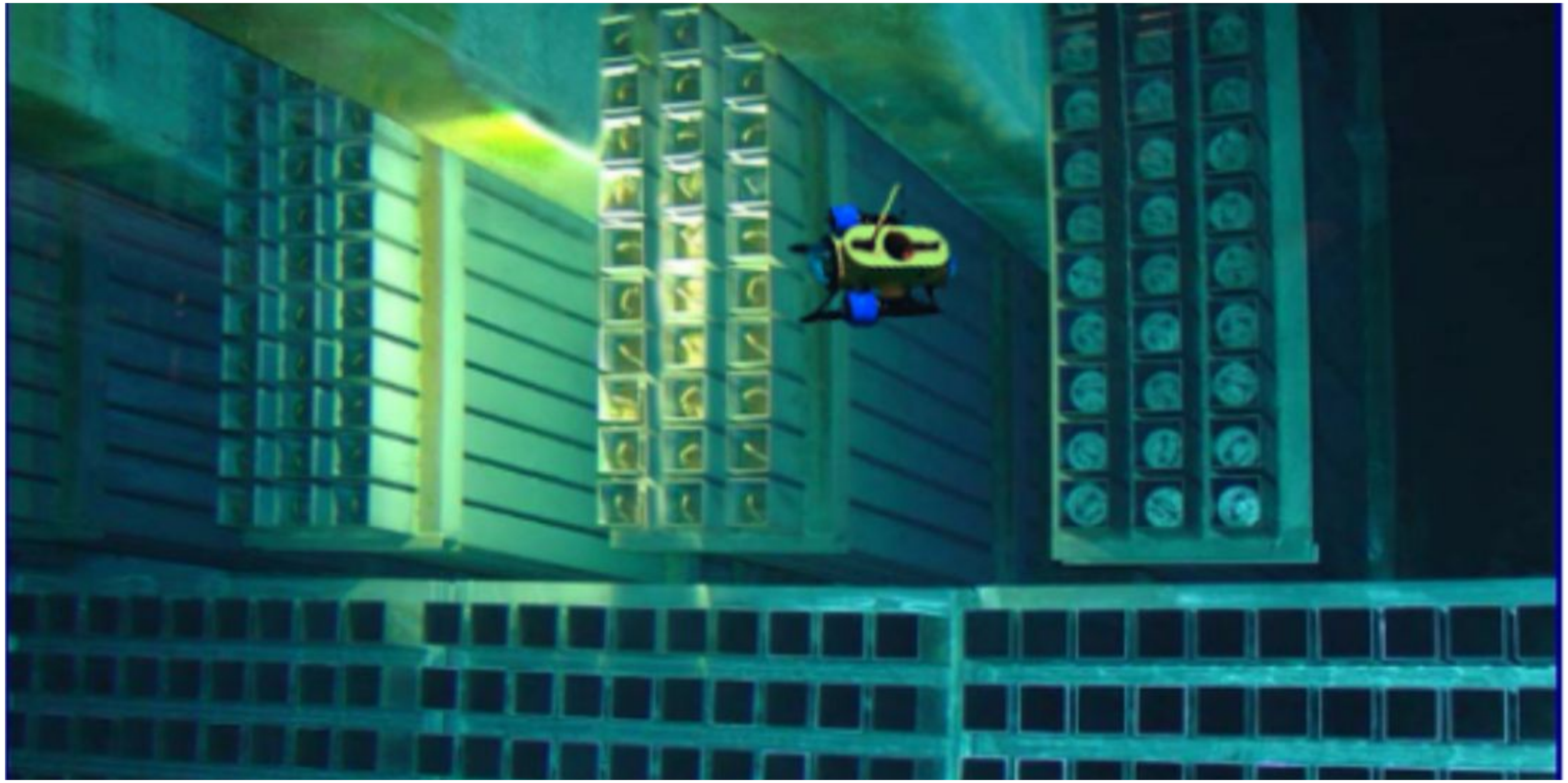
Localized Imaging and Mapping for Underwater Fuel Storage Basins



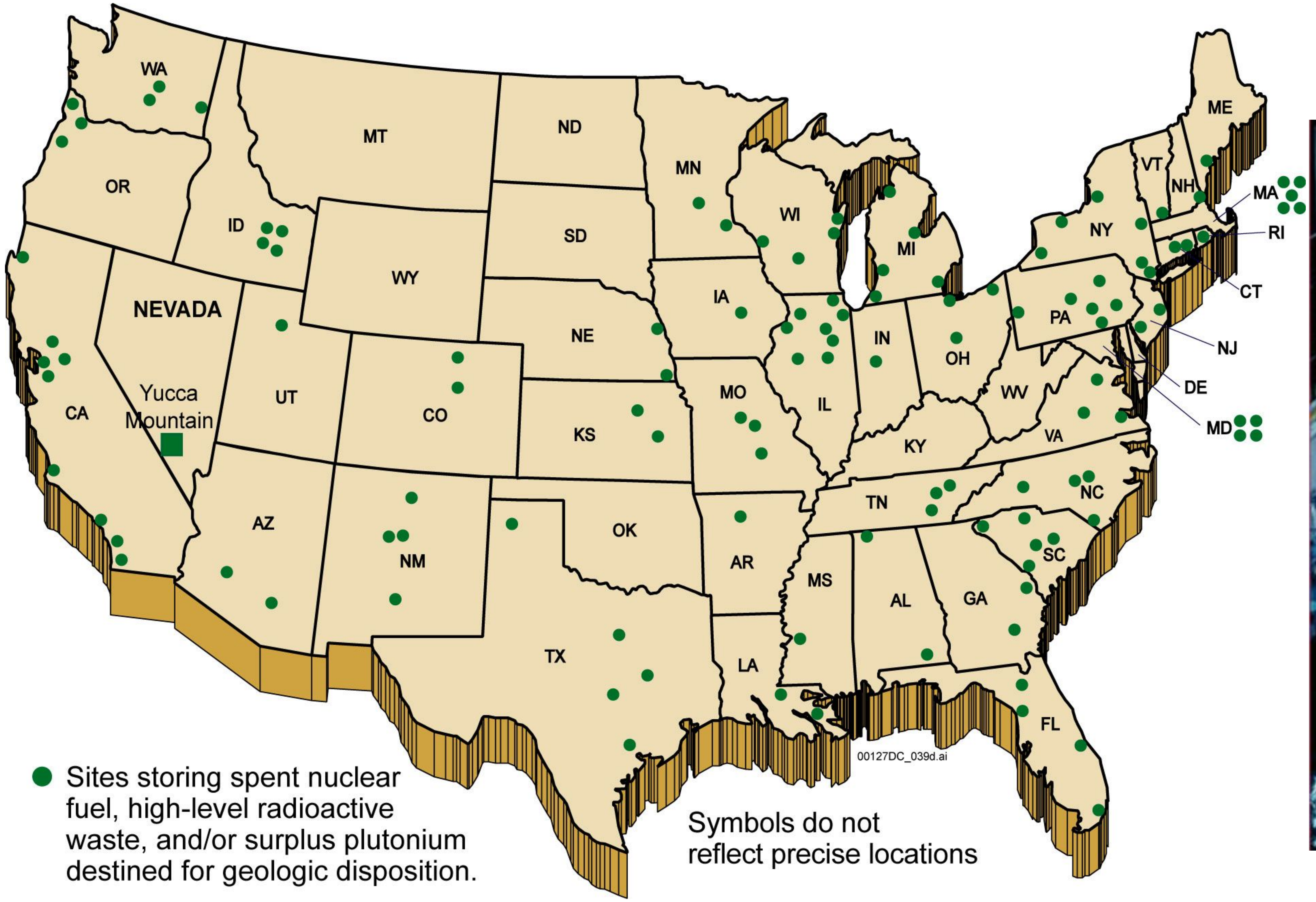
Jerry Hsiung, Andrew Tallaksen, Lawrence Papincak, Sudharshan Suresh, Heather Jones,
William Whittaker, Michael Kaess

THE ROBOTICS INSTITUTE

Carnegie Mellon University

March 22, 2018

Spent Nuclear Fuel (SNF) Storage



Current SNF storage sites

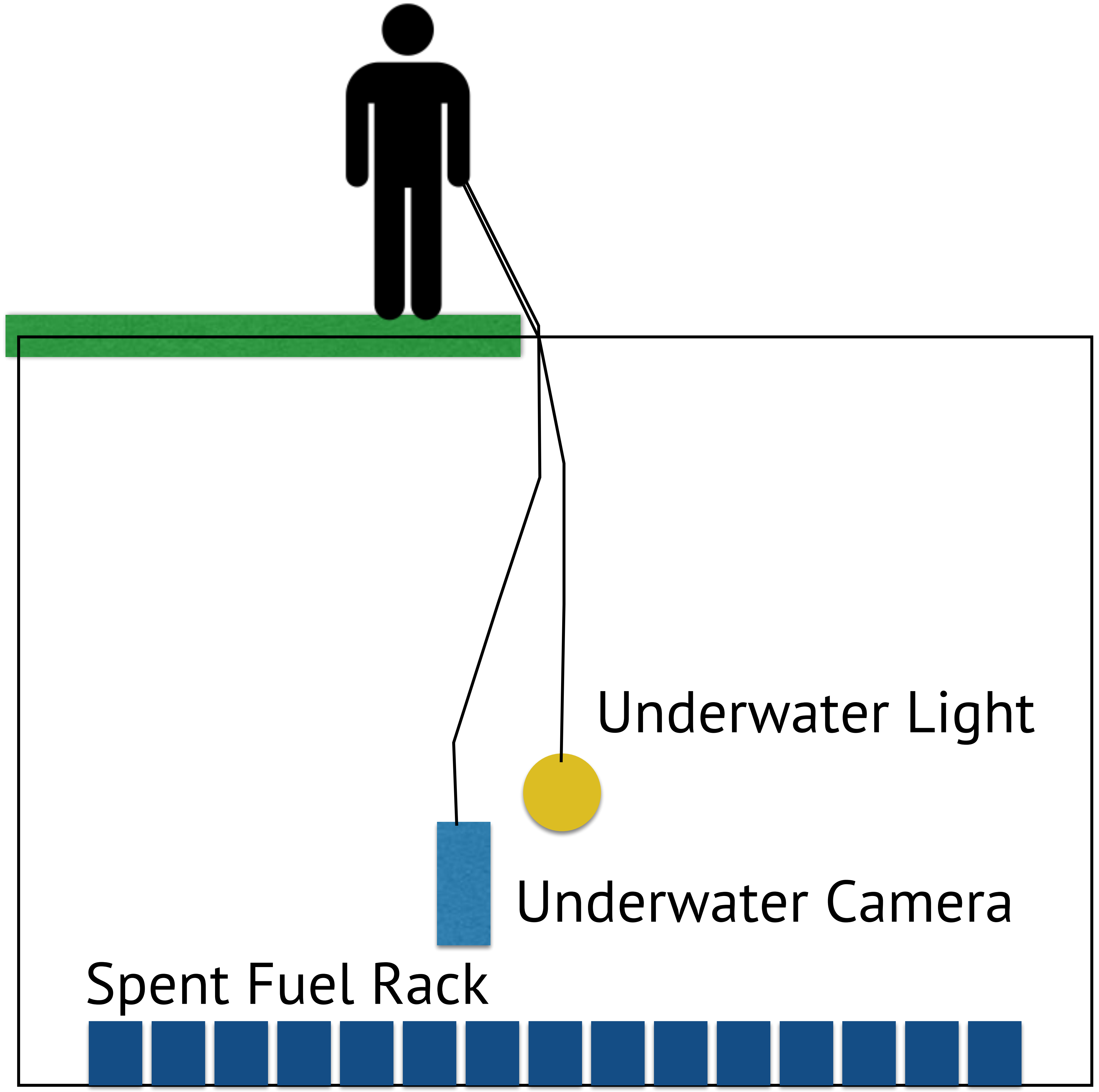
SNF is stored in water pool to shield its radioactive properties

Source: United States Department of Energy

Human Inspection is infeasible

Source: TWI Ltd.

Current SNF Inspection Methods



Source: Unit 4 Spent Fuel Pool Inspection 2012, Fukushima Daiichi

Existing Inspection Examples


Storage Conditions of Reactive Metal Fuel in L-Basin
at the Savannah River Site

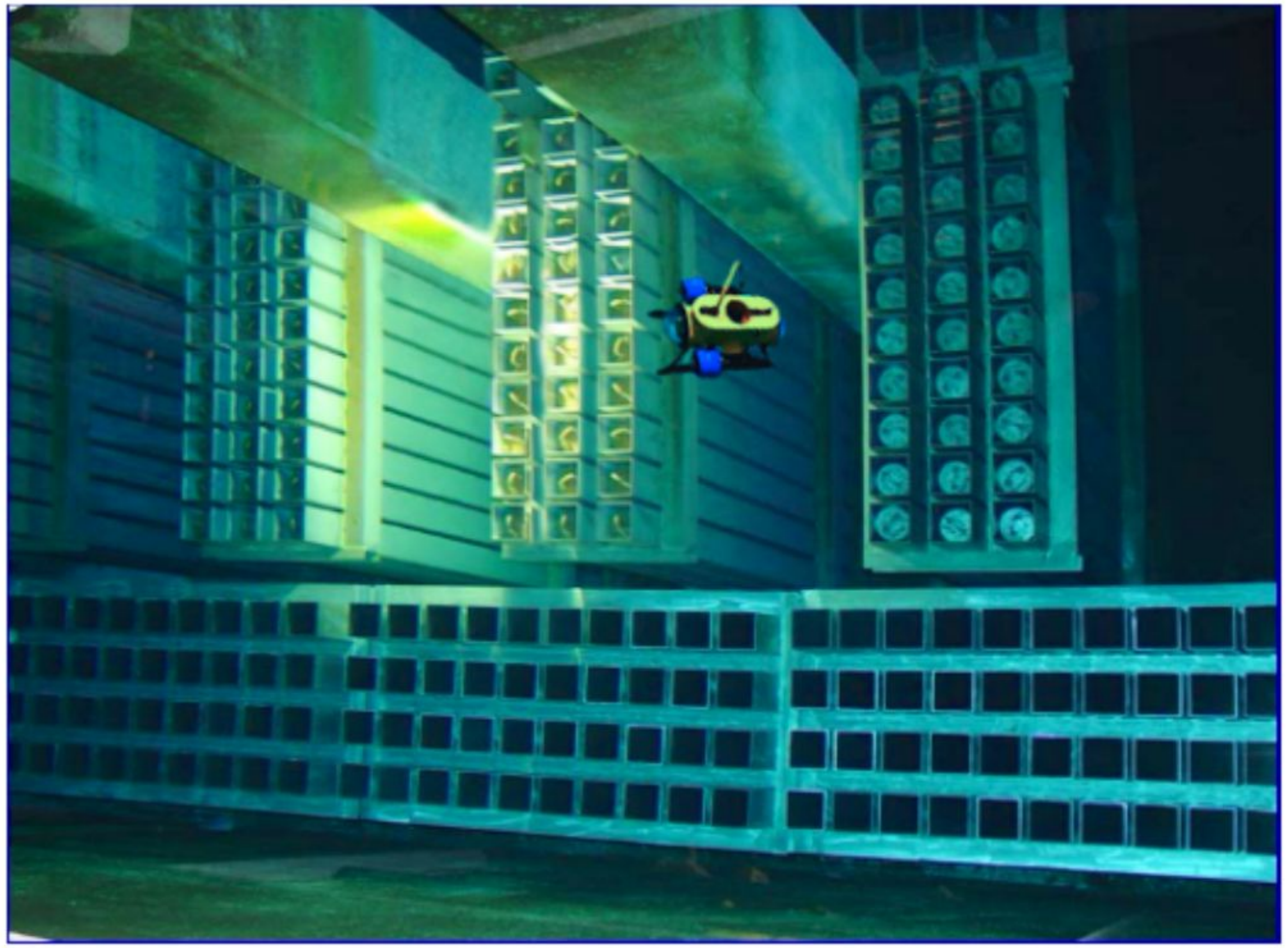
Defense Nuclear Facilities Safety Board
Technical Report

