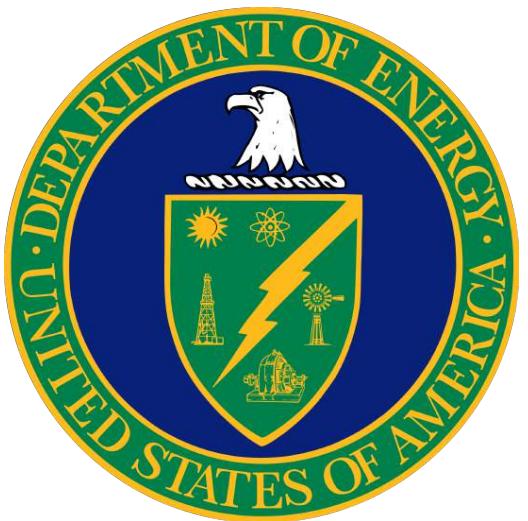
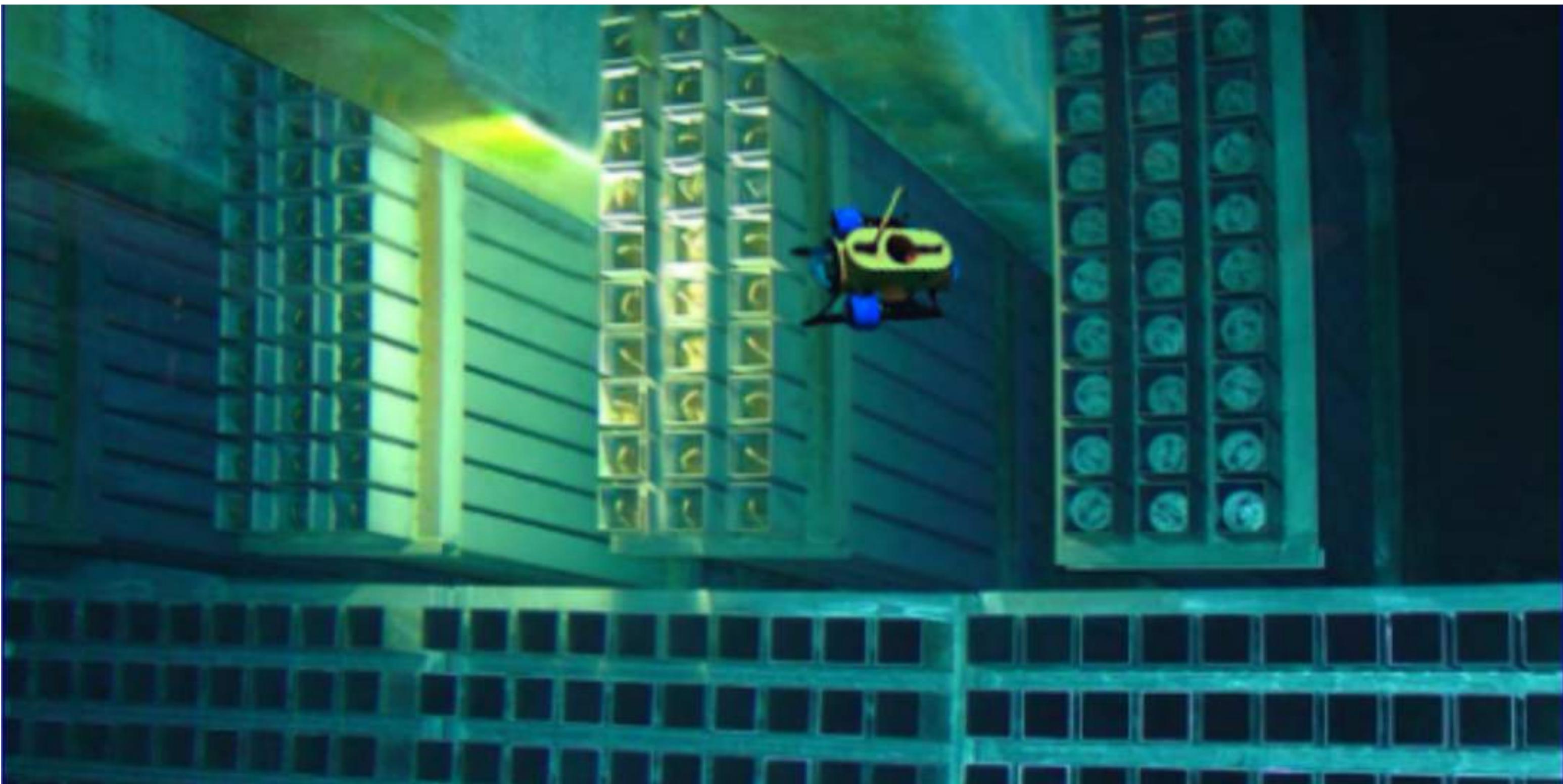
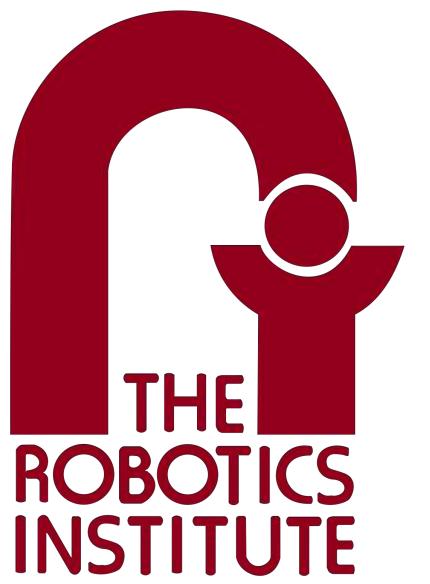


Localized Imaging and Mapping for Underwater Fuel Storage Basins



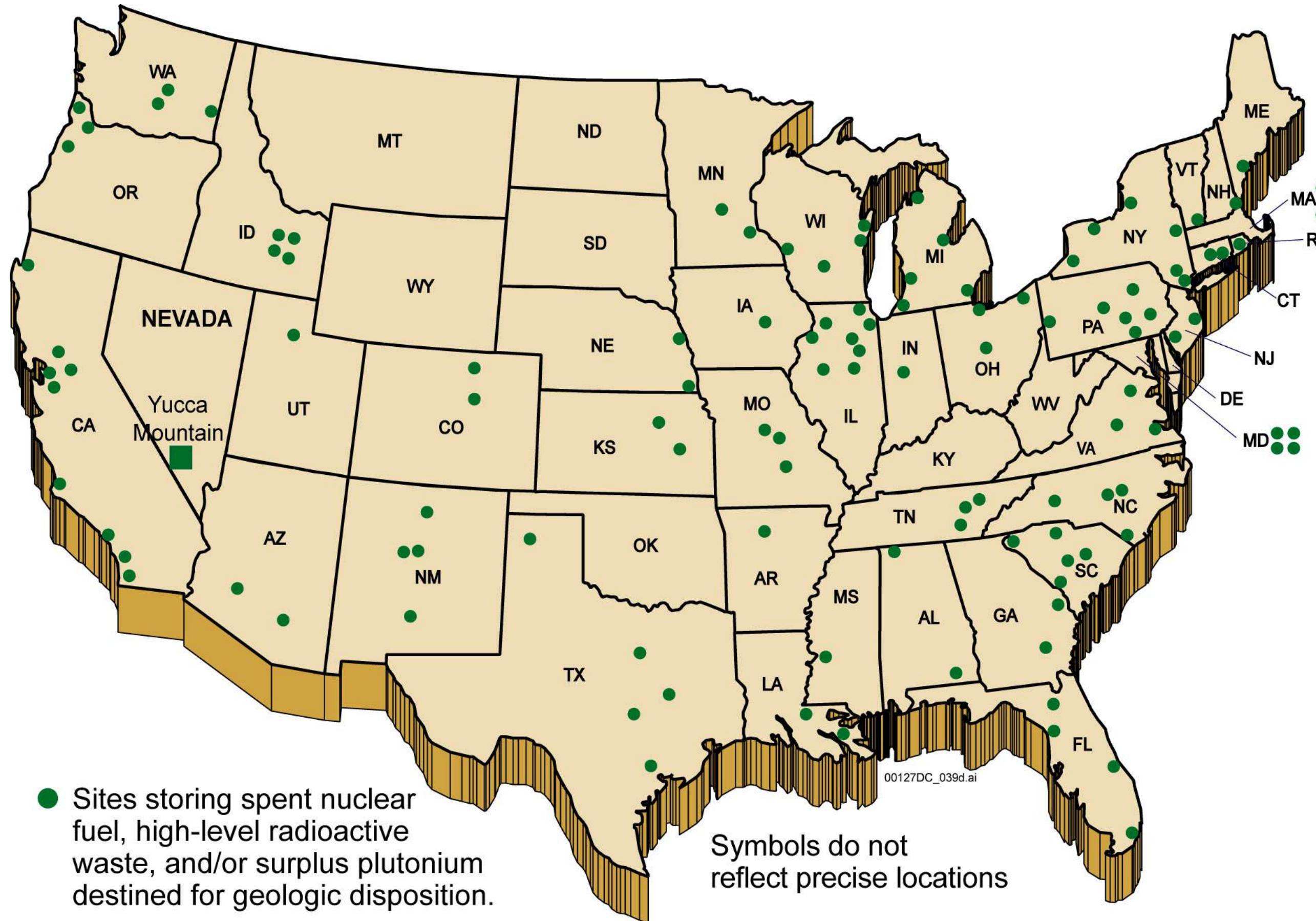
Jerry Hsiung, Andrew Tallaksen, Lawrence Papincak, Sudharshan Suresh, Heather Jones,
William Whittaker, Michael Kaess