January 2013

Savannah Rivers Site’s ageing cracked SNF containers

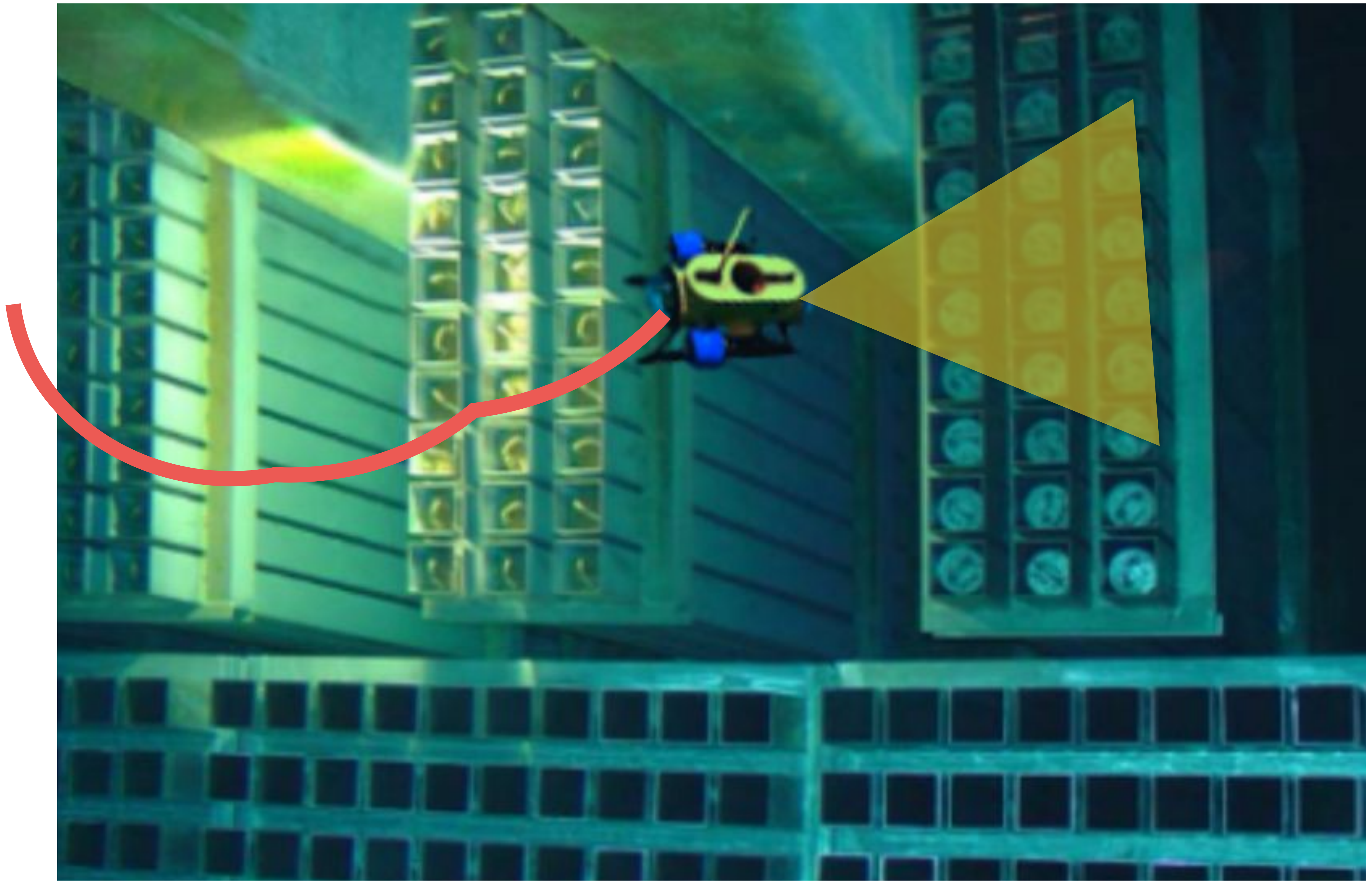
Source: Defence Nuclear Facilities Safety Board

Remotely Operated Sensor Package

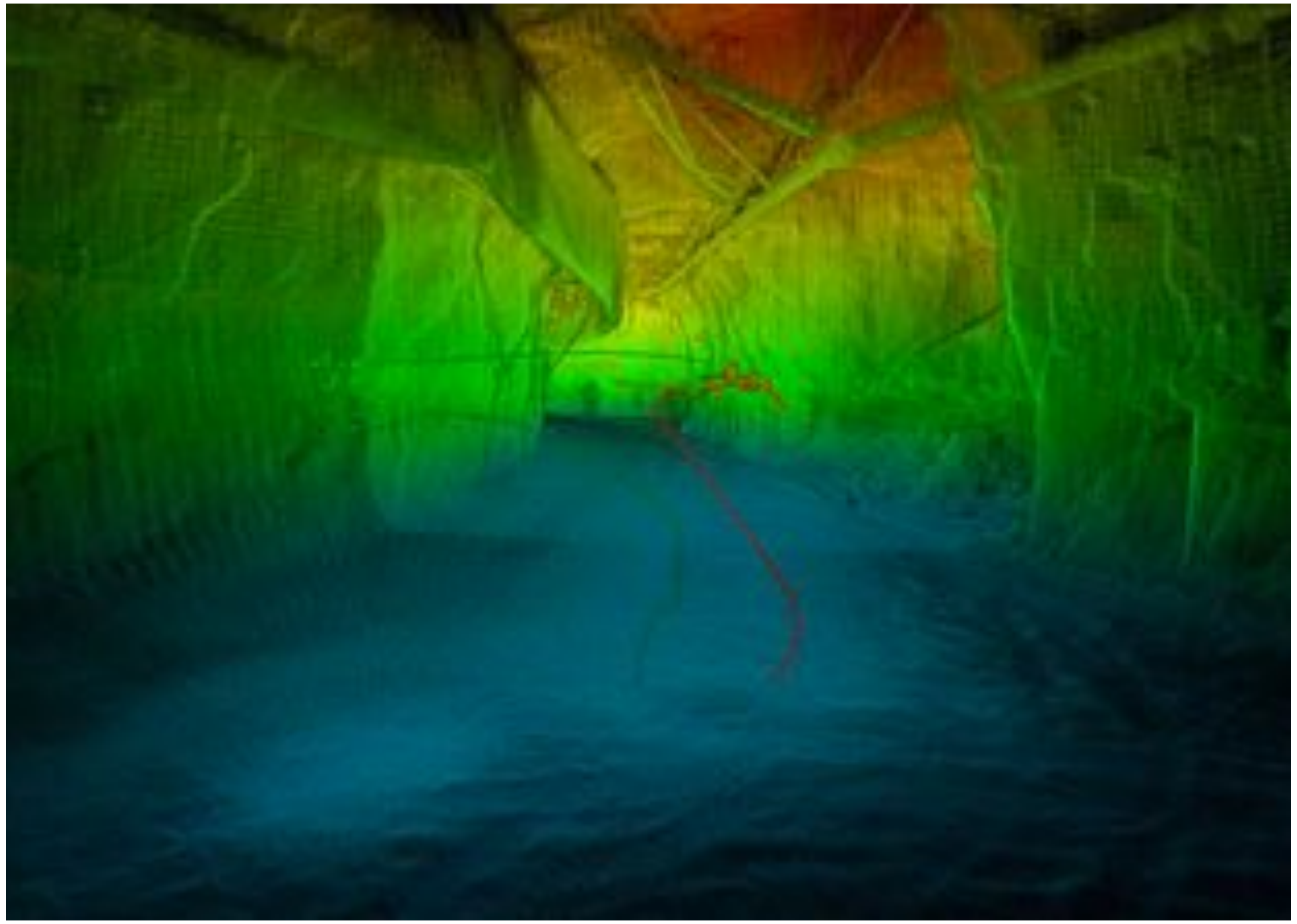


A robot-mounted sensor pod will provide localised inspection, enabling operators to pinpoint sensor reading locations relative to 3D structure.