March 22, 2018



Carnegie
Mellon
University

Spent Nuclear Fuel (SNF) Storage



Current SNF storage sites

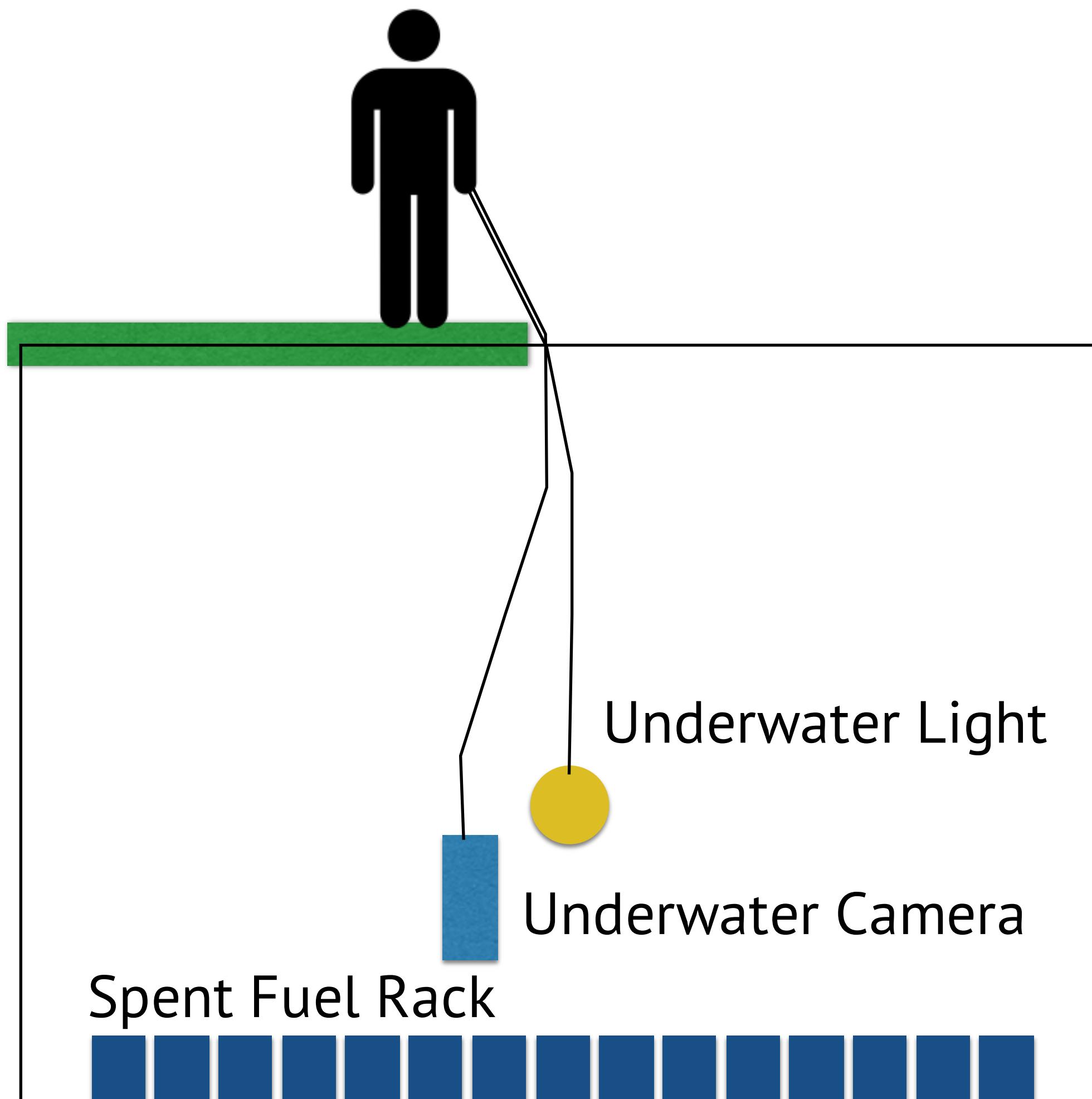


SNF is stored in water pool to shield its radioactive properties

Human Inspection is infeasible



Current SNF Inspection Methods



Existing Inspection Examples

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

Defense Nuclear Facilities Safety Board
Technical Report

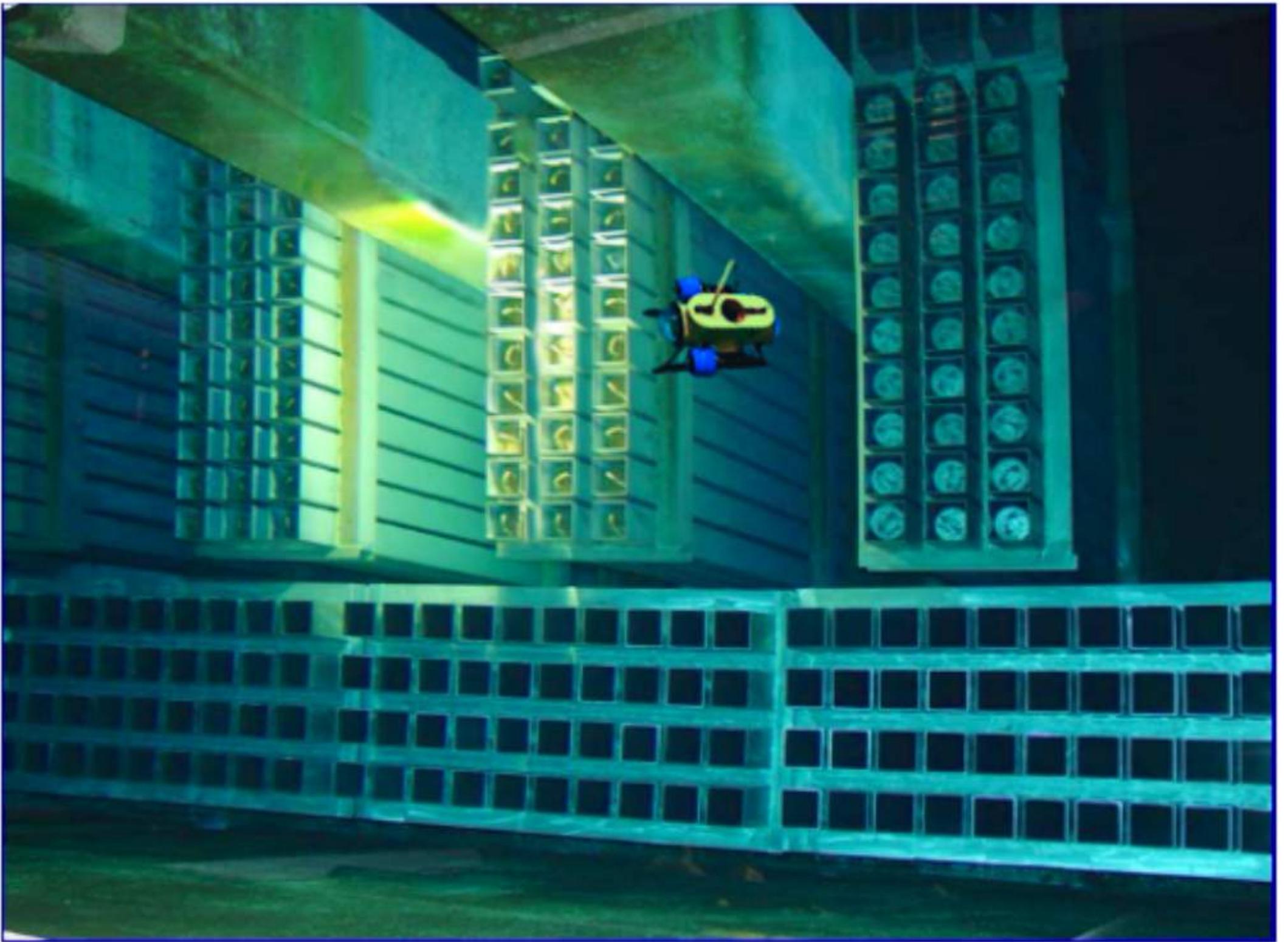


January 2013



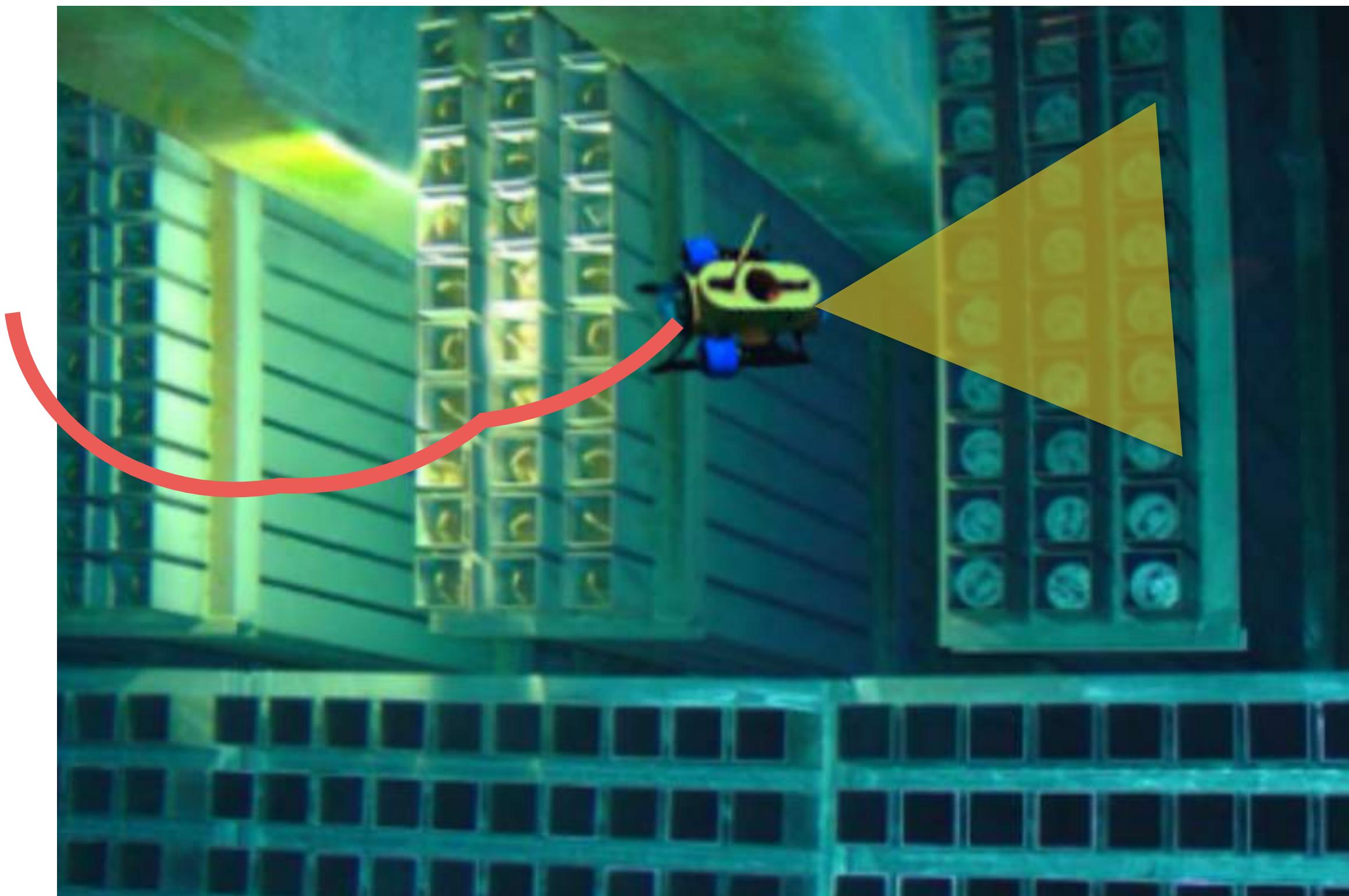
Savannah River Site's ageing cracked SNF containers