Remotely Operated Inspection System



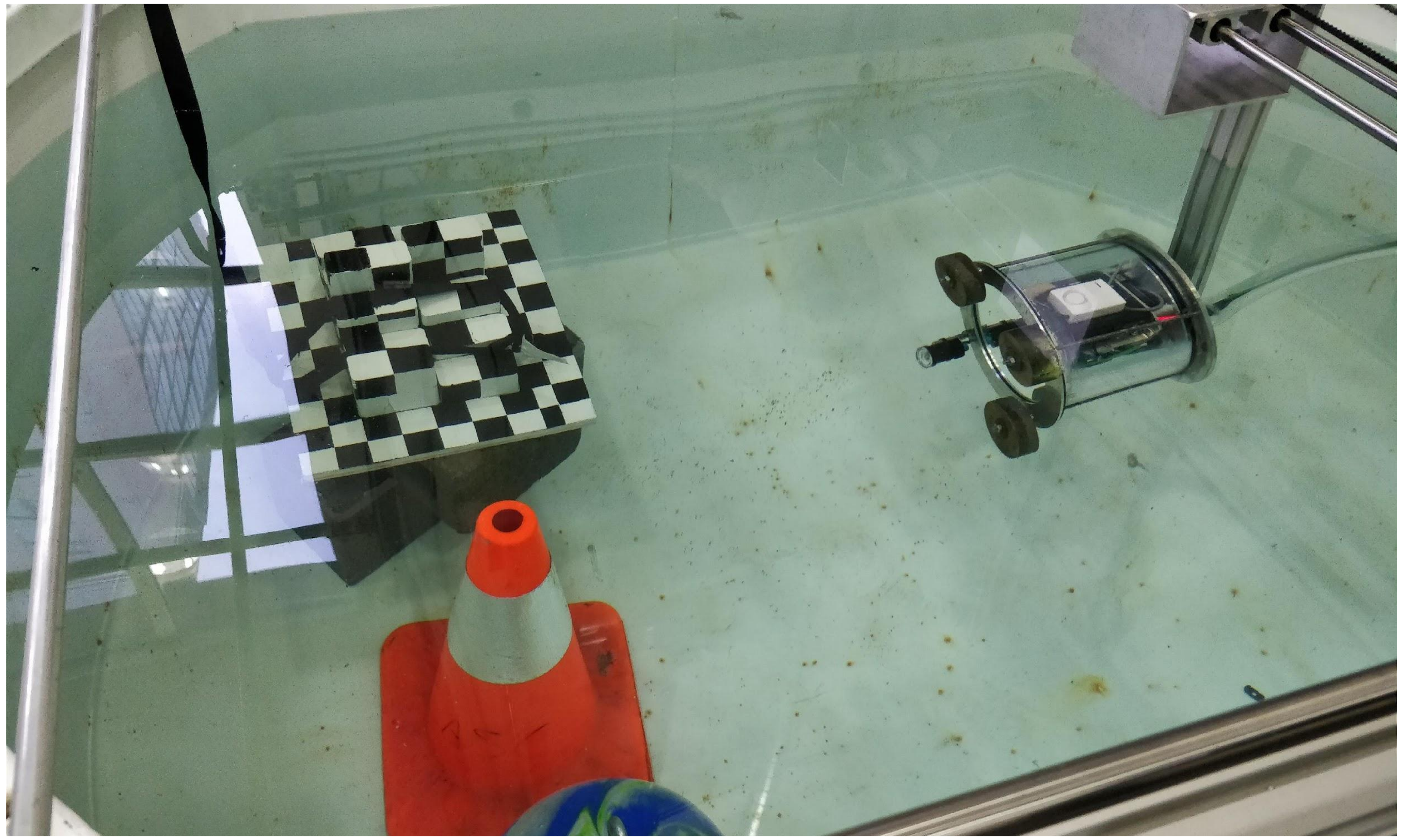
Localised Data Collection



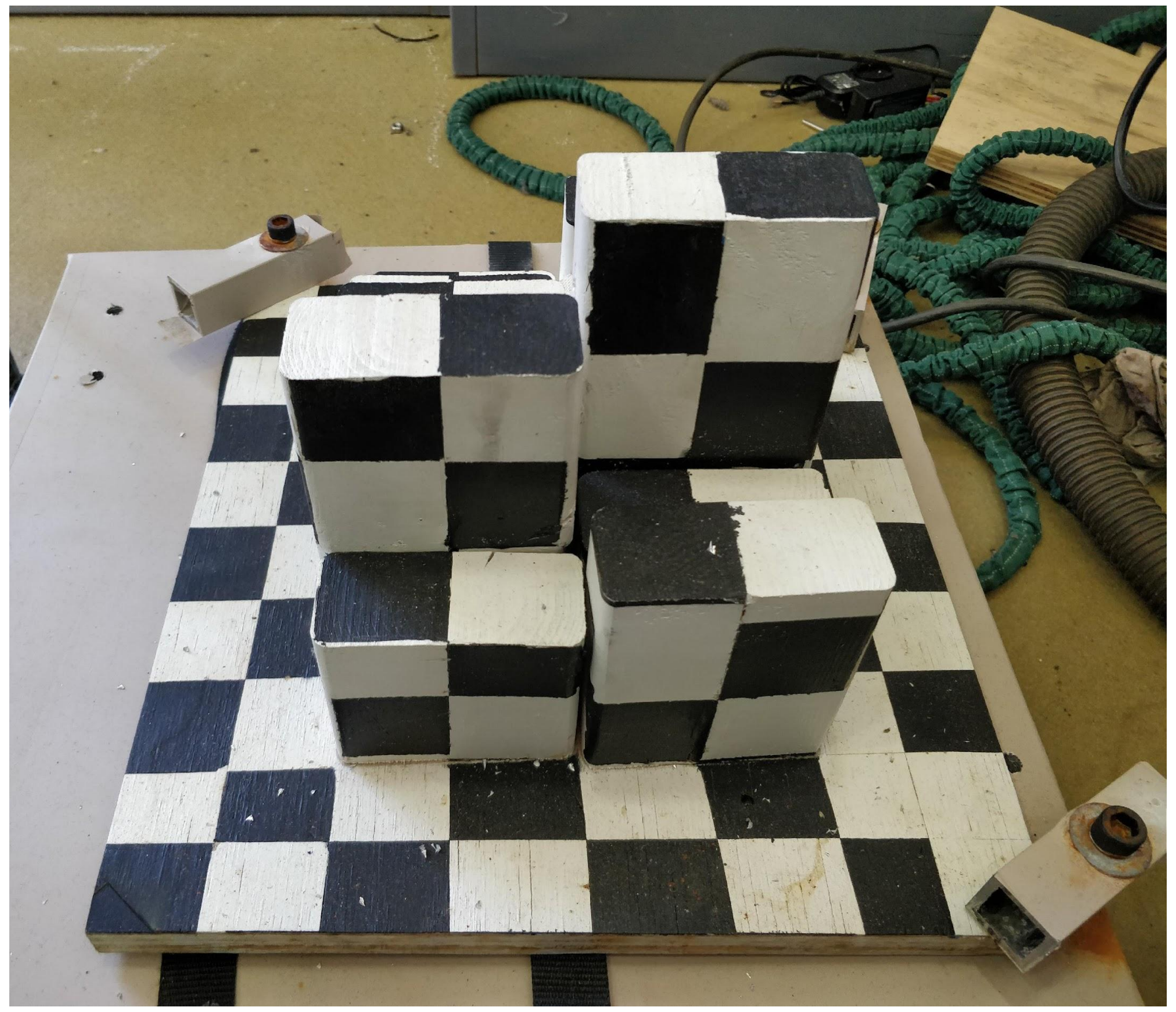
Model Reconstruction

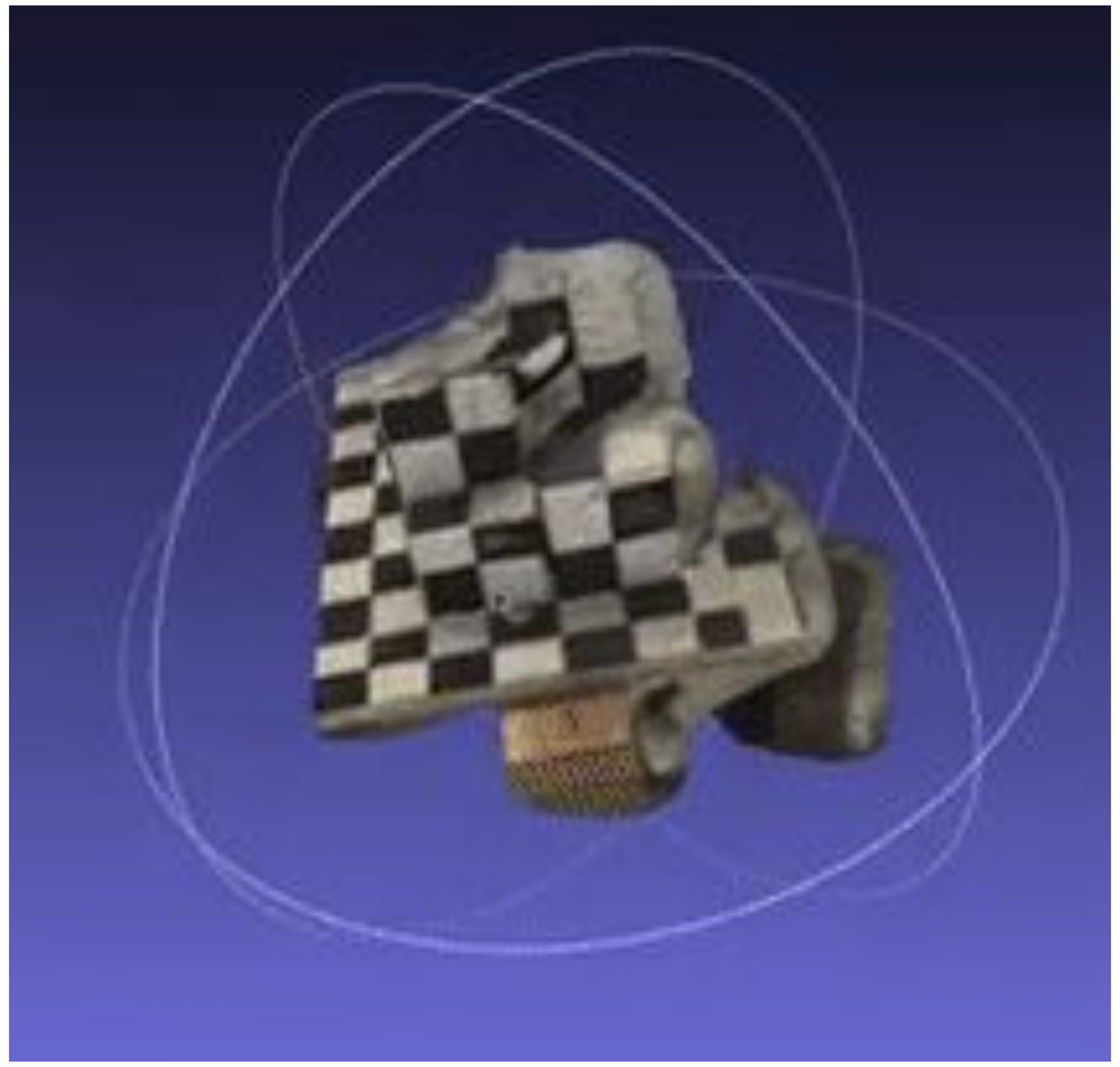
Underwater Mapping

- Underwater & real-time data collection
- 3D reconstruction using image sequences (Structure from Motion)



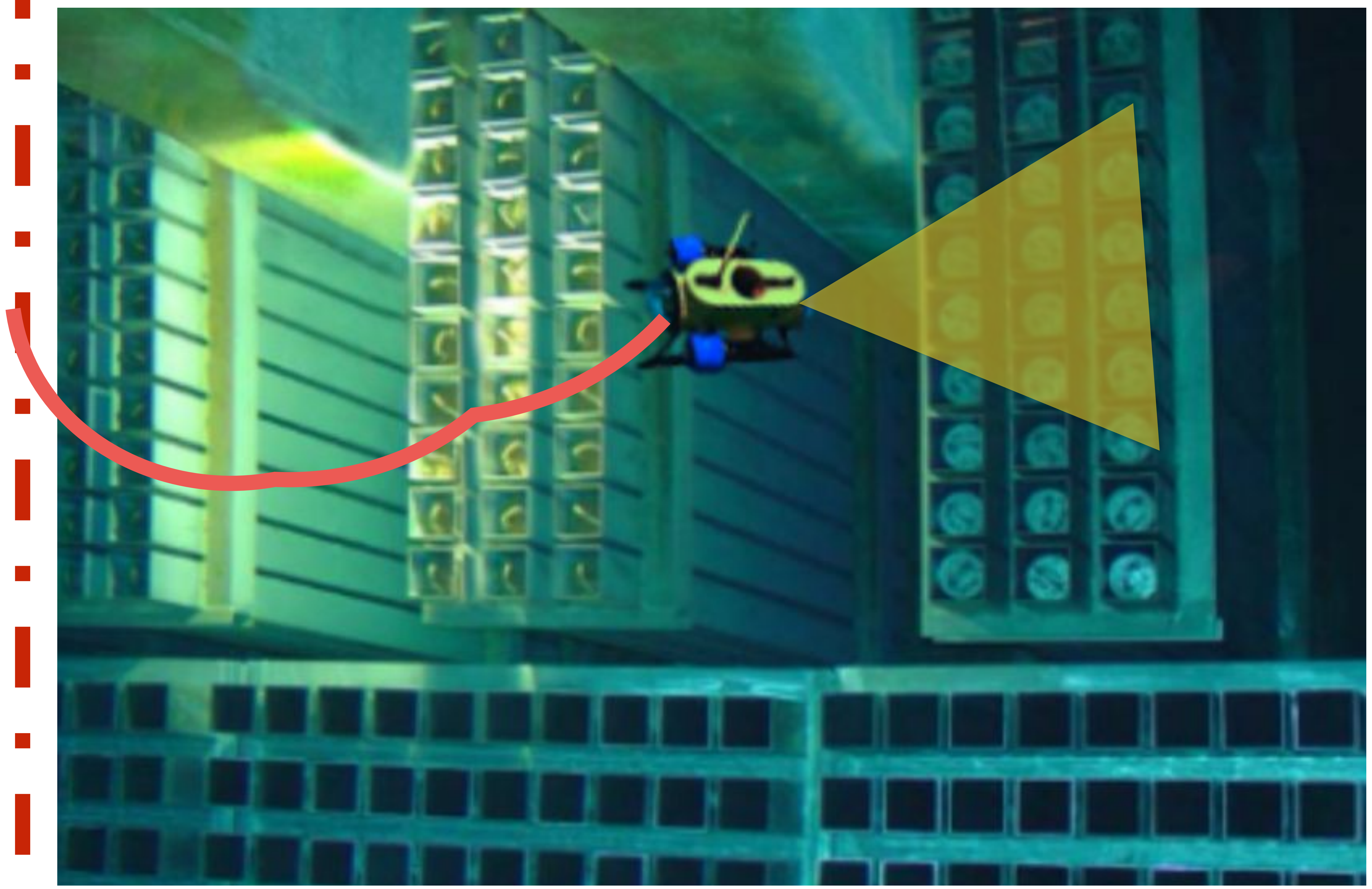
Checkered blocks





Bowling Ball

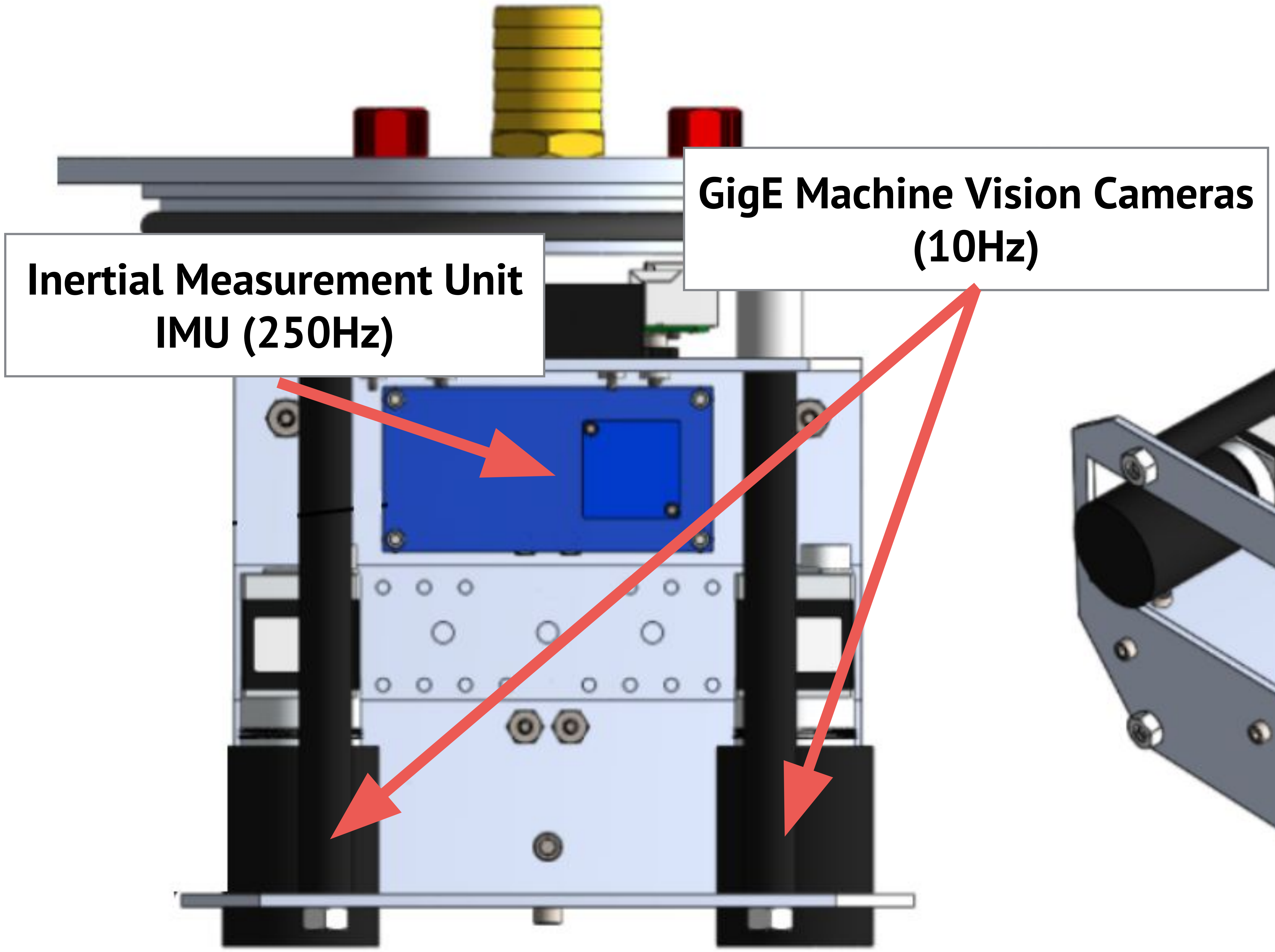
Today's Talk...

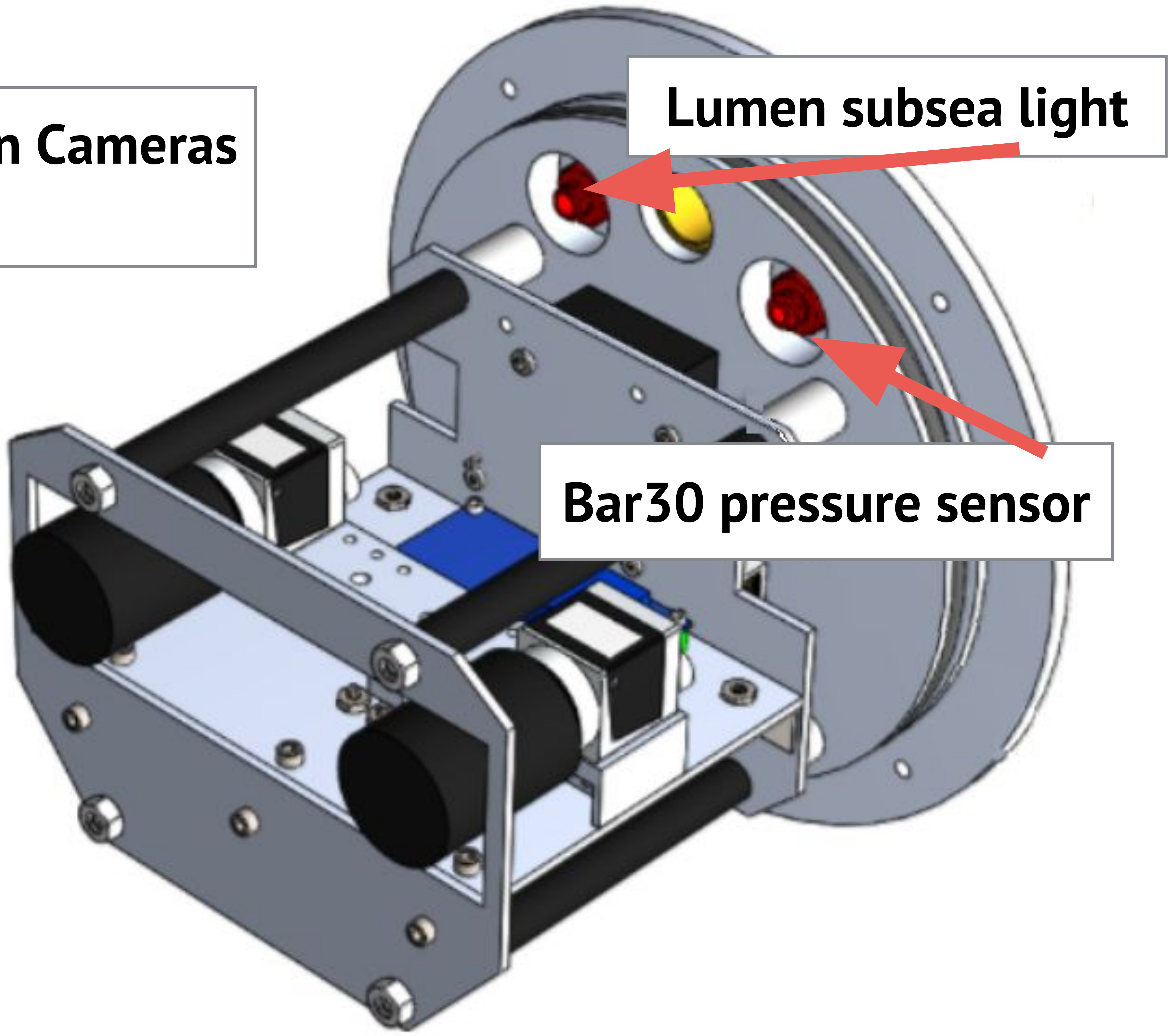


Localised Data Collection

Model Reconstruction

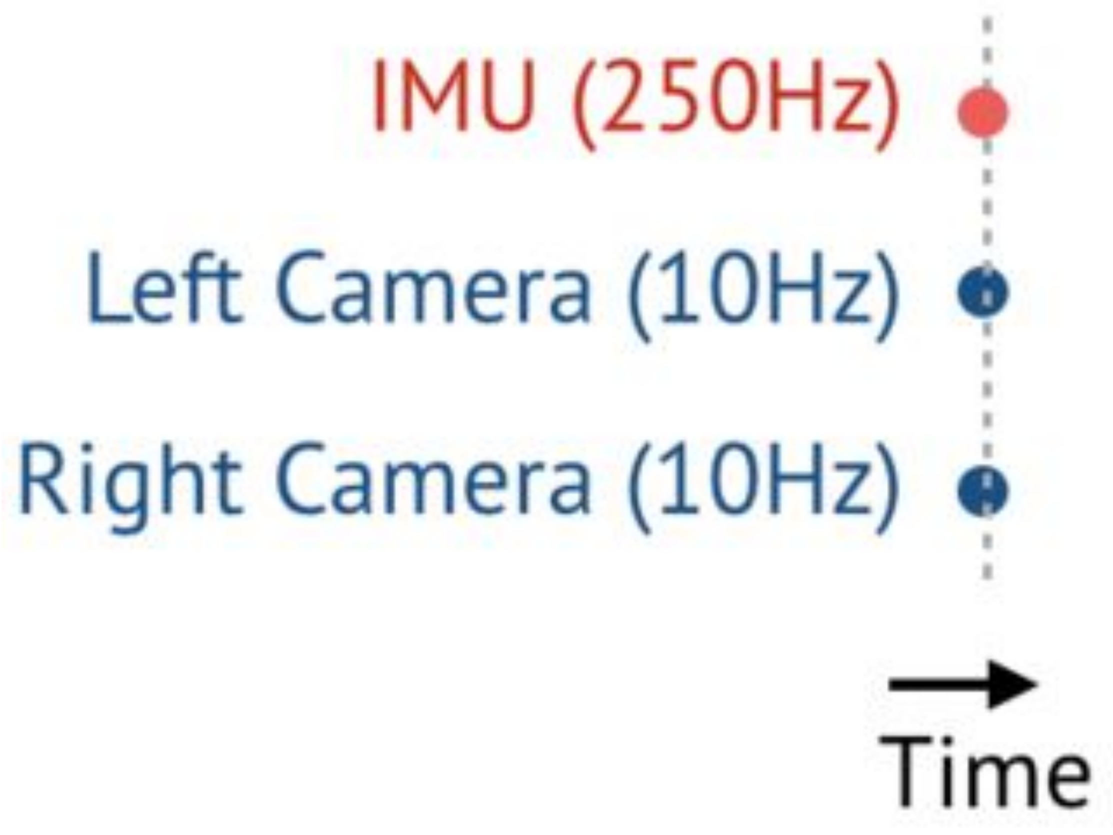
Inspection Sensor Pod



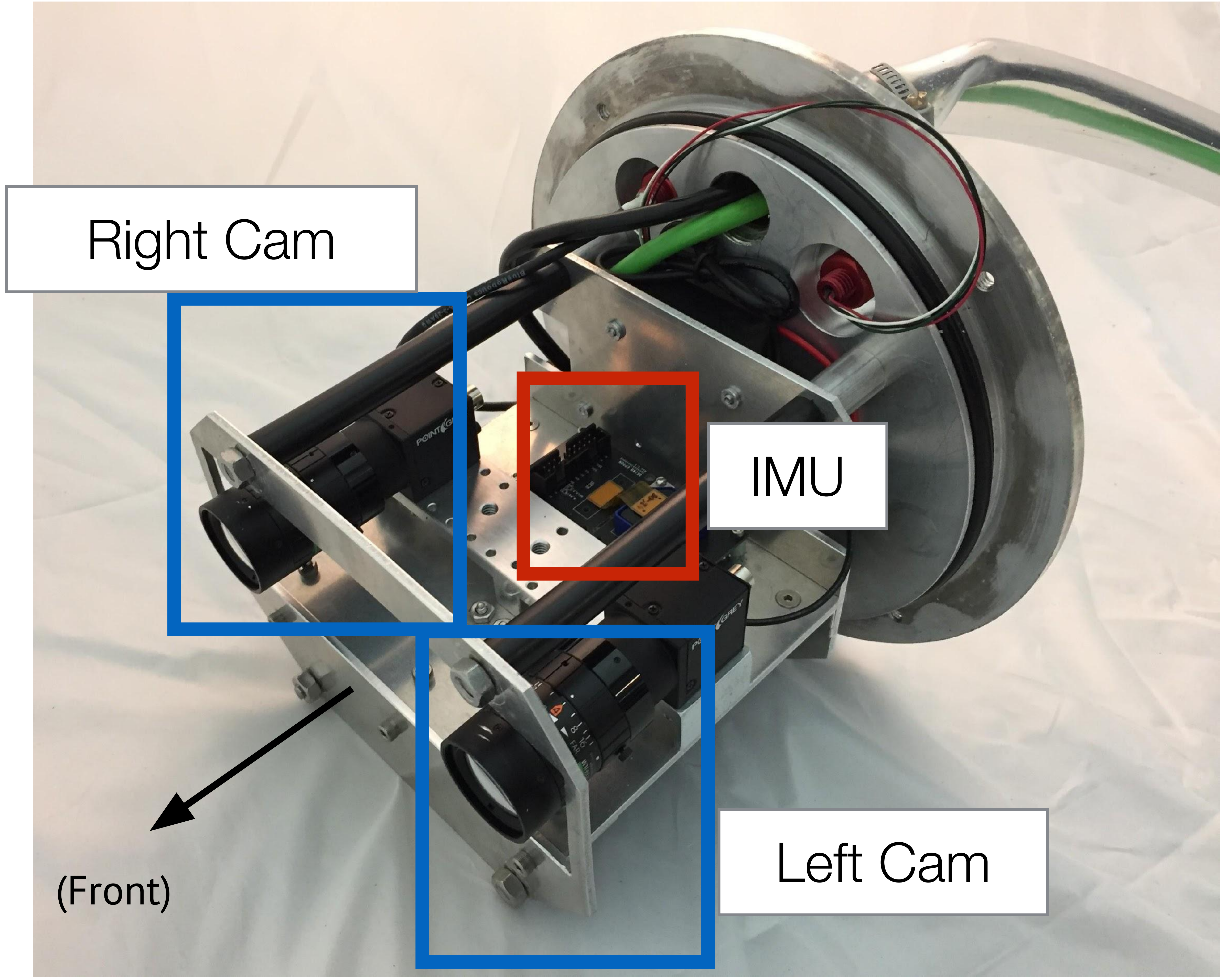


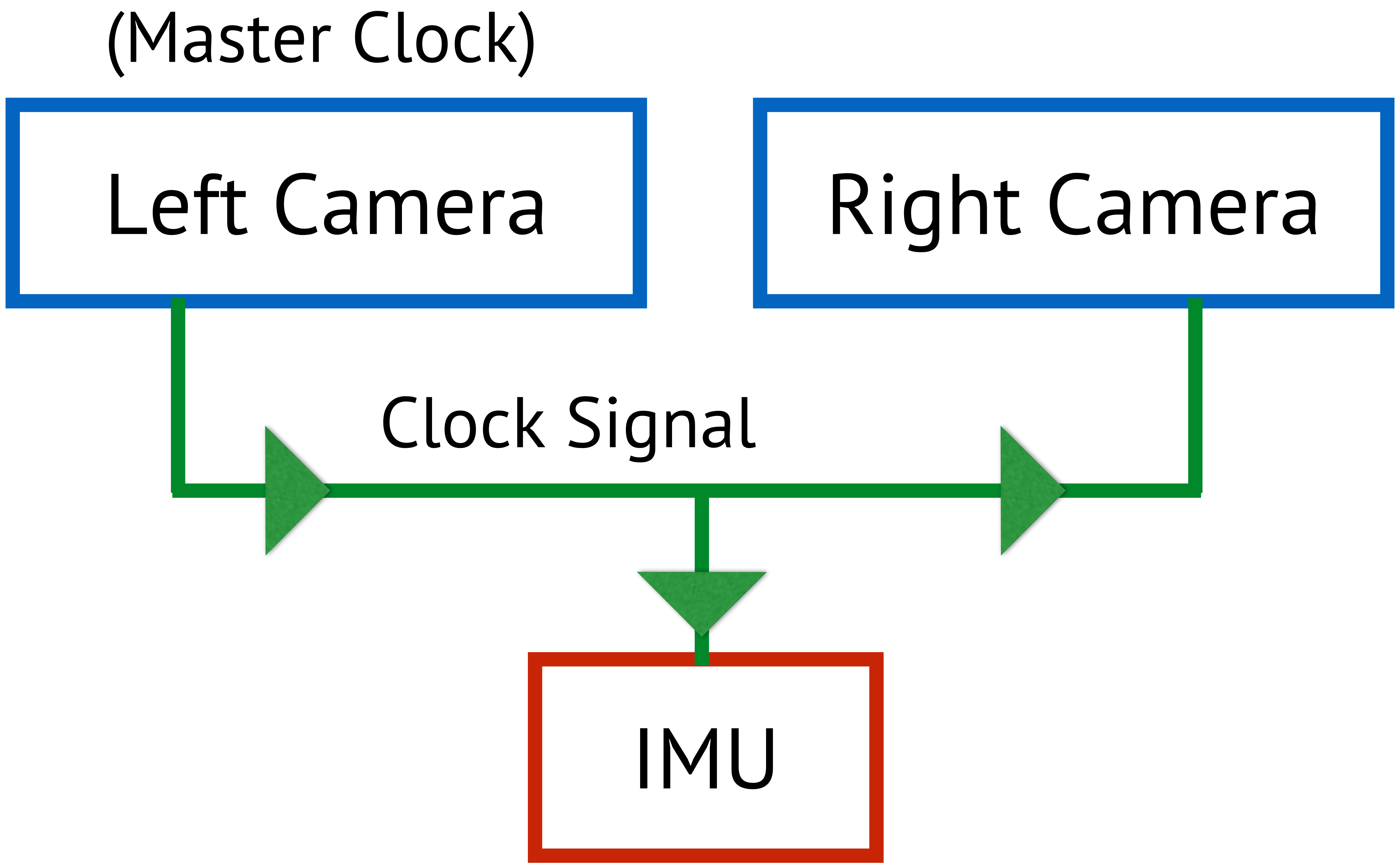
Time-Synchronisation of Sensors

- Each sensor uses its own clock to time stamp data
- Essential to ensure accurate sensor fusion for localisation
- Sensors record at various rates
- Clock drifts!