Remotely Operated Sensor Package

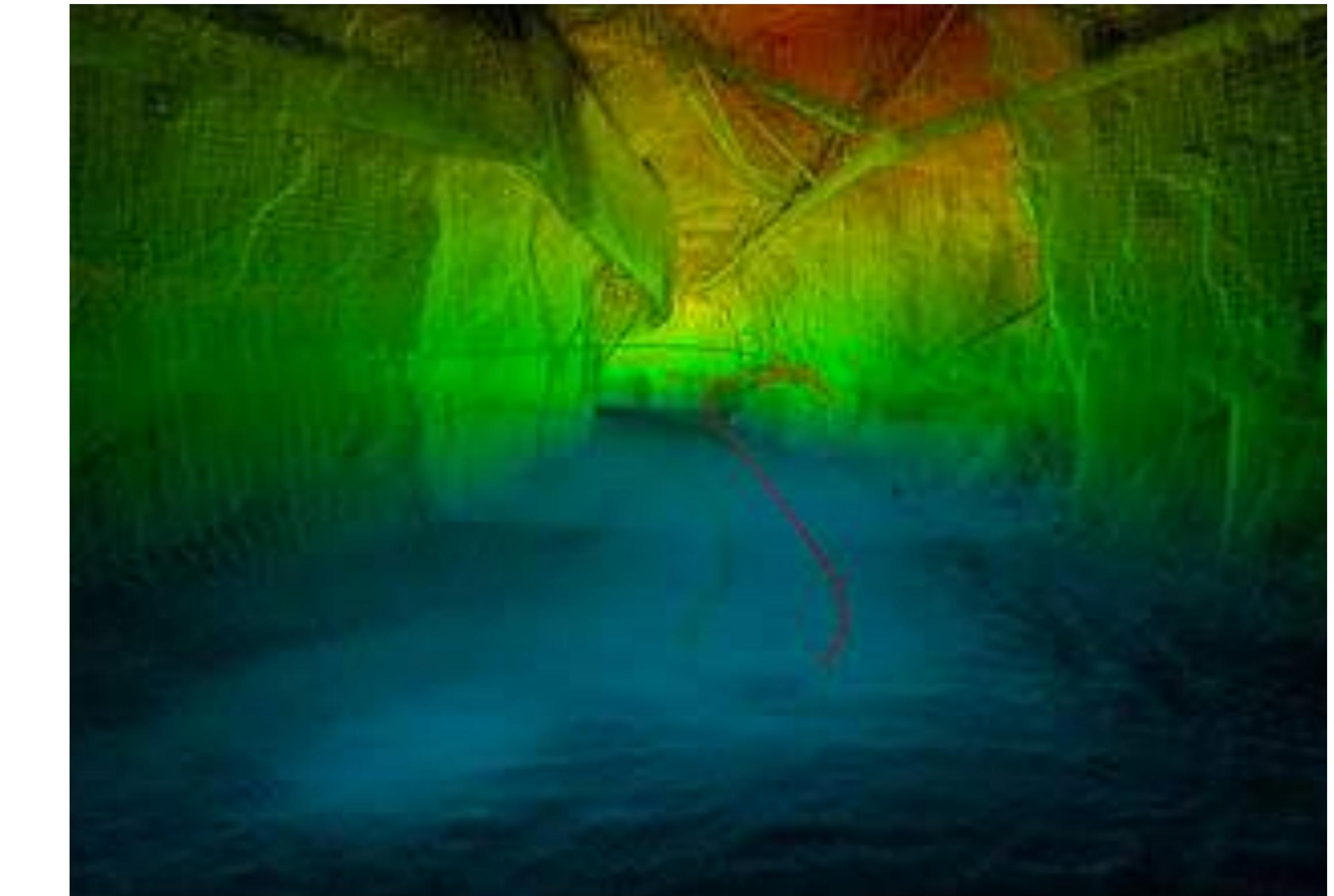


A robot-mounted sensor pod will provide localised inspection, enabling operators to pinpoint sensor reading locations relative to 3D structure.

Remotely Operated Inspection System



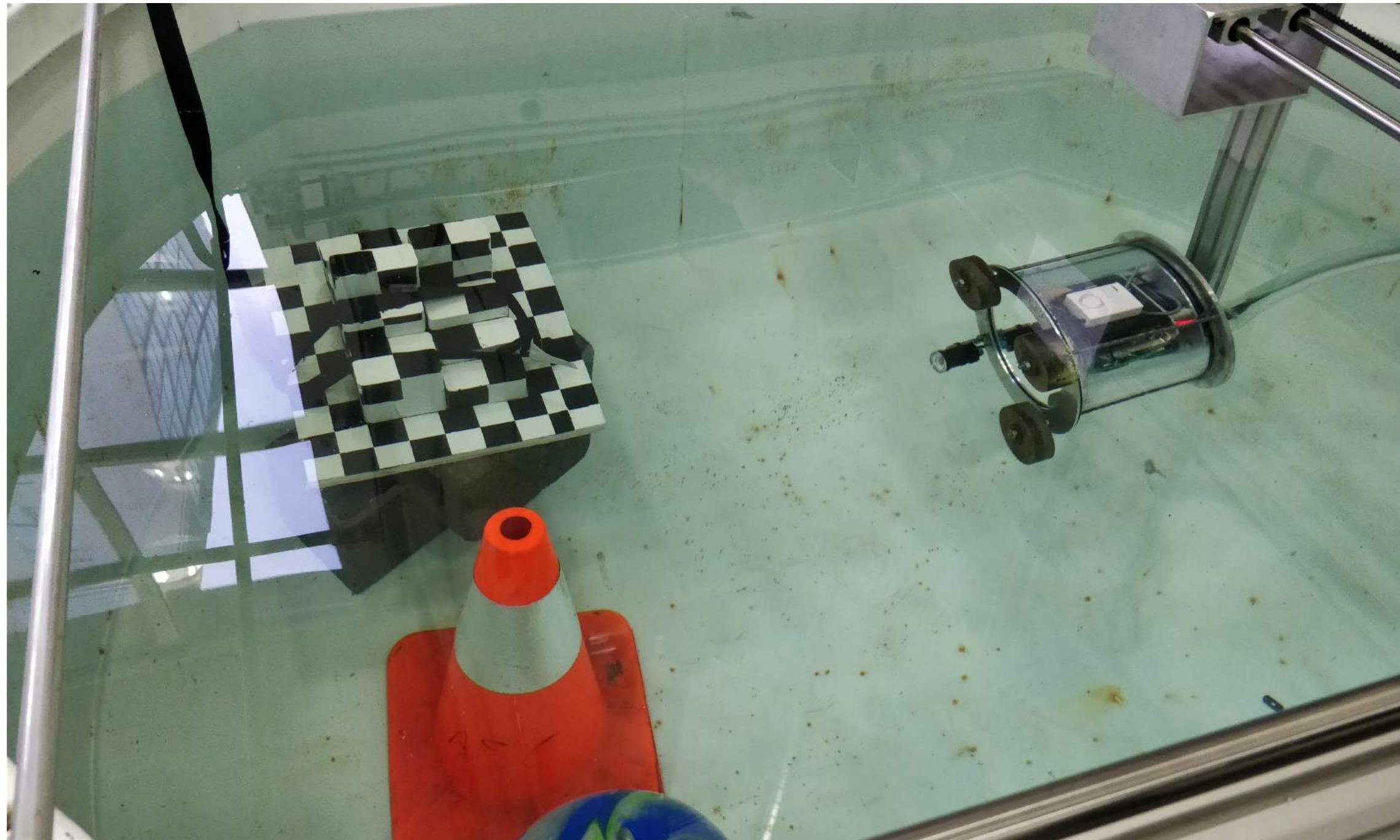
Localised Data Collection



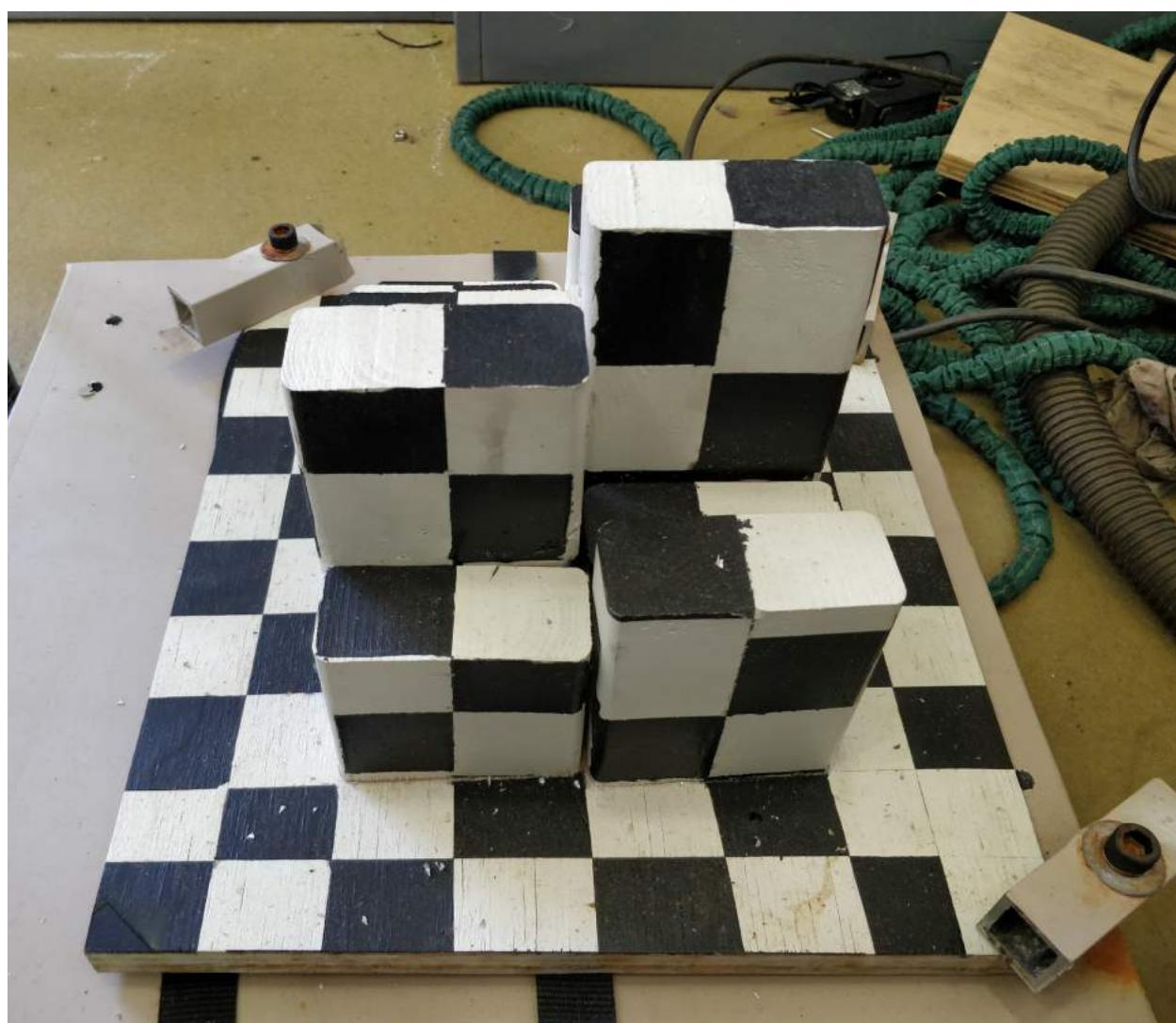
Model Reconstruction

Underwater Mapping

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



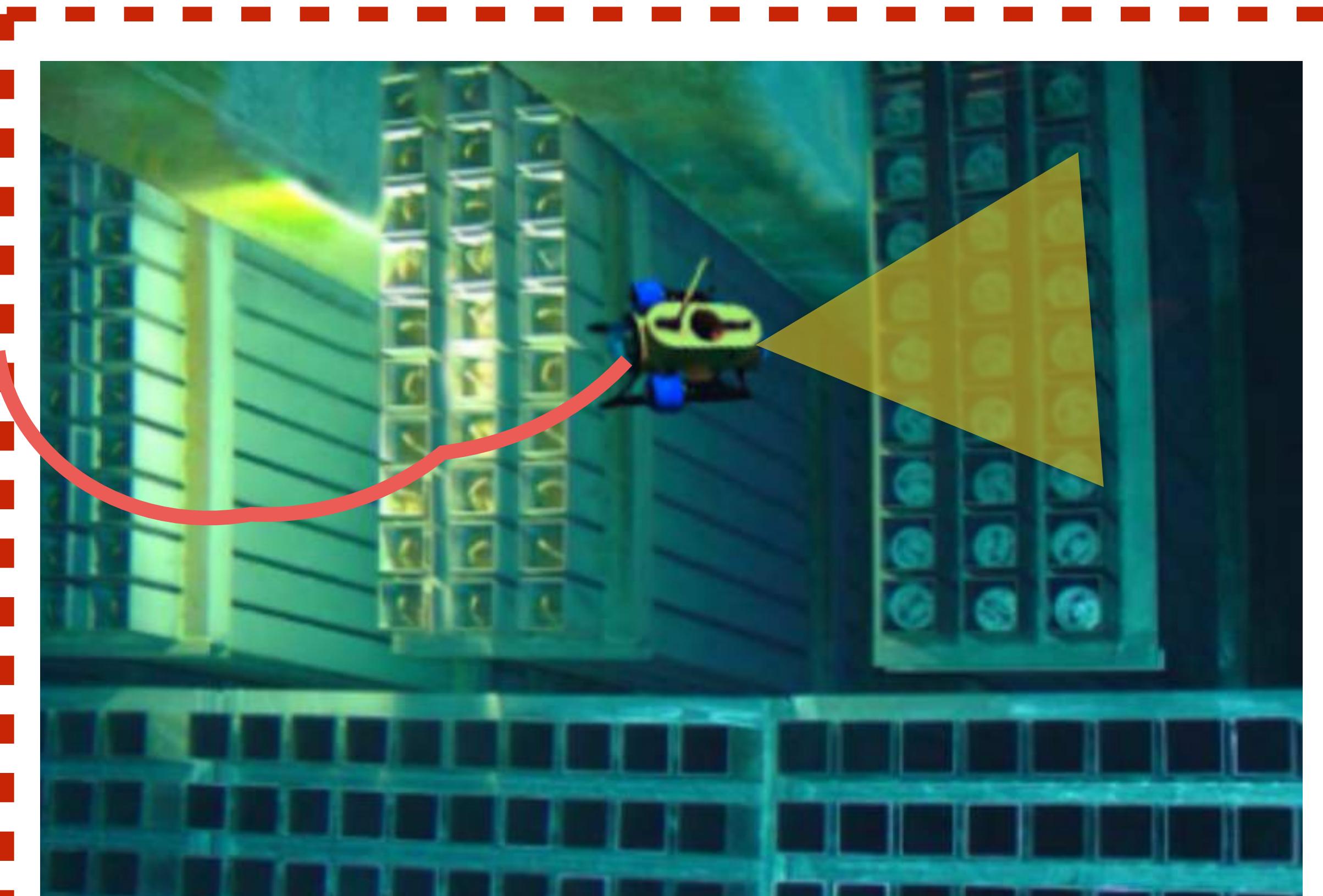
Checkered blocks



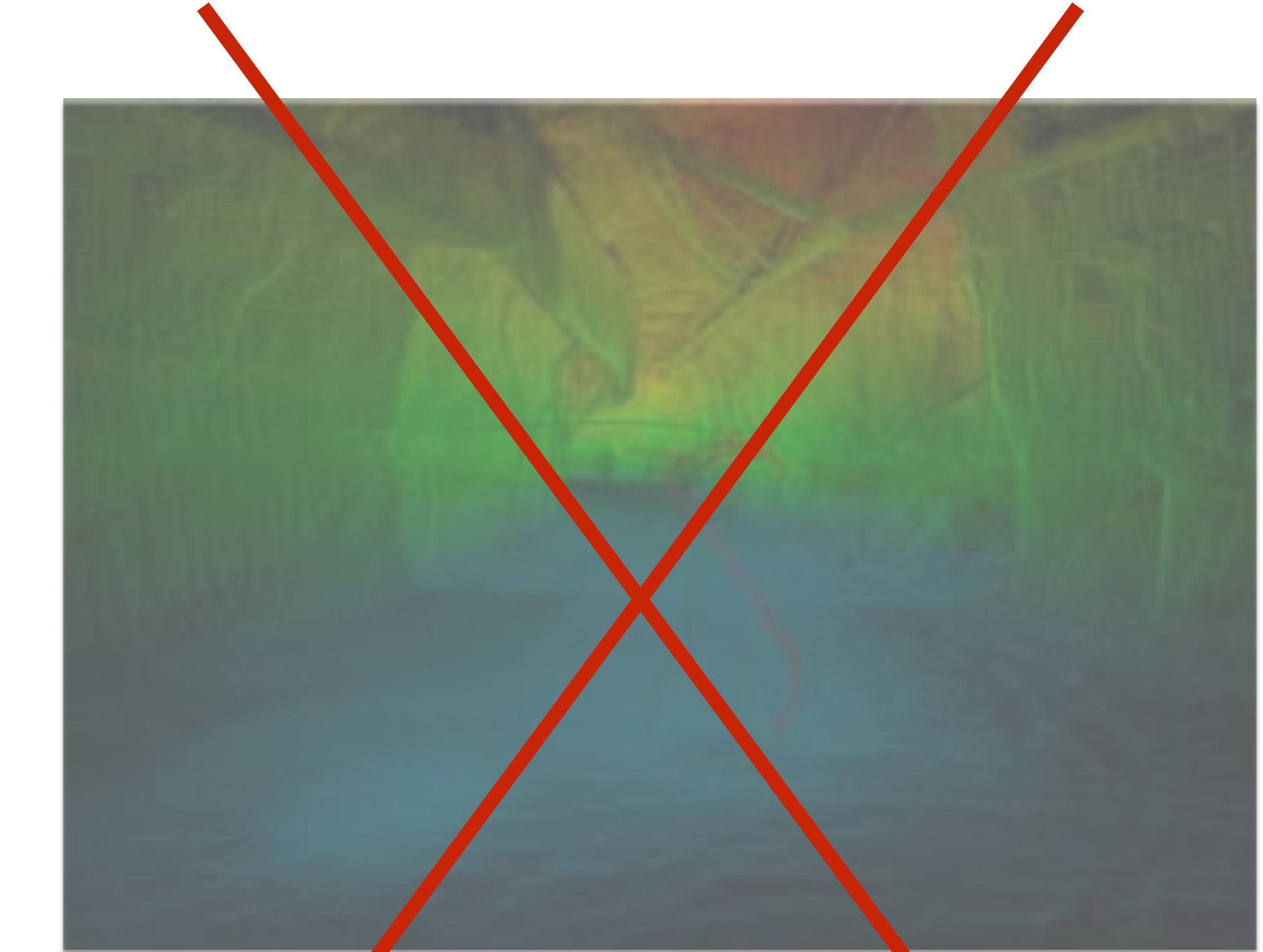
Bowling Ball



Today's Talk...