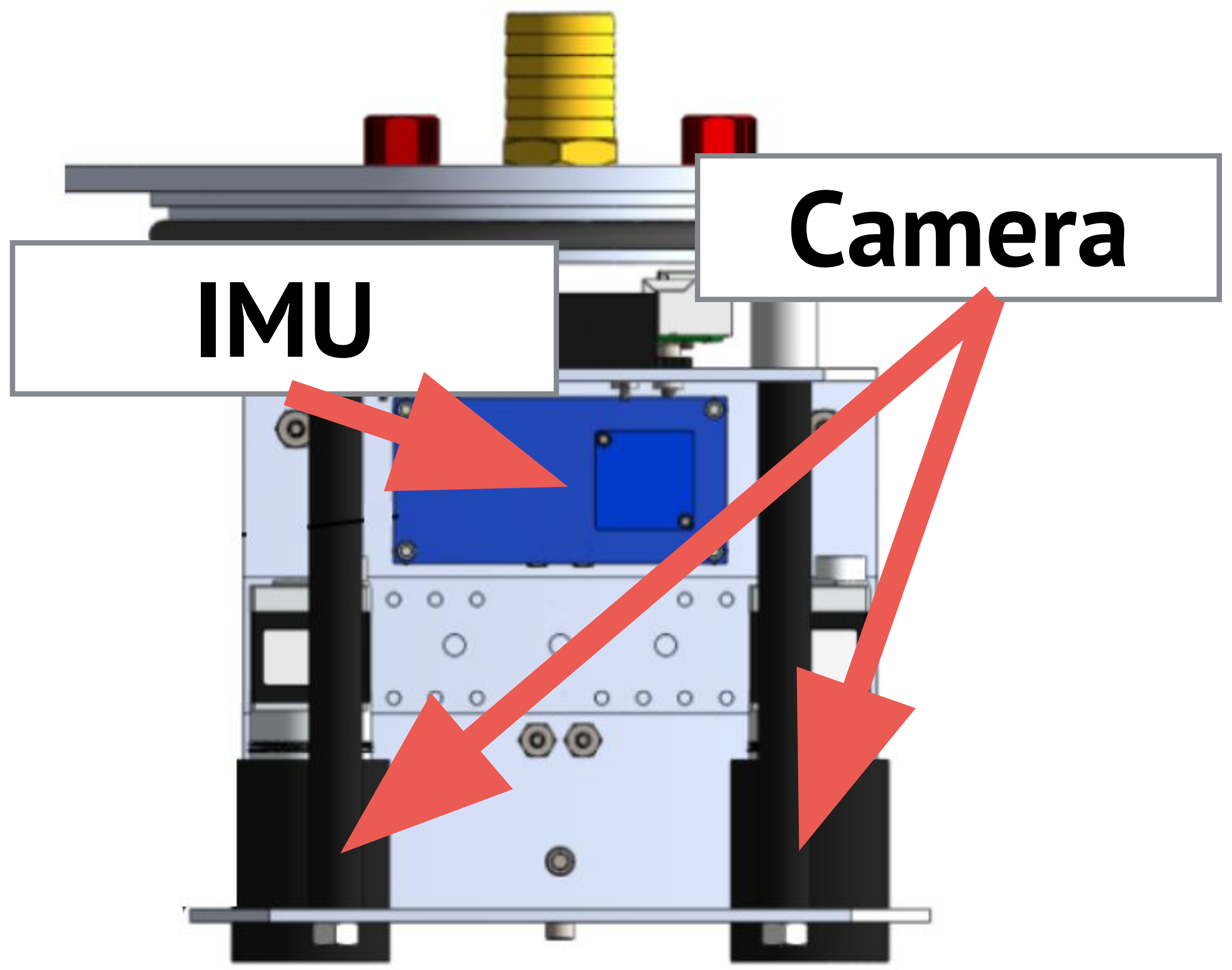
Hardware Synchronisation



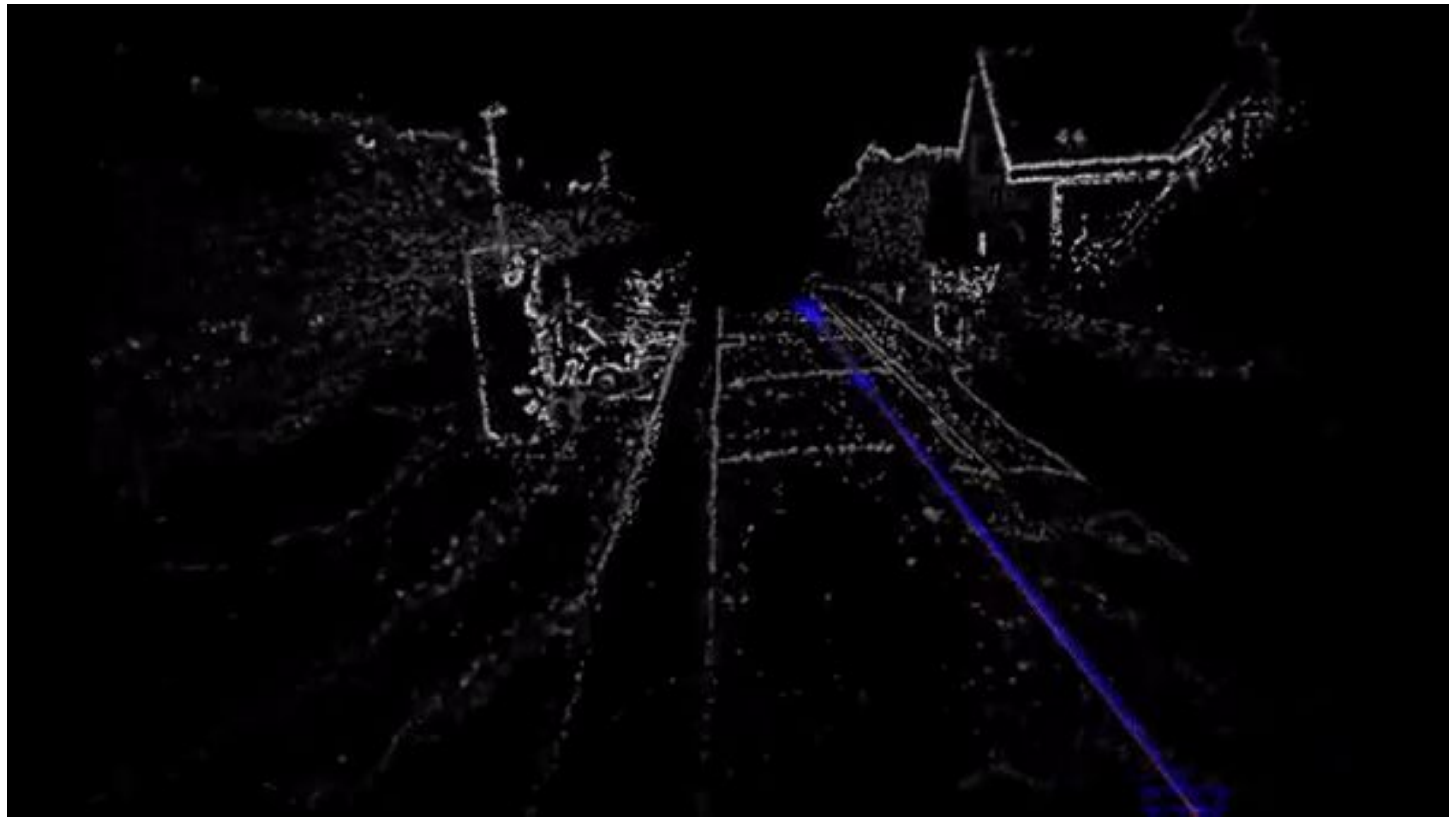


Waterproof enclosure

Odometry Algorithms



- Inertial Odometry is commonly used but it drifts
- Visual Odometry are effective but for small motions (DSO, ORB-SLAM)



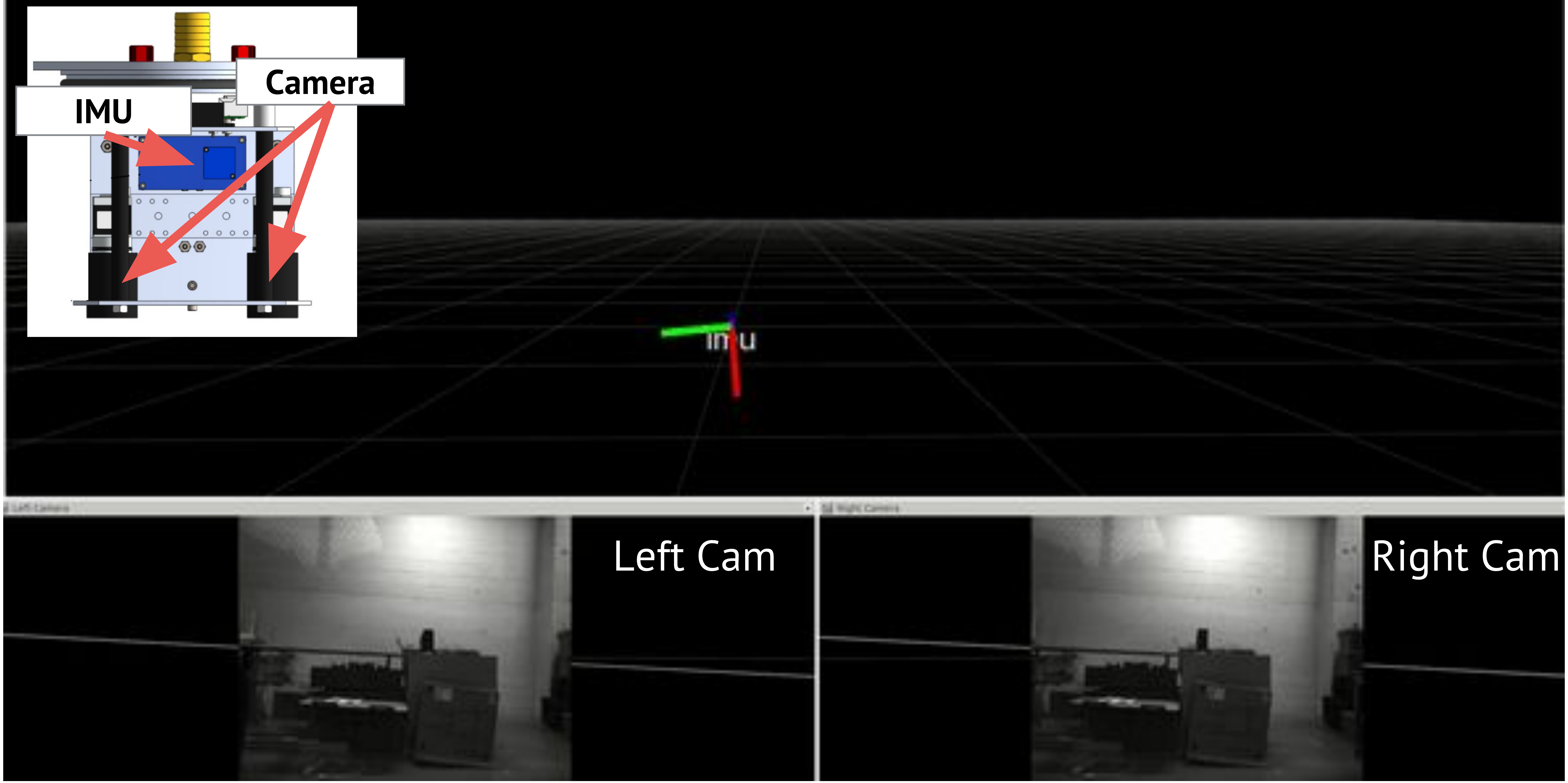
J Engel et al.
"DSO"

R Mur-Artal et al.
"ORB-SLAM"

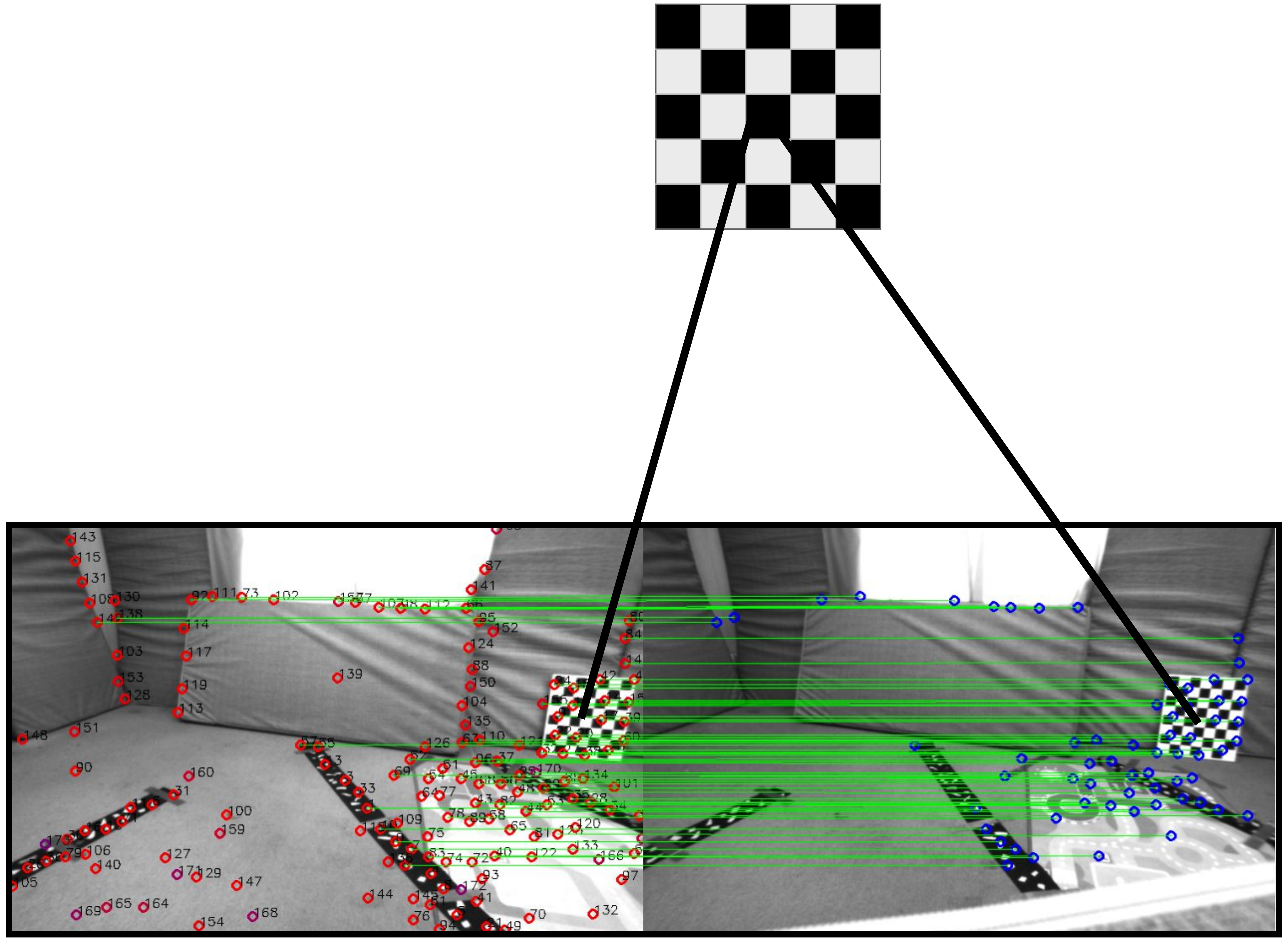
Visual-Inertial Odometry (VIO) Algorithm

- Combines the bests from visual and inertial information
- Utilizes synchronised sensor information