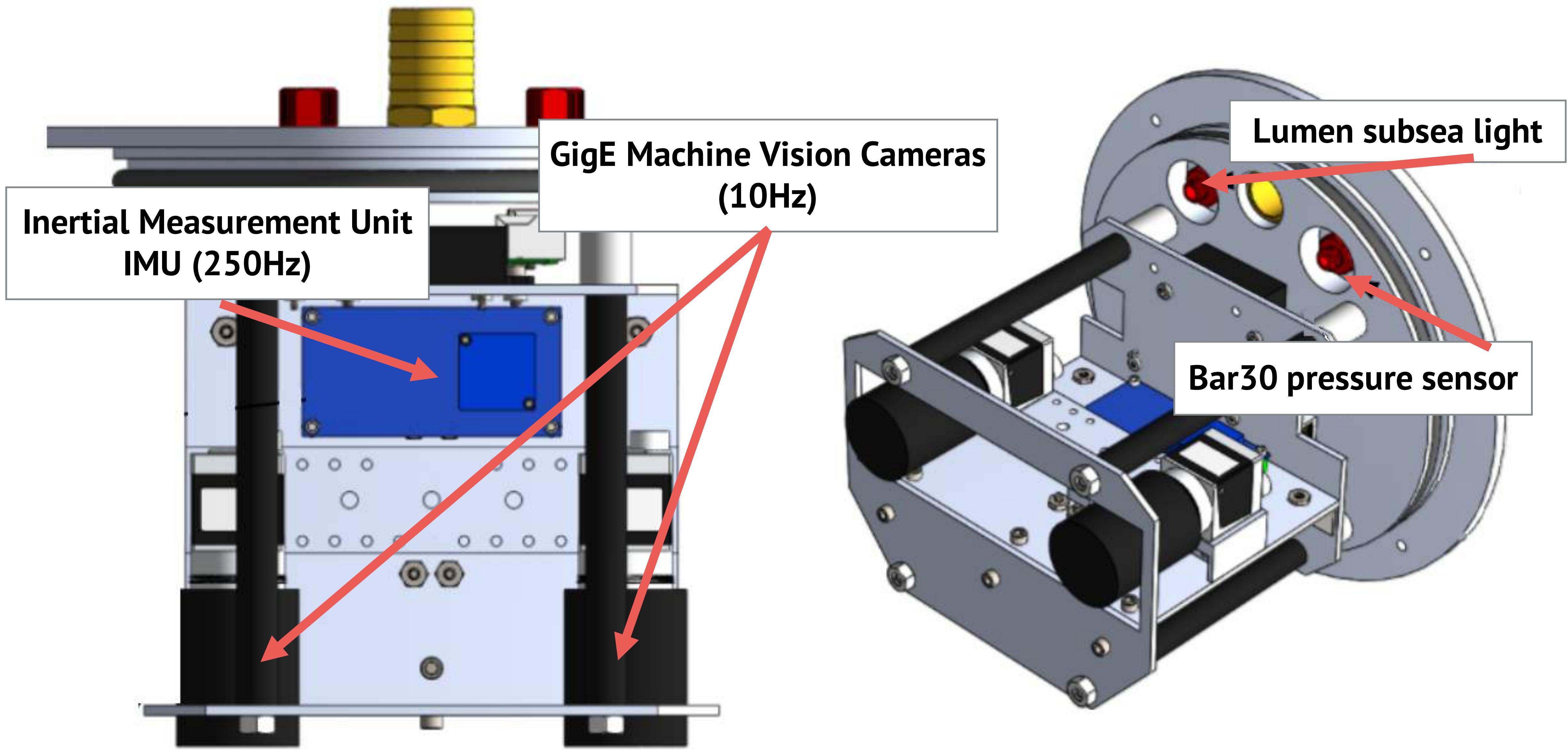


Localised Data Collection



Model Reconstruction

Inspection Sensor Pod

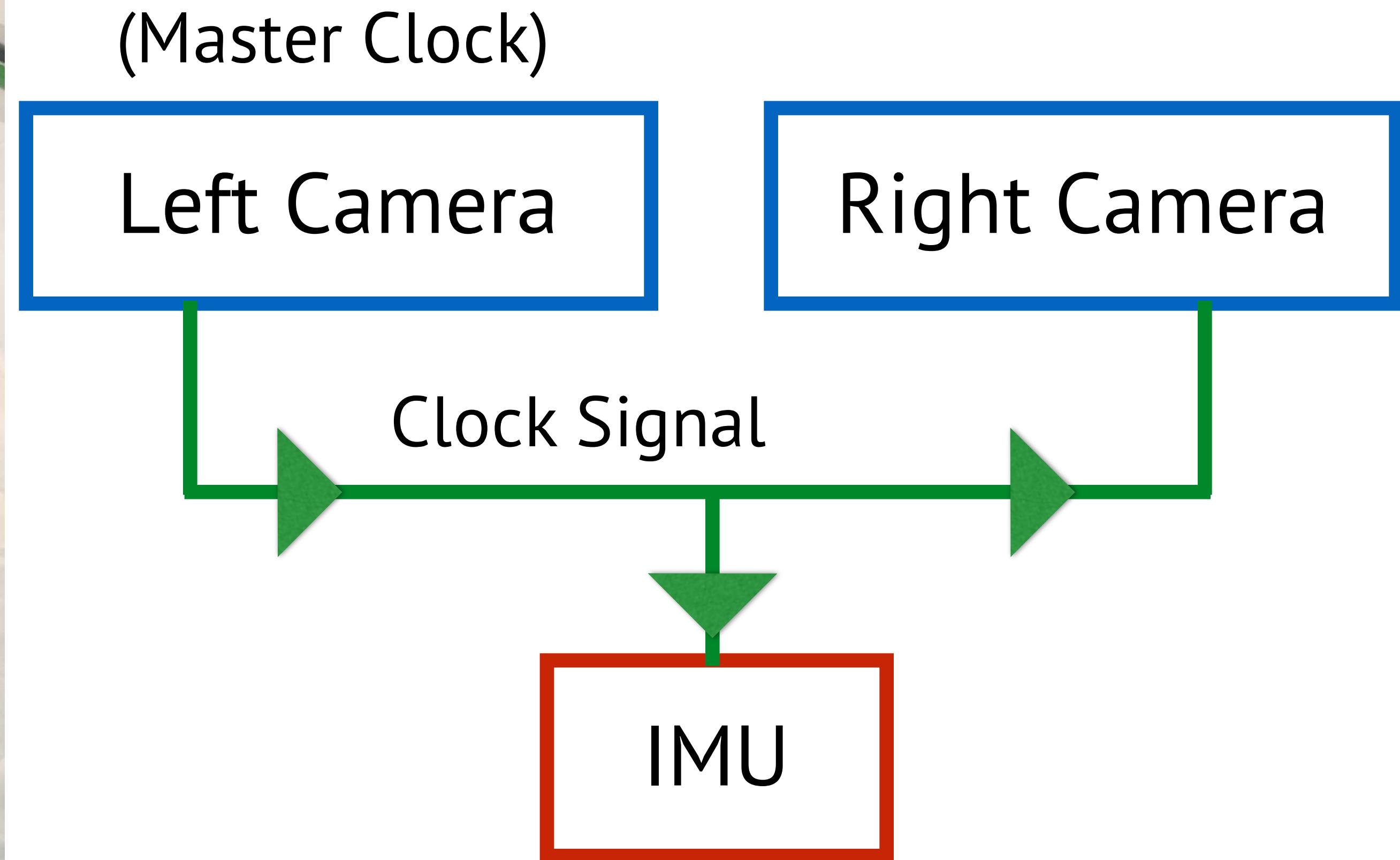
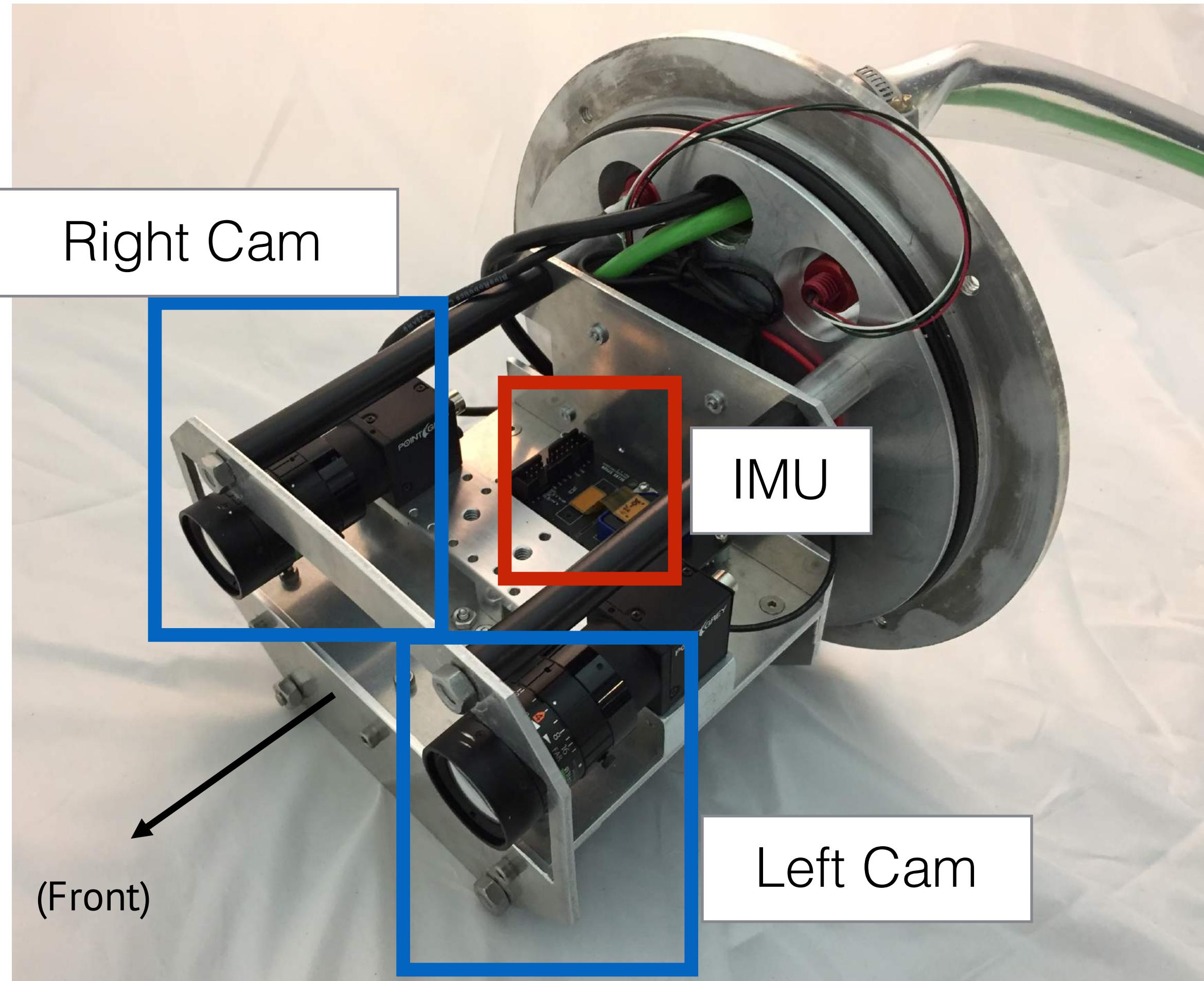


Time-Synchronisation of Sensors

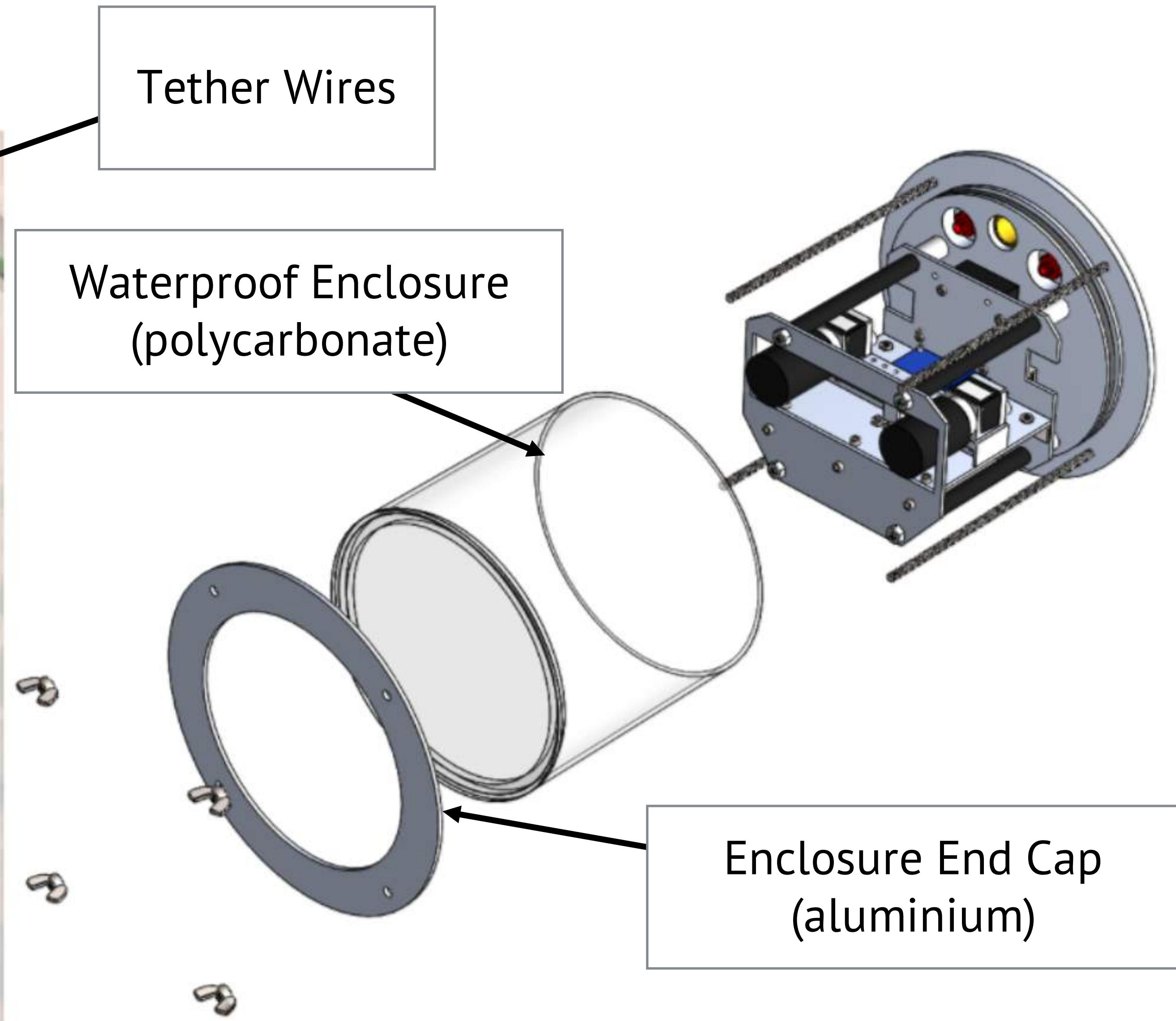
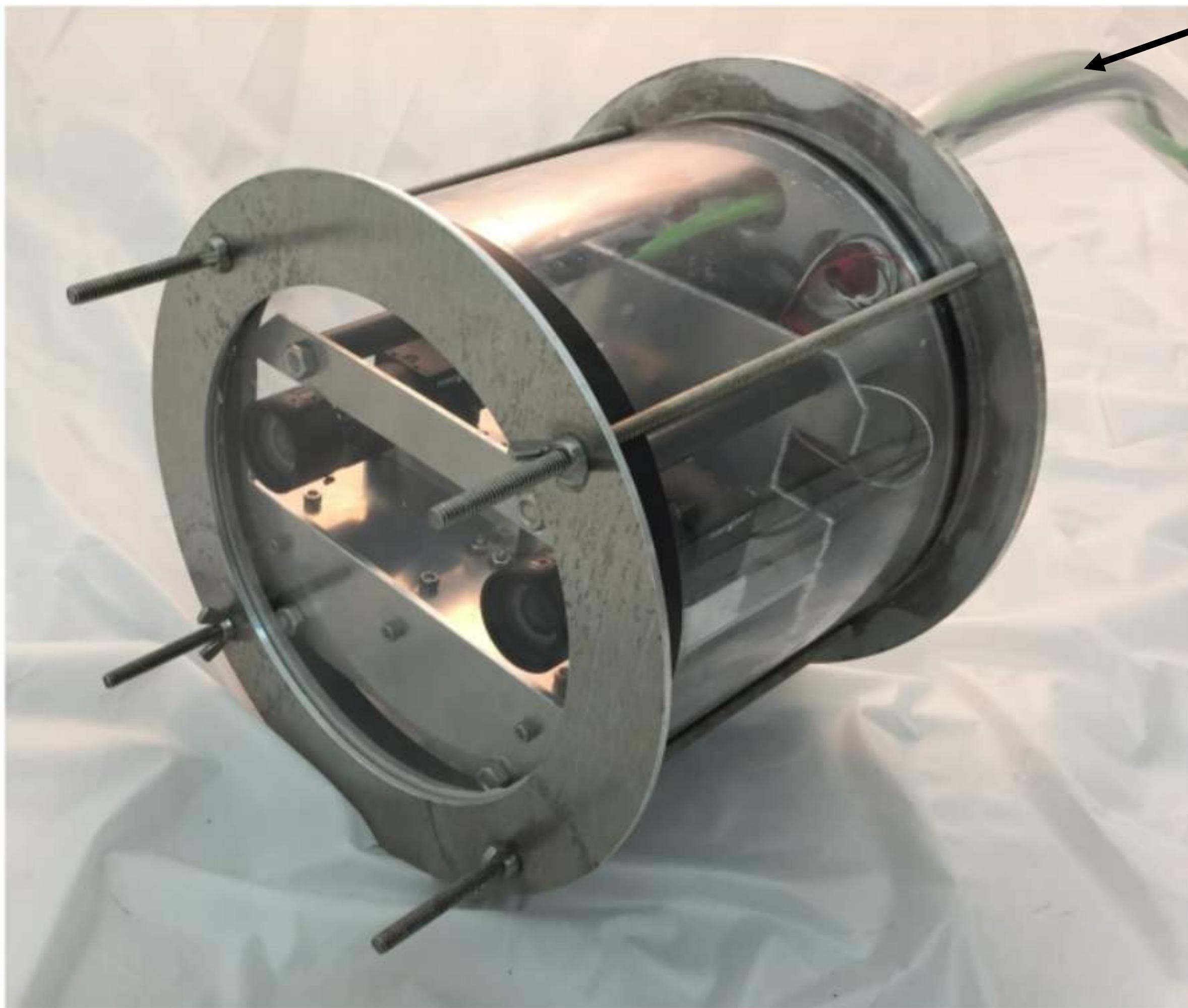
- ▶ Each sensor uses its own clock to time stamp data
- ▶ Essential to ensure accurate sensor fusion for localisation
- ▶ Sensors record at various rates
- ▶ Clock drifts!



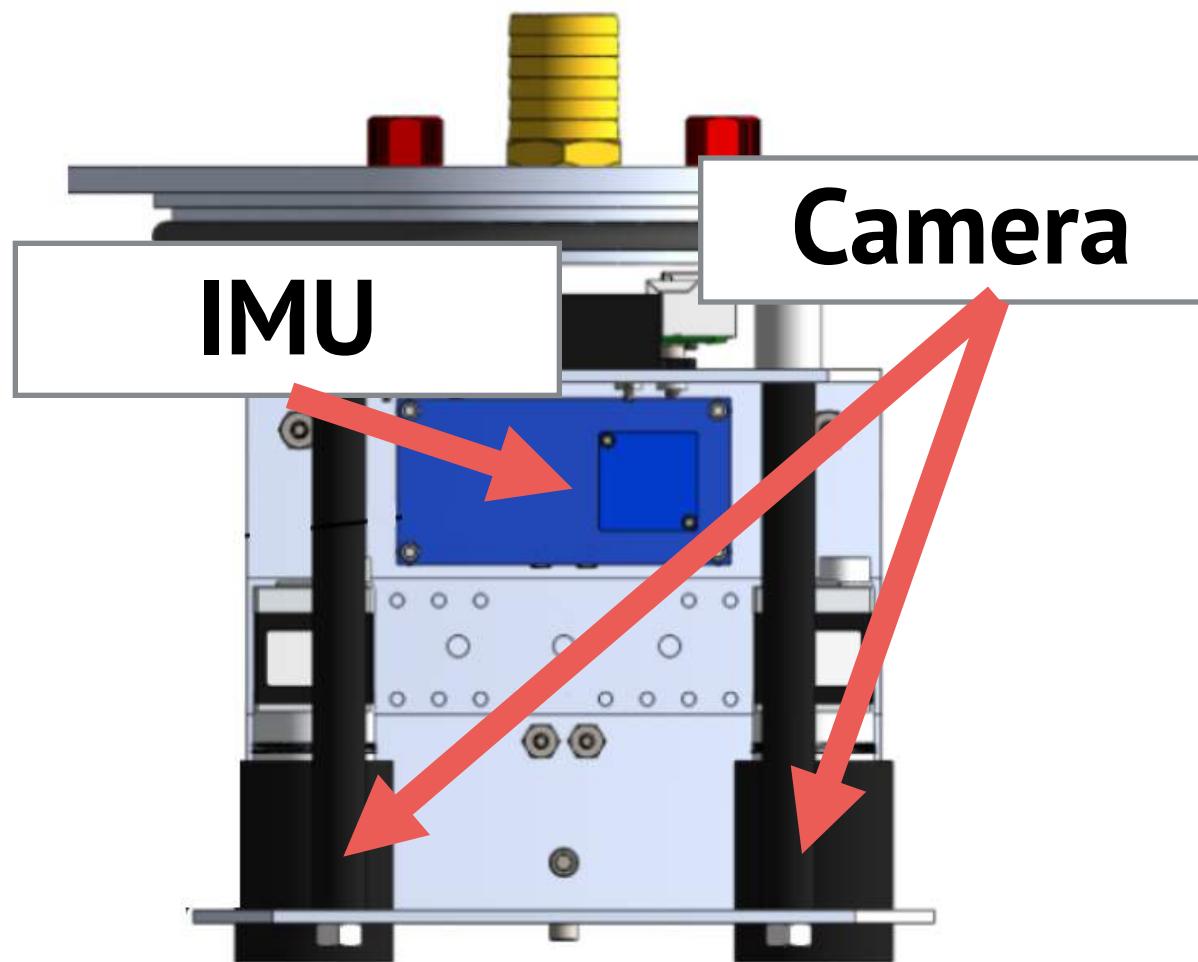
Hardware Synchronisation



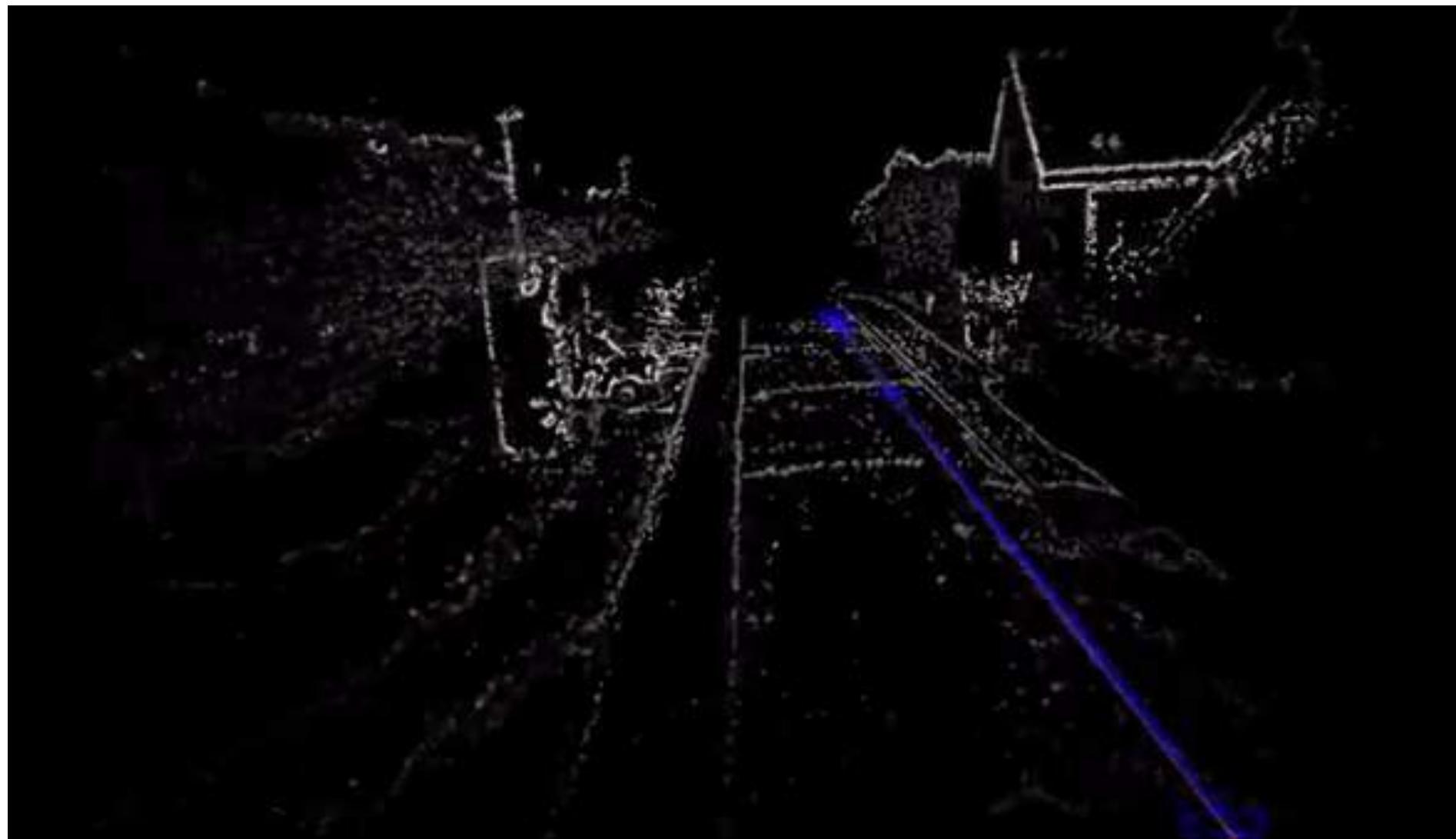
Waterproof enclosure



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”