VIO for Inspection

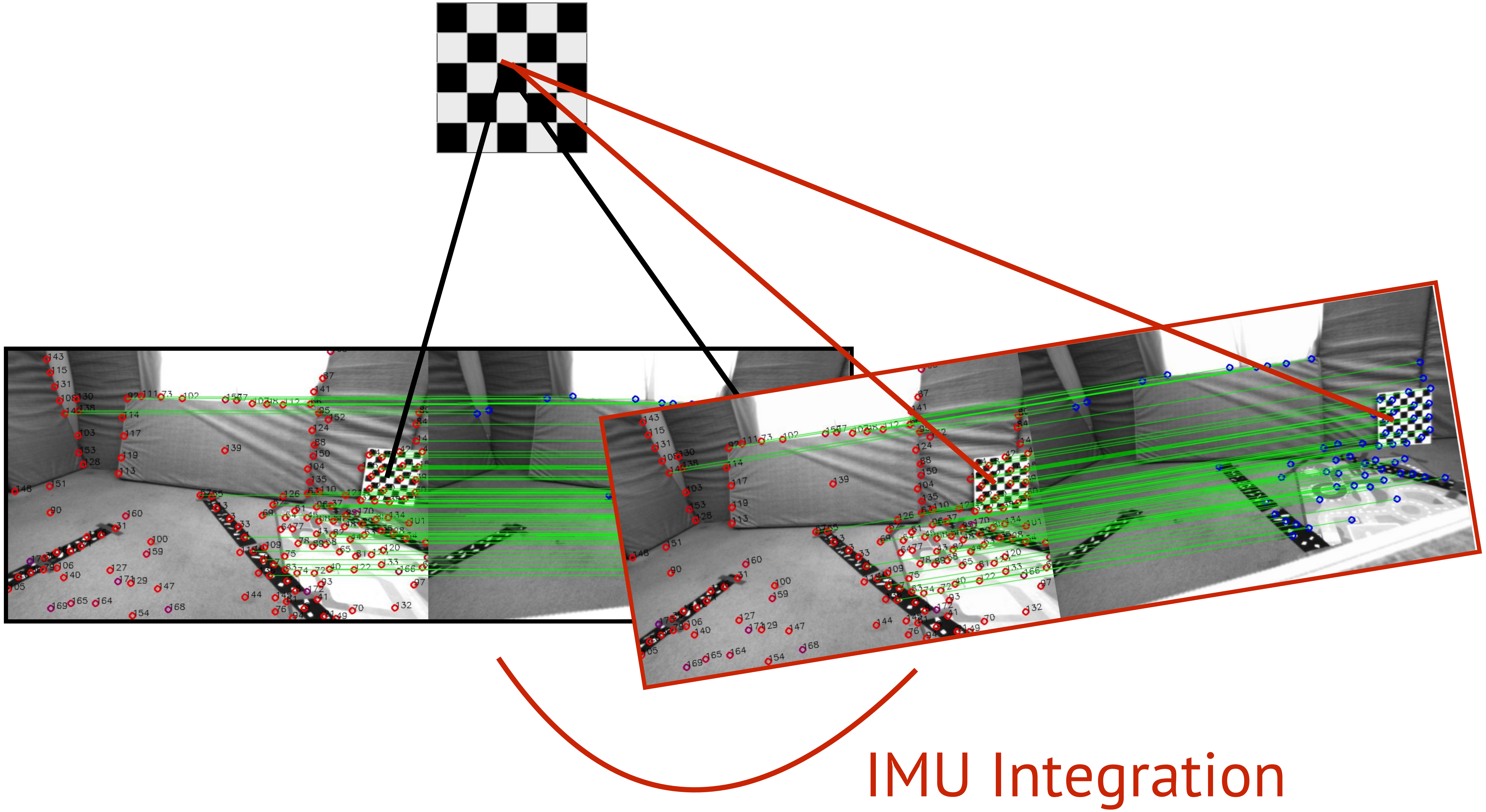


Stereo Triangulation for VIO

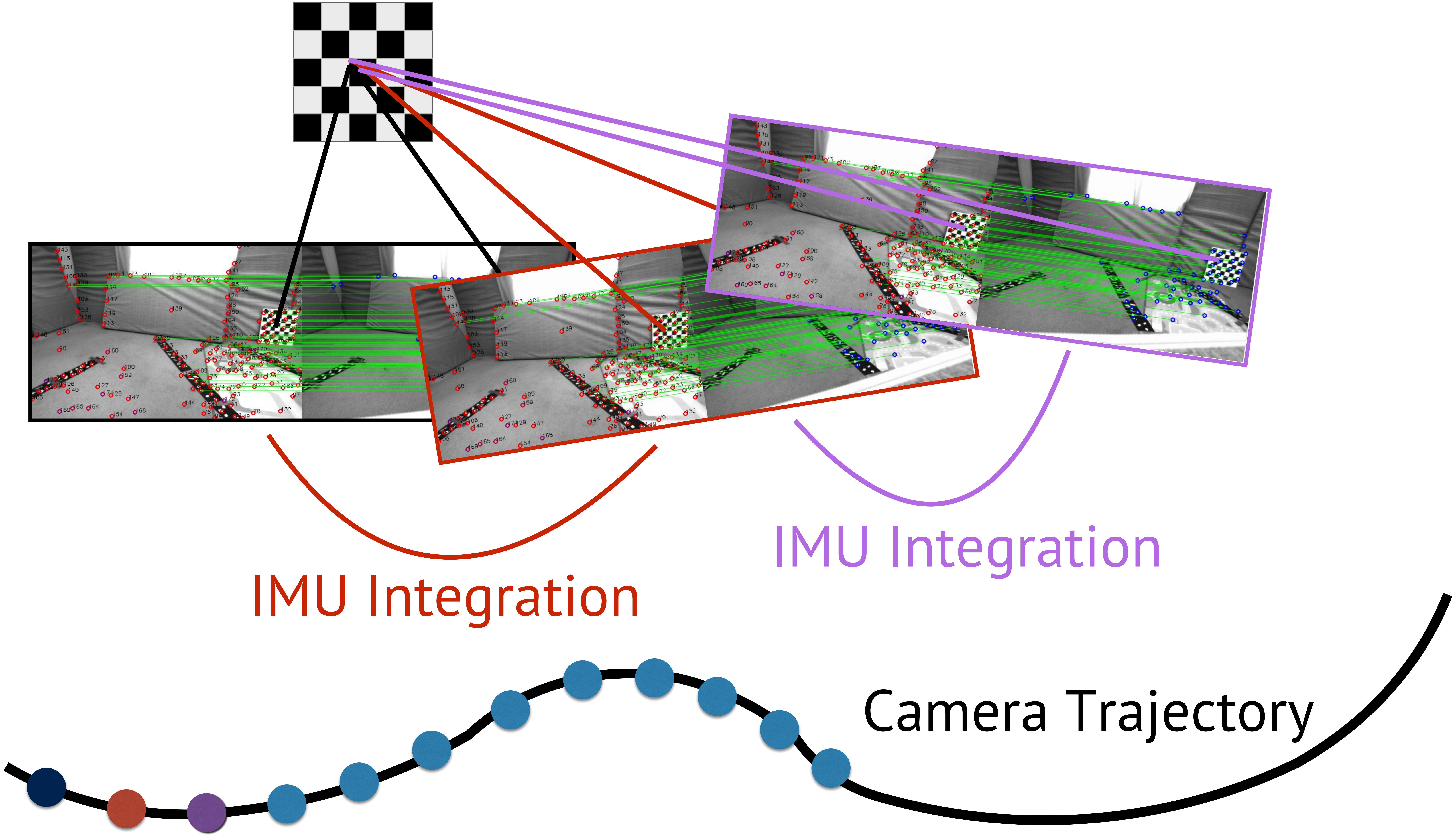


The corresponding points are triangulated into the 3D world

Camera moves...

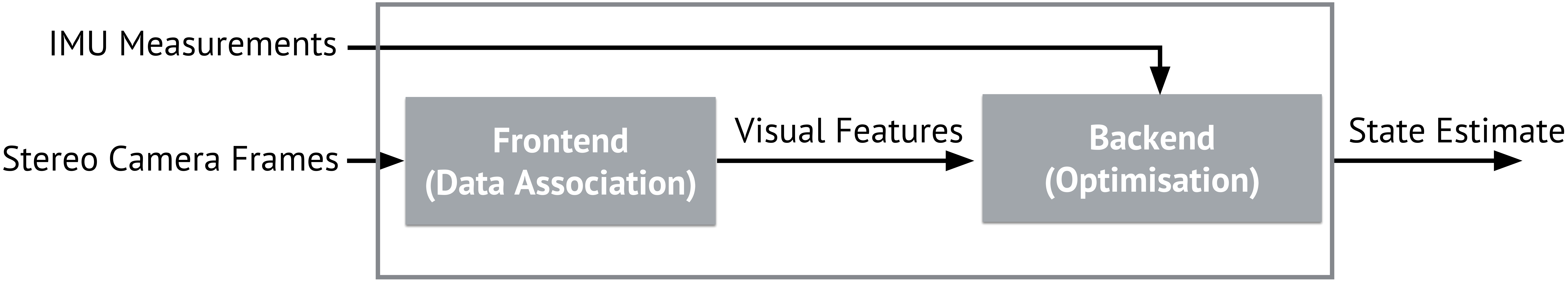


A sequence of camera movements

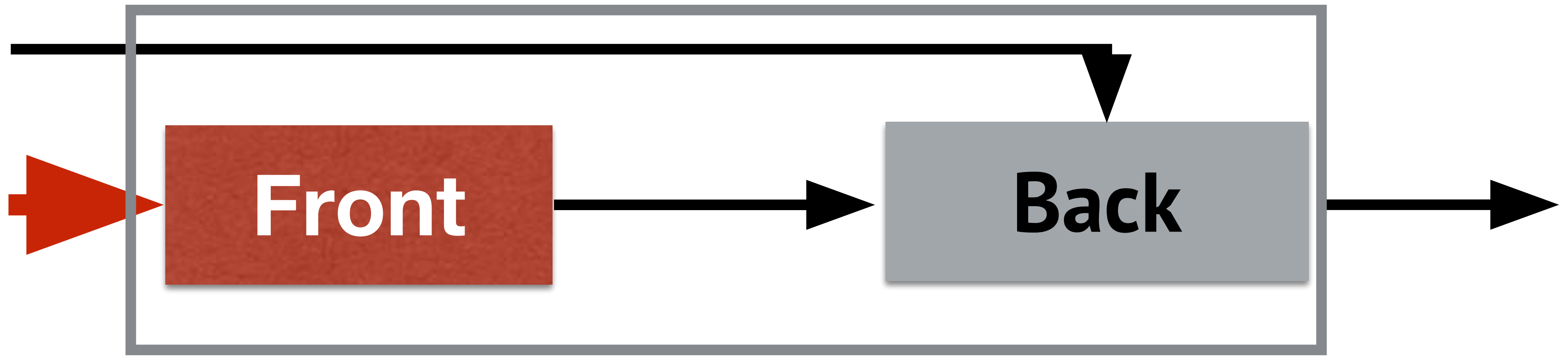


Details of the VIO system

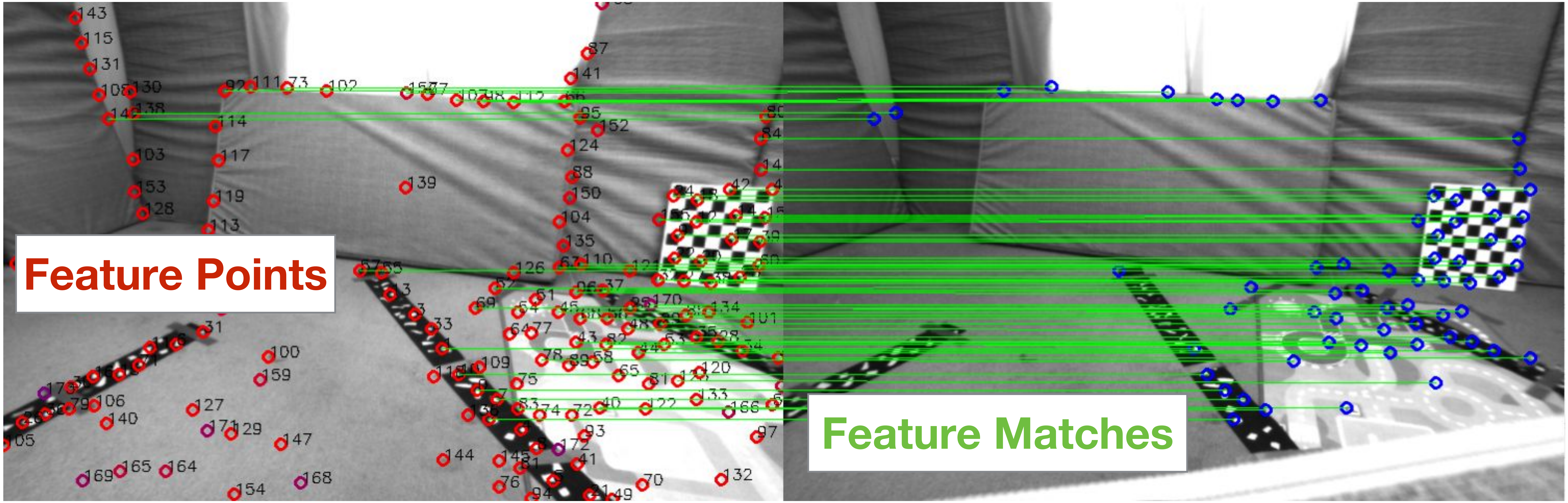
- A VIO system consists of a frontend and a backend parts
- Data association Frontend
  Optimisation Backend



Data Association Frontend

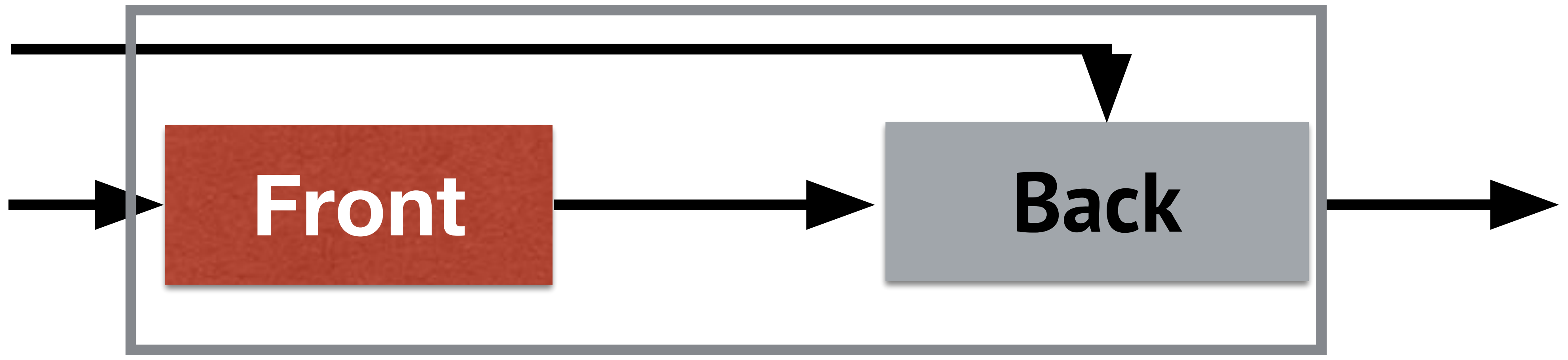


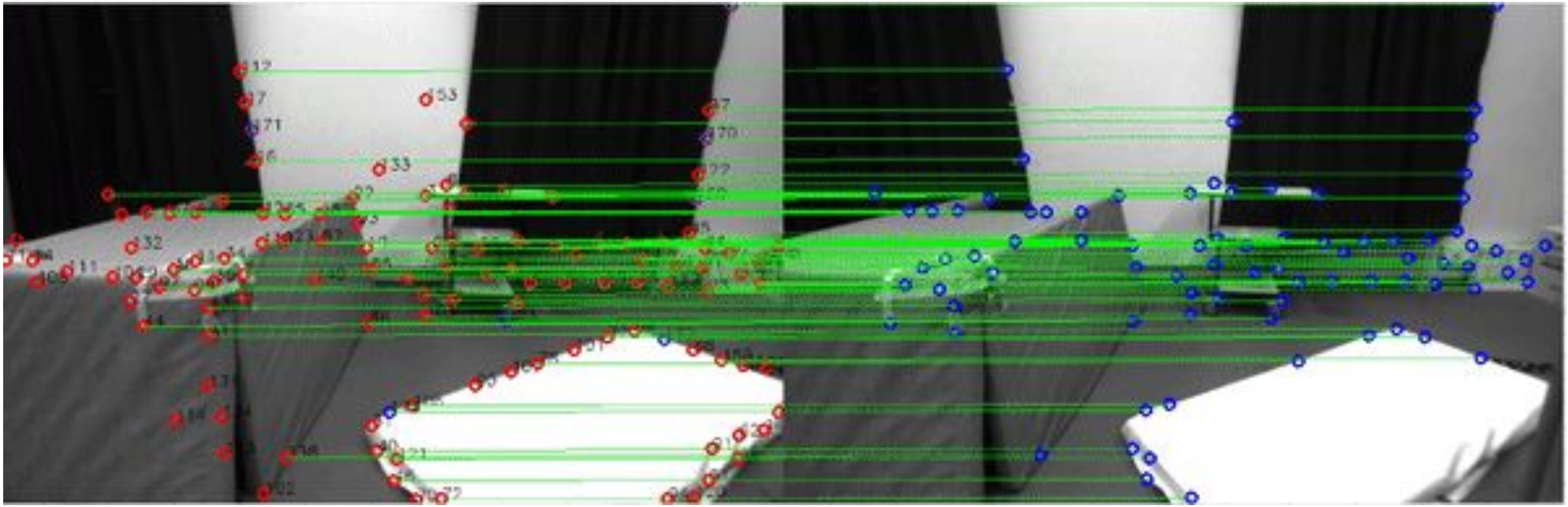
- Shi-Tomashi Corner Detector
- Lukas-Kanade Optical Flow feature tracking algorithm (up to 200Hz)