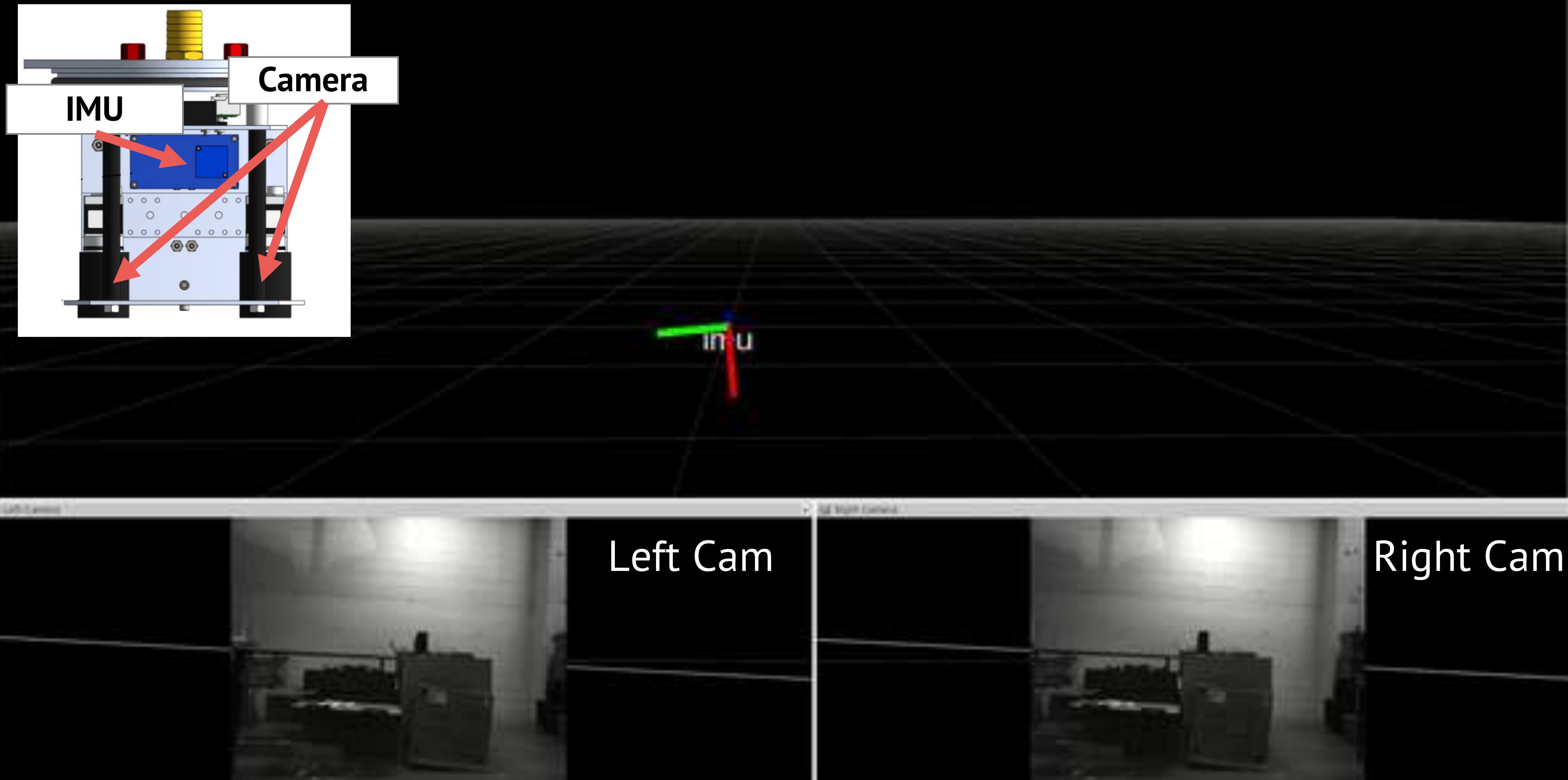
R Mur-Artal et al. “ORB-SLAM”

Visual-Inertial Odometry (VIO) Algorithm

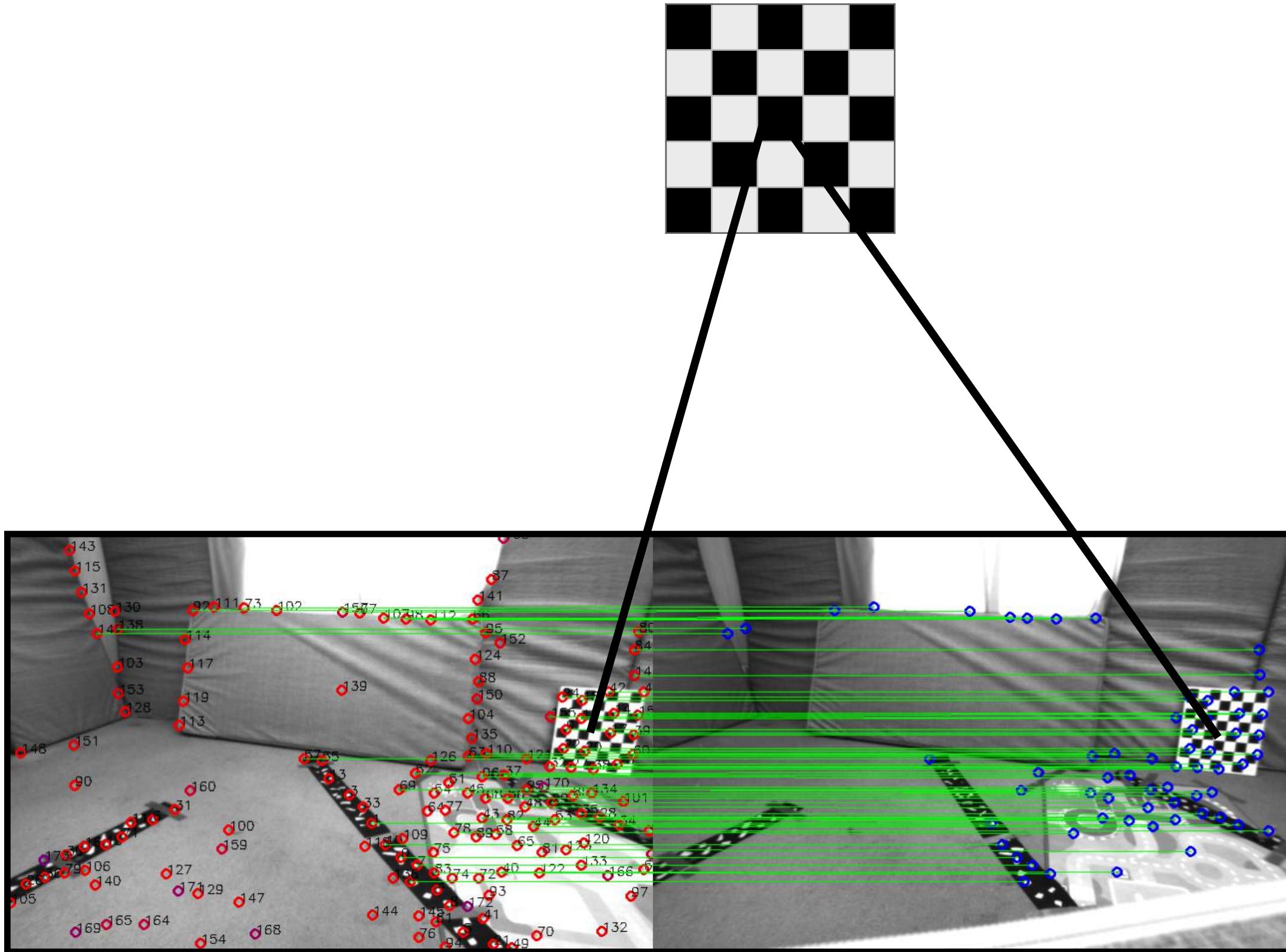
- Combines the bests from visual and inertial information
- Utilizes synchronised sensor information