Left Camera Frame   Right Camera Frame

Data Association Frontend

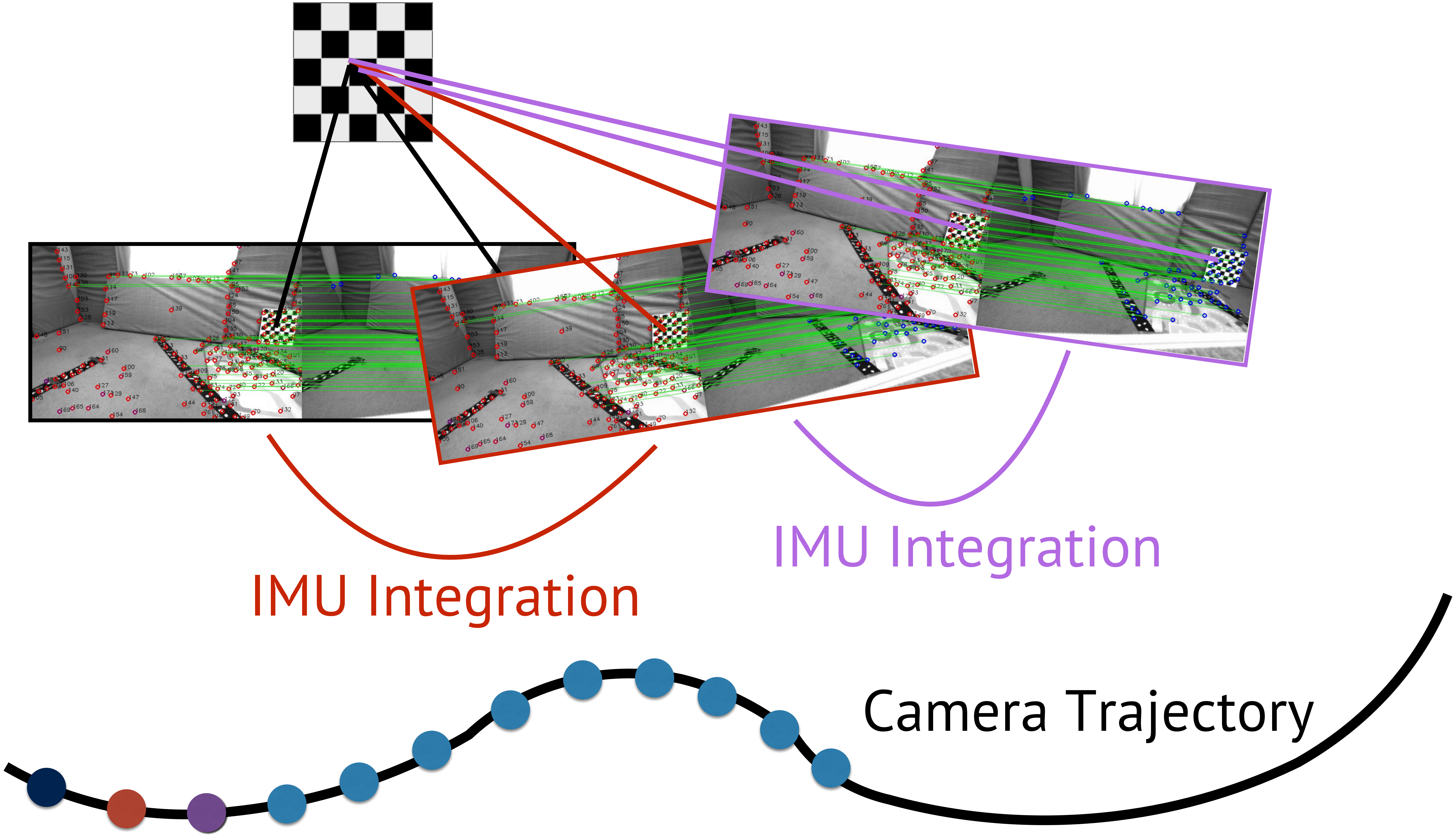




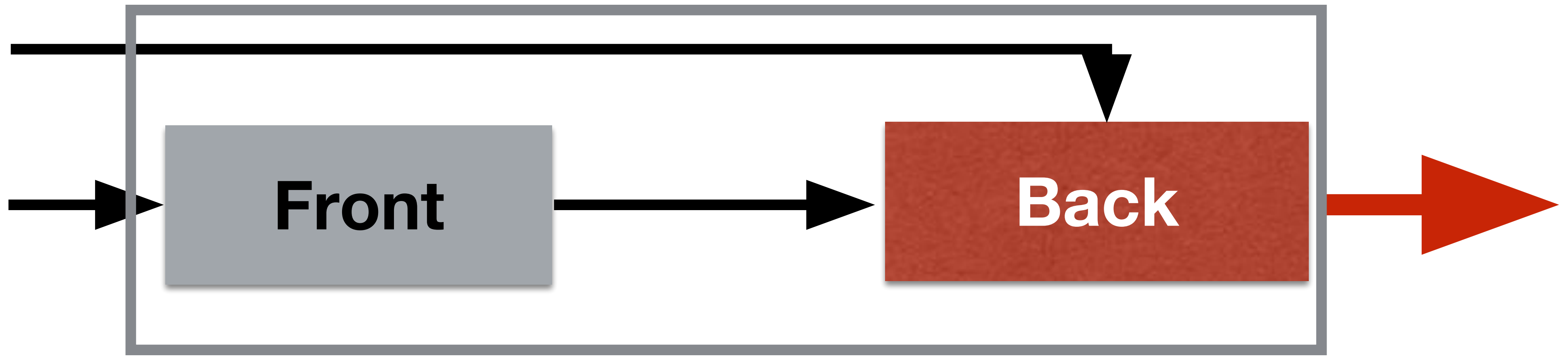
Left Camera Frame

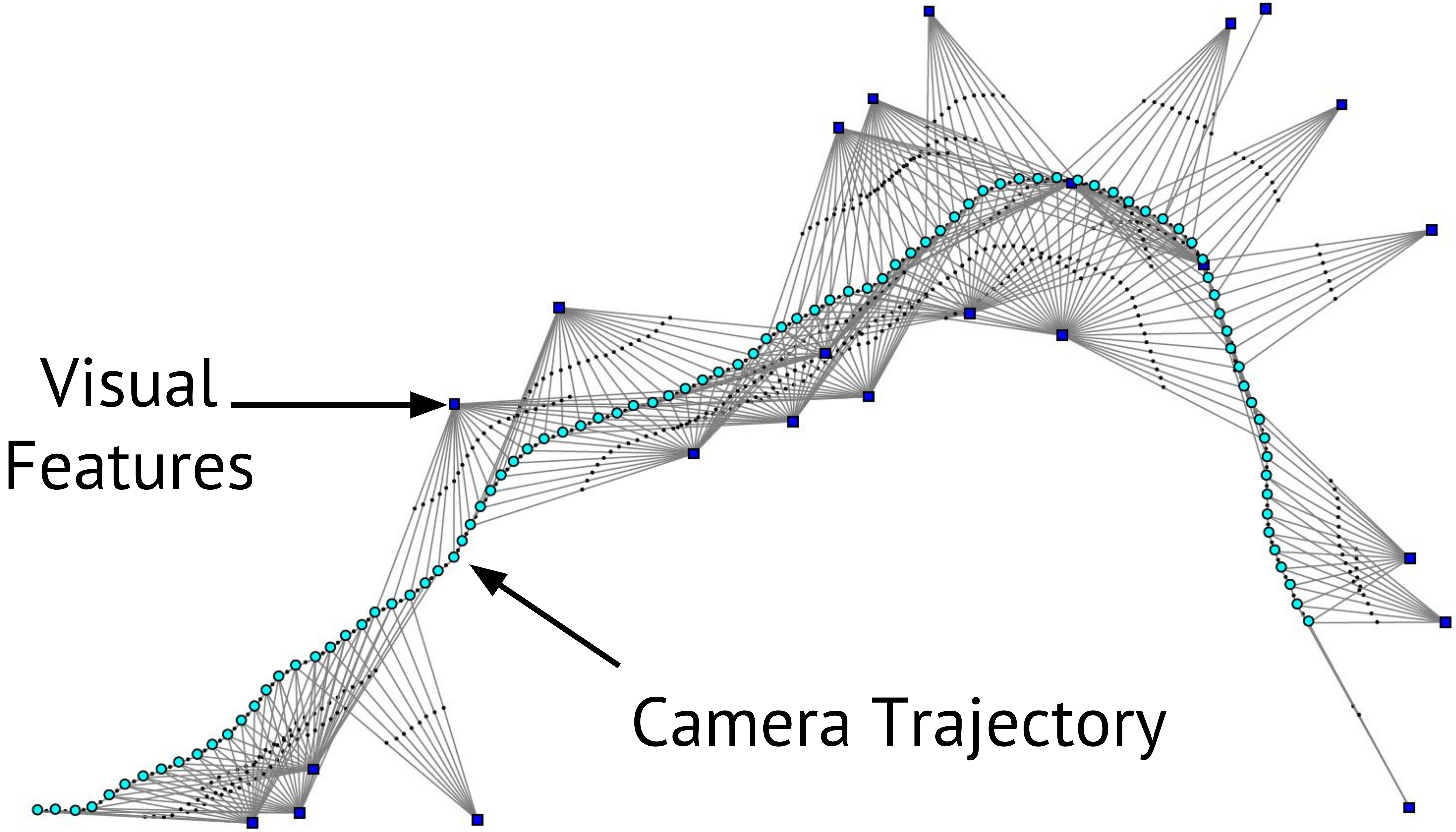
Right Camera Frame

A sequence of camera movements



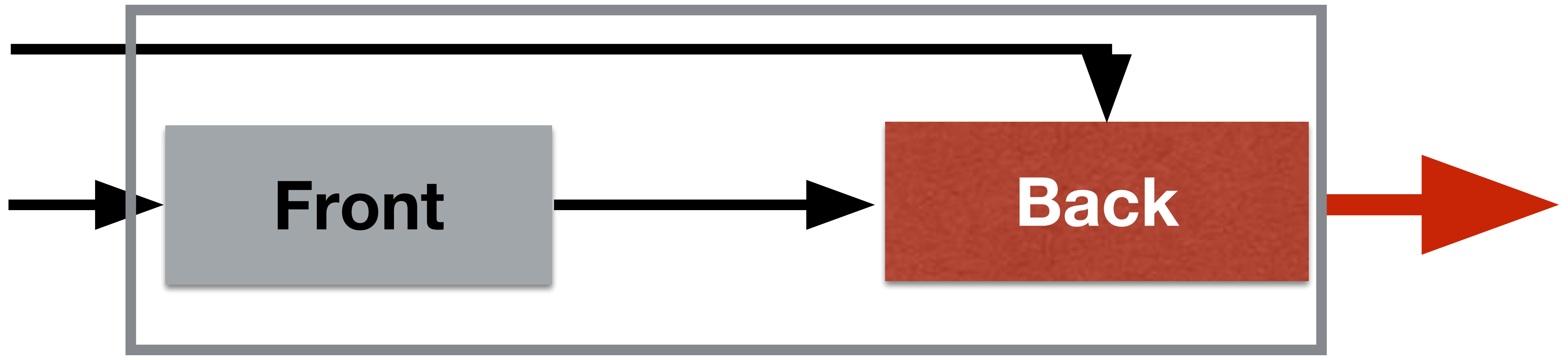
Optimisation Backend

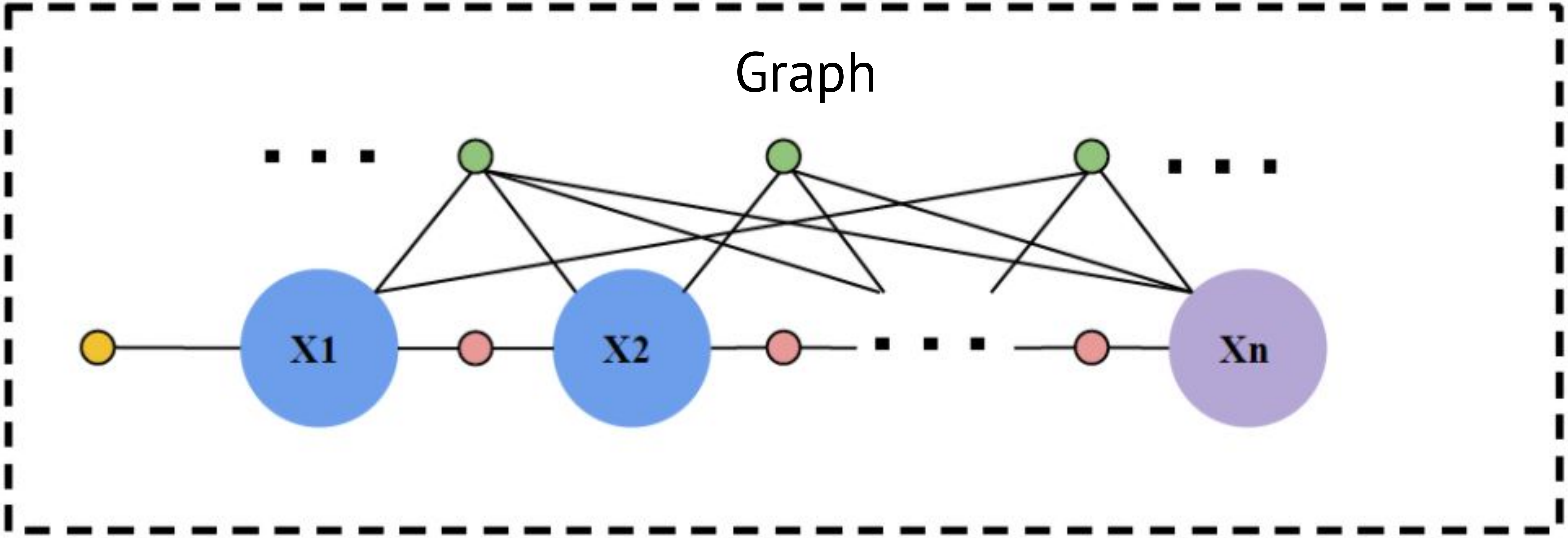




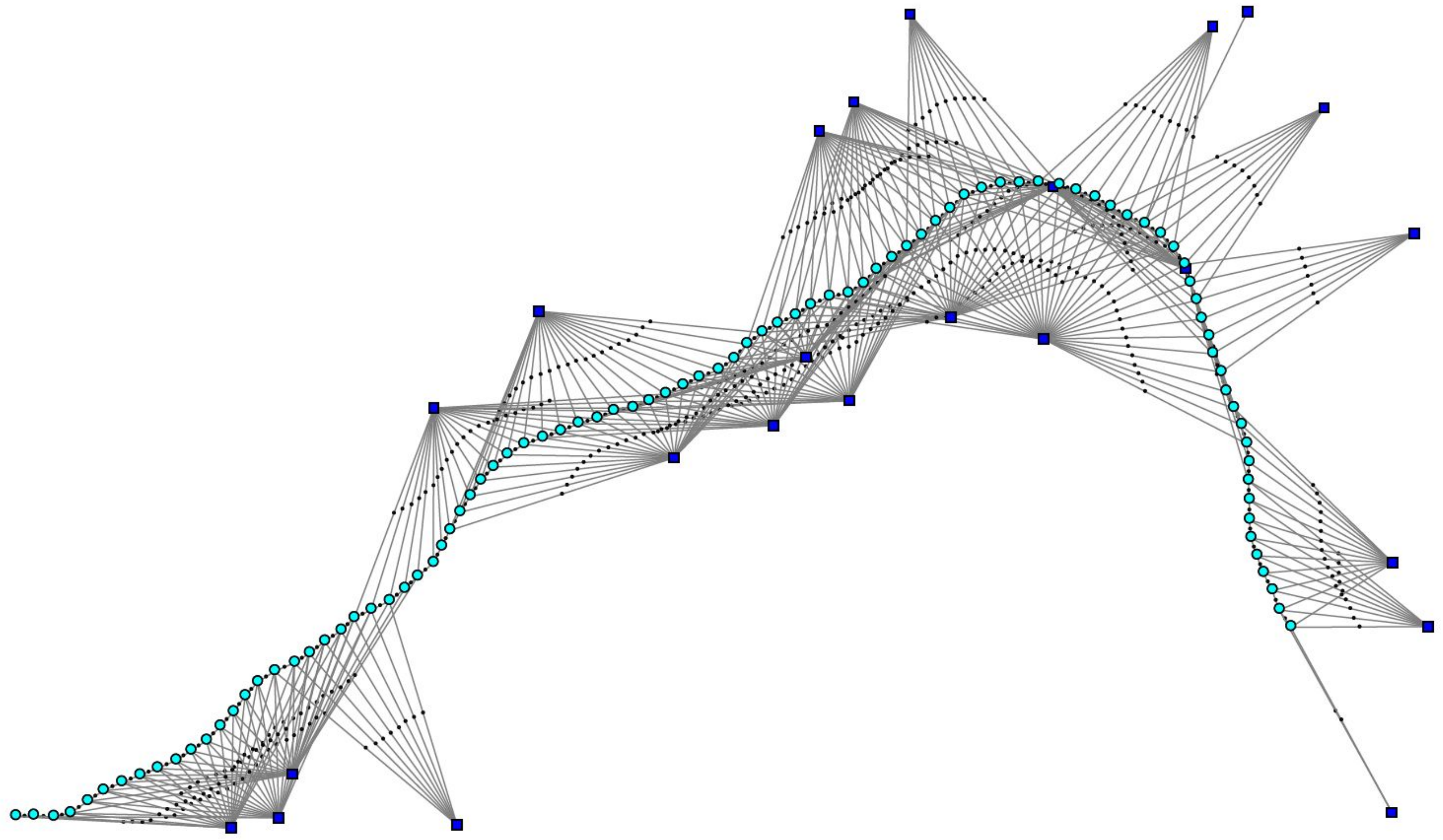
Source: F. Dellaert and M. Kaess, "Factor graphs for robot perception"

Optimisation Using Graphs



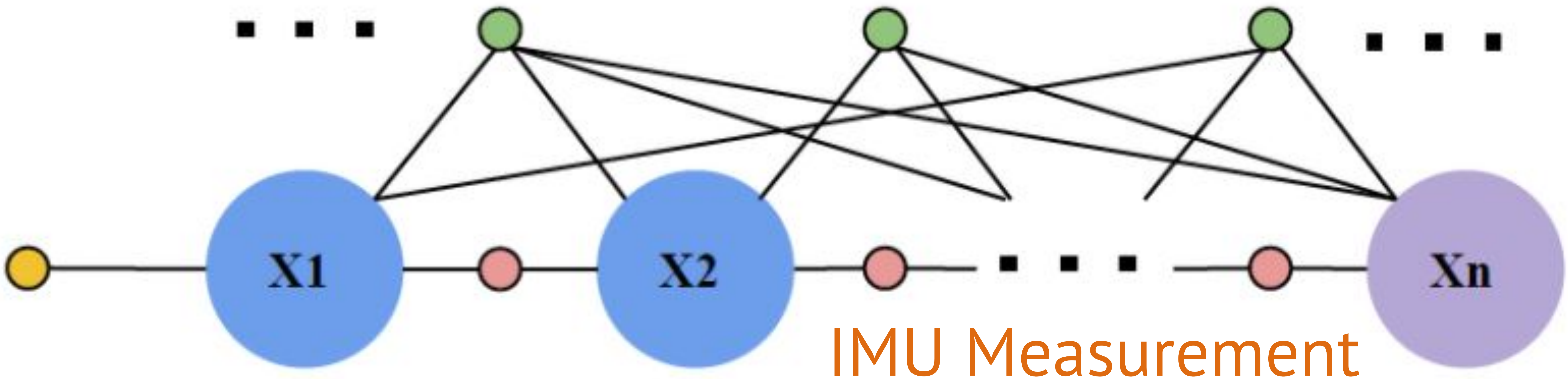


Graph Optimisation



- Specifies the relationships between variables and measurements

Visual Measurement

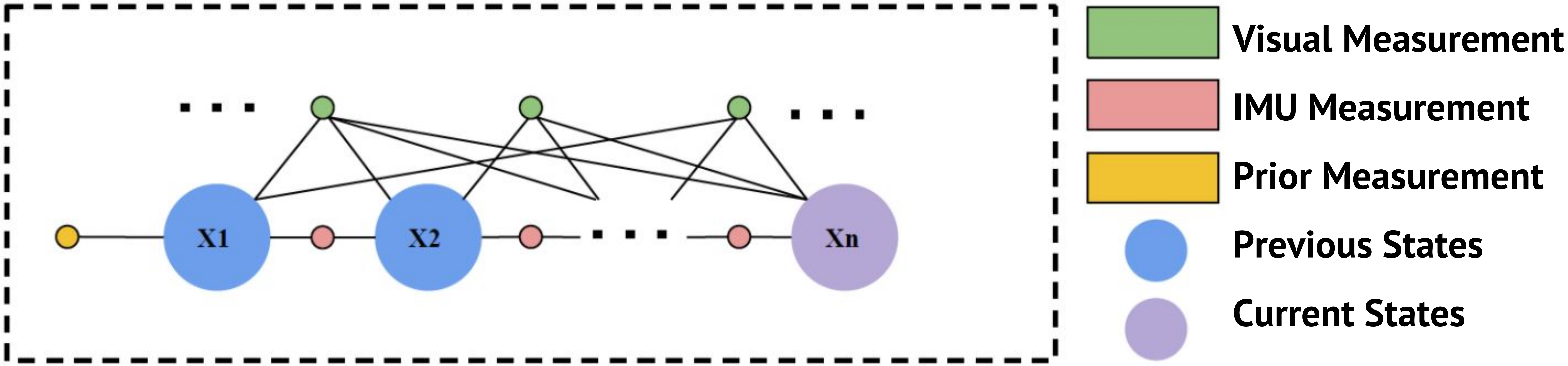


IMU Measurement

X = Camera States
(Position, Orientation, ...)

Time

Graph Optimisation

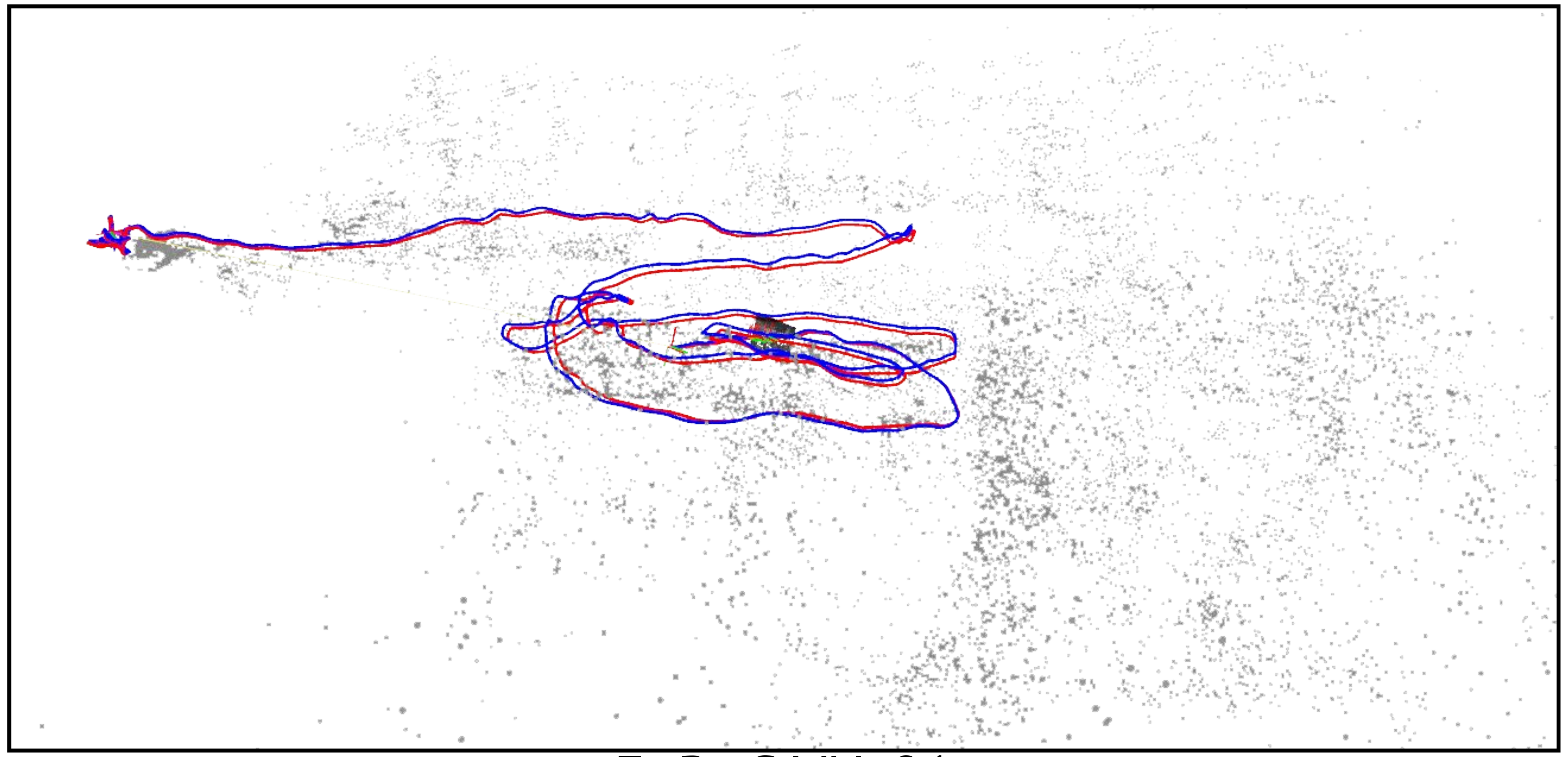


$$\chi^* = \underset{\chi_k}{argmin} \left(p(\chi_0) \prod_{(i,j)\in I_k} p(z_{ij}^{imu} | x_i, x_j) \prod_{i\in I_k} \prod_{l\in C_i} p(z_{il}^{cam} | x_i) \right)$$

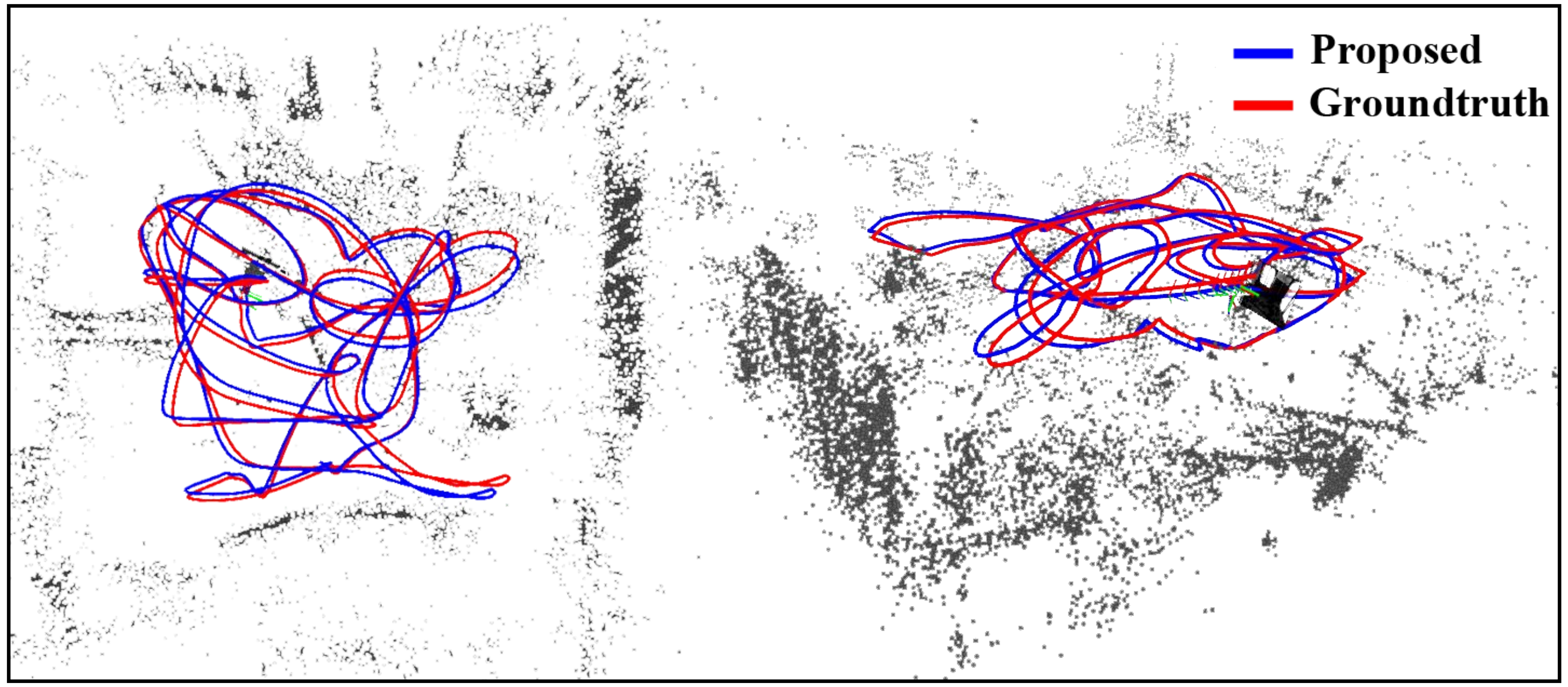
- Solution is given by the optimal estimate that best explains all sensor measurements
- Also known as **Maximum a Posterior Estimate (MAP)**

VIO Datasets Trials

		RMSE	Mean	Median	Std	Min	Max
Absolute Trajectory Error (ATE)	Positional (m)	**0.131**	0.123	0.118	0.044	0.025	0.238
Relative Pose Error (RPE)	Translational (m)	0.037	0.032	0.027	0.020	0.001	0.164
	Rotational (°)	**0.652**	0.506	0.407	0.411	0.016	3.729



EuRoC VH_01
Dataset



EuRoC V2_01
Dataset

Summary

- A localised inspection solution is essential to ensure an efficient, consistent, and accurate inspection process.
- A visual-inertial odometry algorithm is presented to allow accurate localisation in an underwater environment.
- A time-synchronised sensor pod is required for the data to be sent instantaneously and concurrently.
- With localisation information and synchronised data, 3D models can be reconstructed.

Thank you!

- Andrew Tallaksen
- Lawrence Papincak
- Sudharshan Suresh
- Heather Jones
- William Whittaker
- Michael Kaess