VIO for Inspection

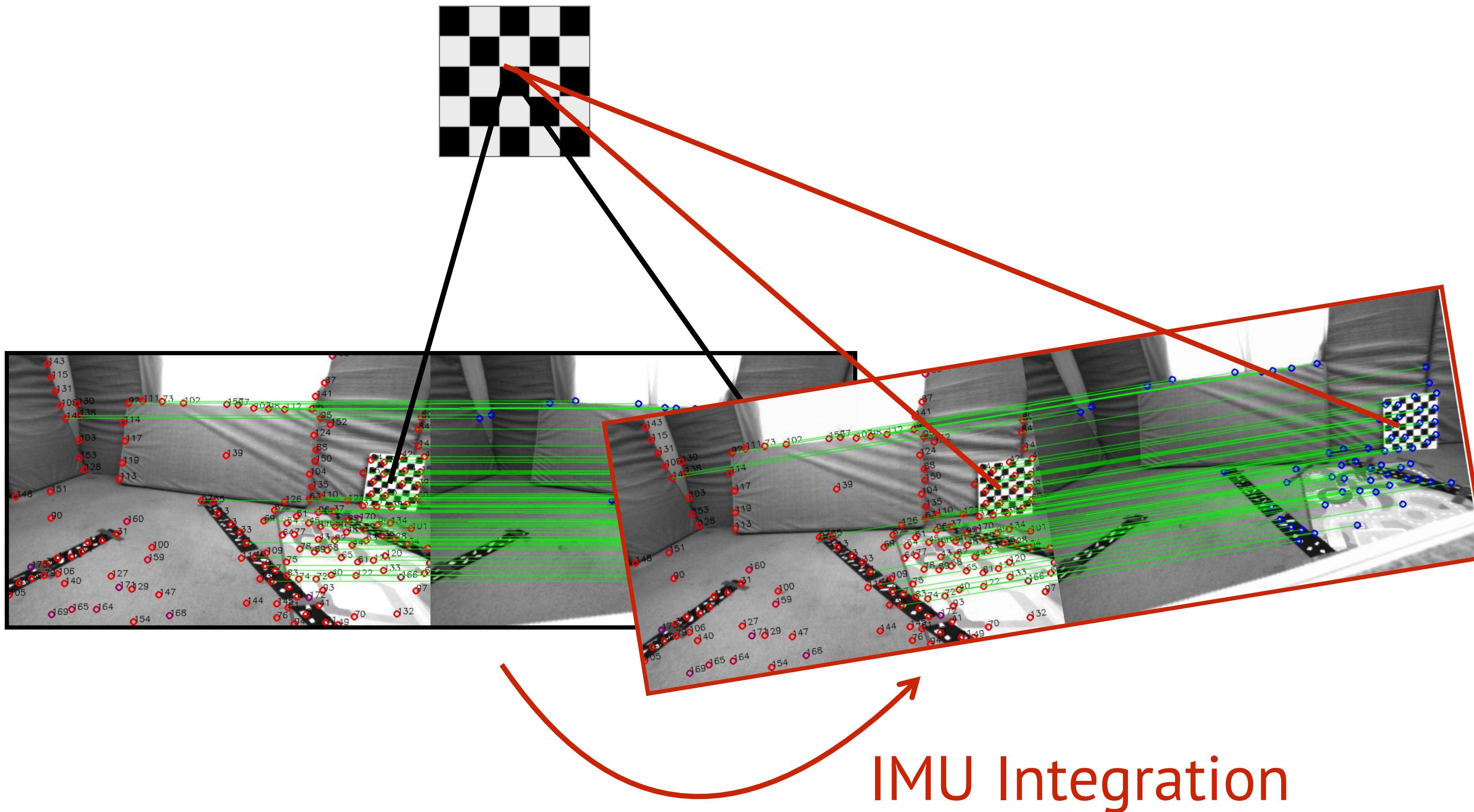


Stereo Triangulation for VIO

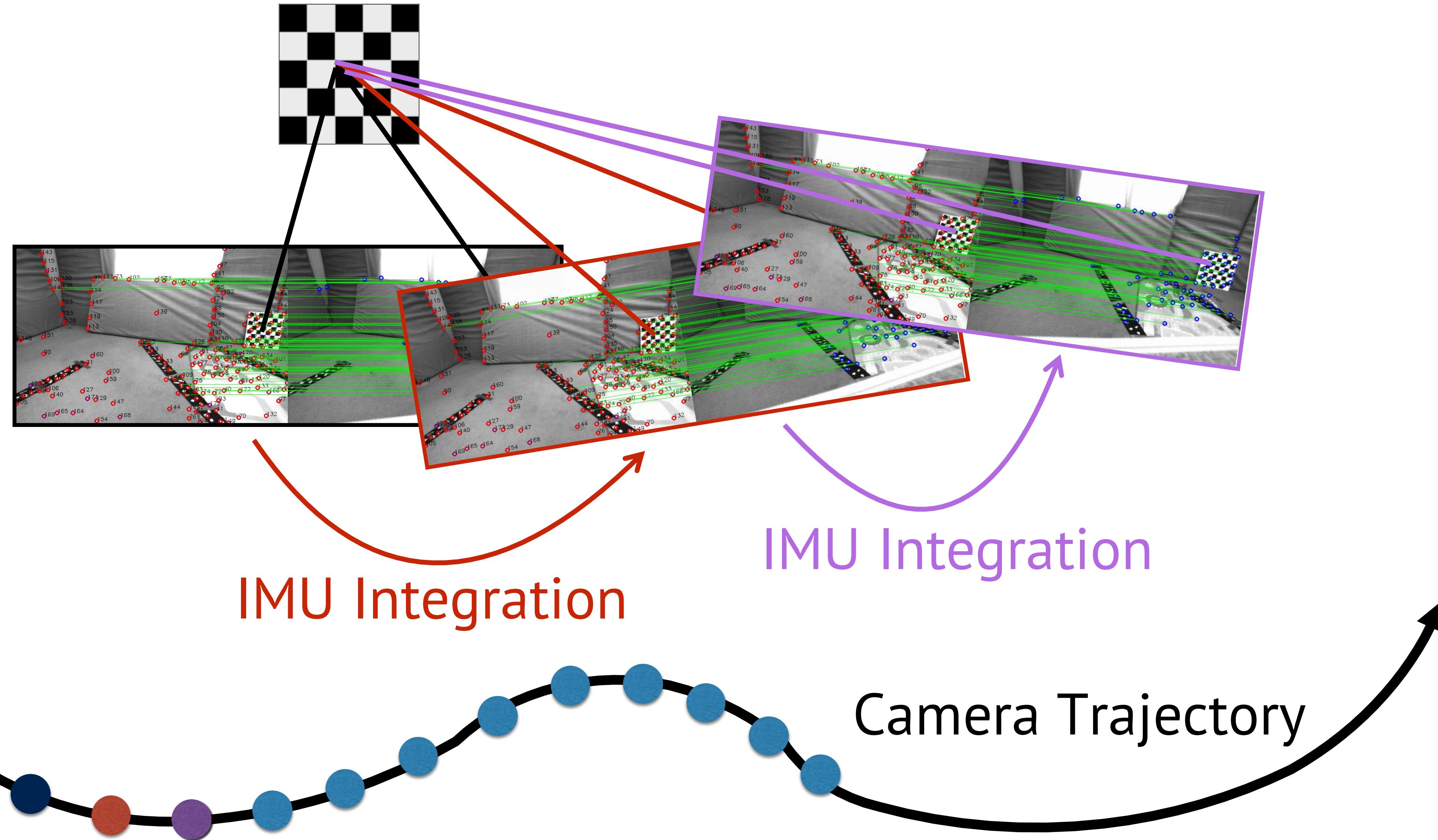


The corresponding points are triangulated into the 3D world

Camera moves...

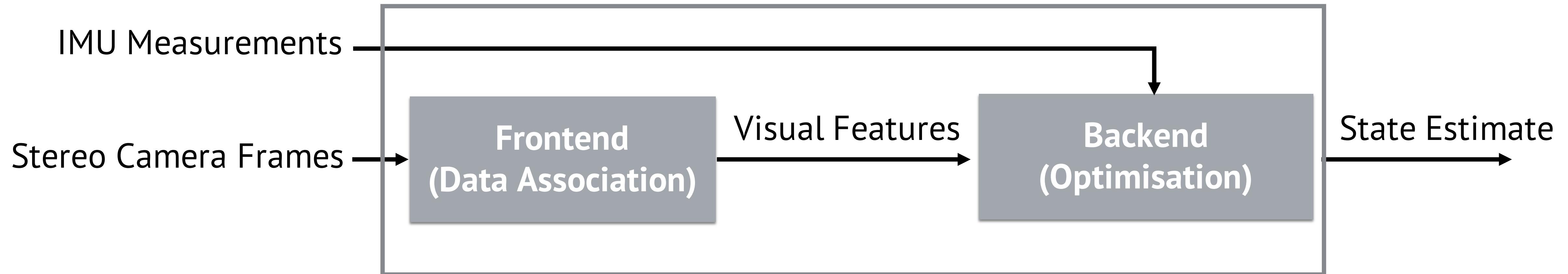


A sequence of camera movements



Details of the VIO system

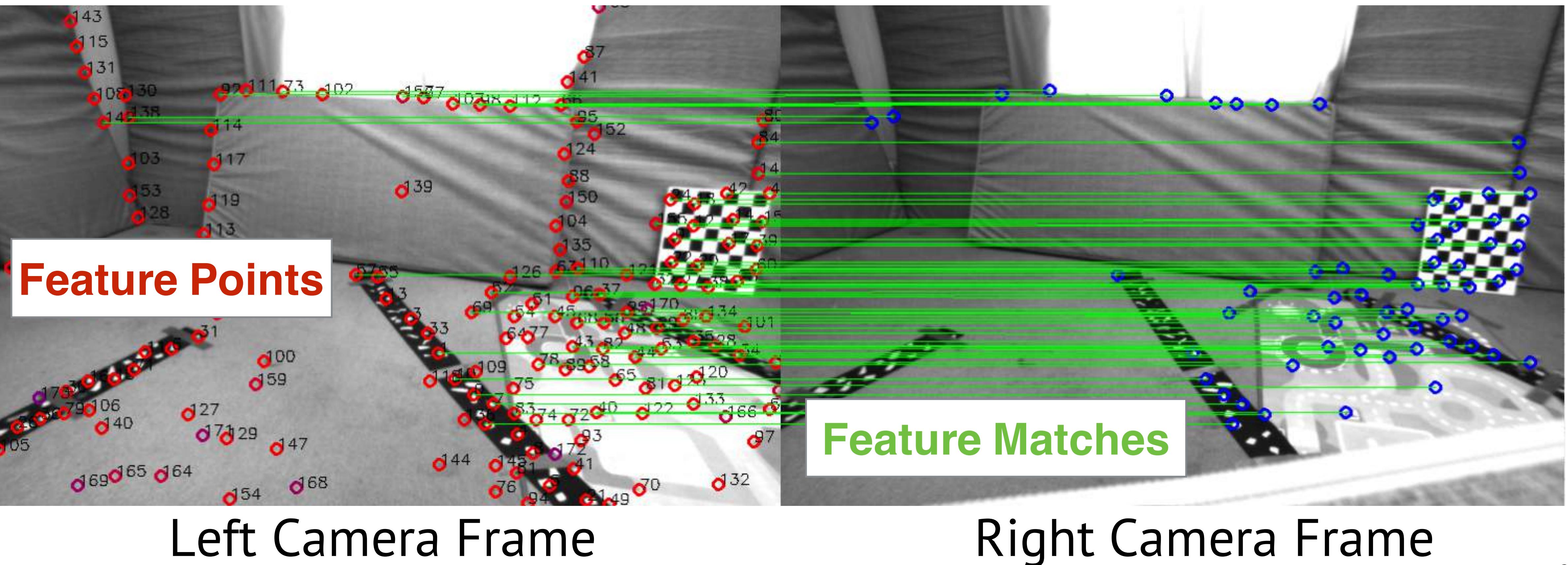
- › A VIO system consists of a frontend and a backend parts
- › Data association Frontend
Optimisation Backend



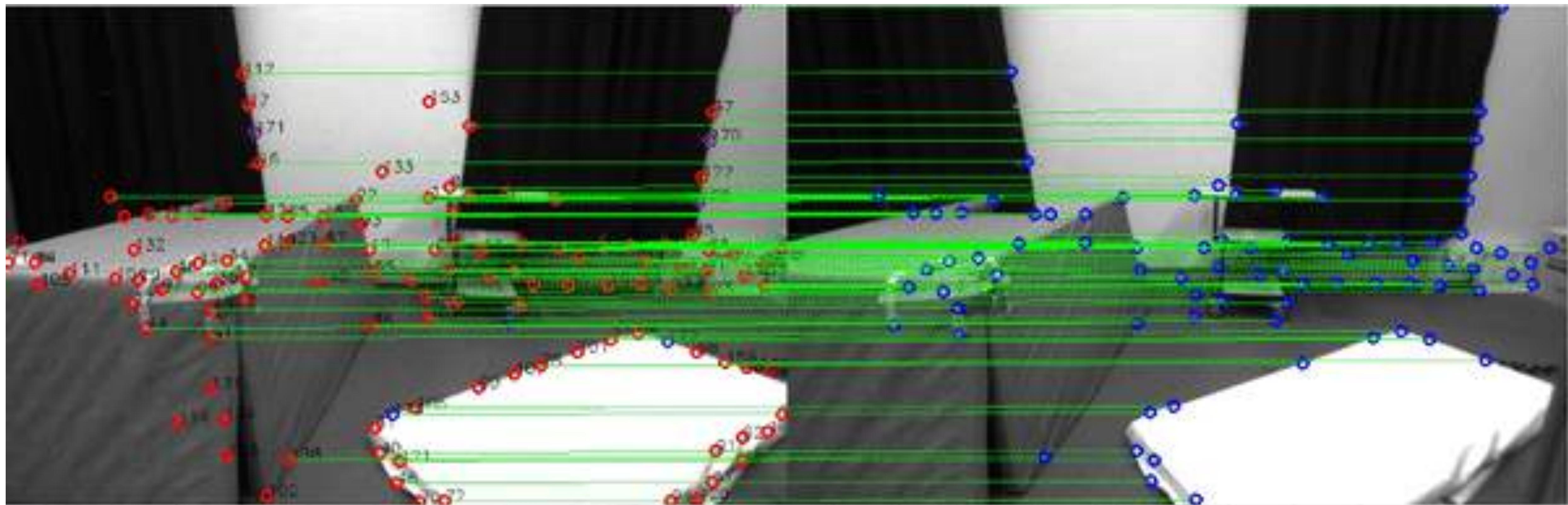
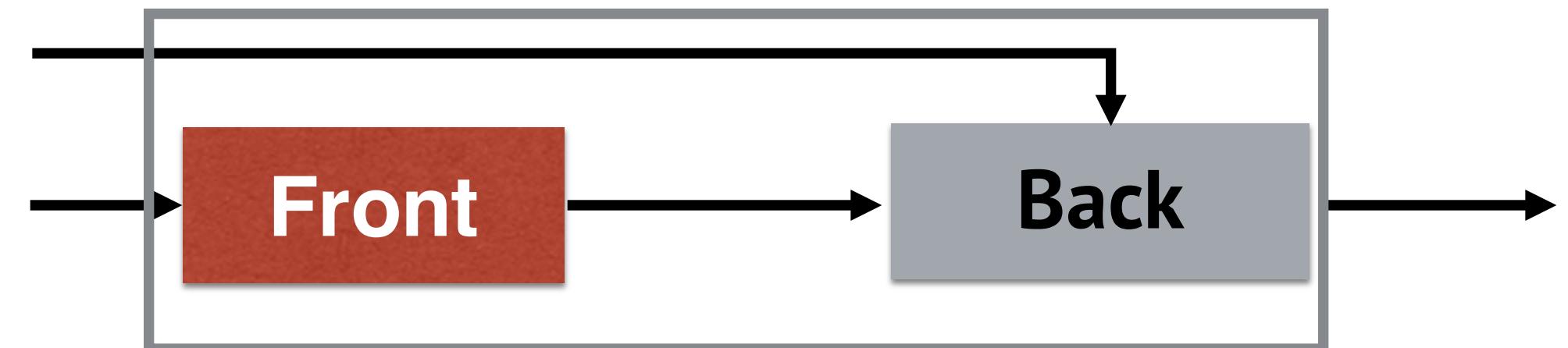
Data Association Frontend

- ▶ Shi-Tomashi Corner Detector

- ▶ Lukas-Kanade Optical Flow feature tracking algorithm (up to 200Hz)



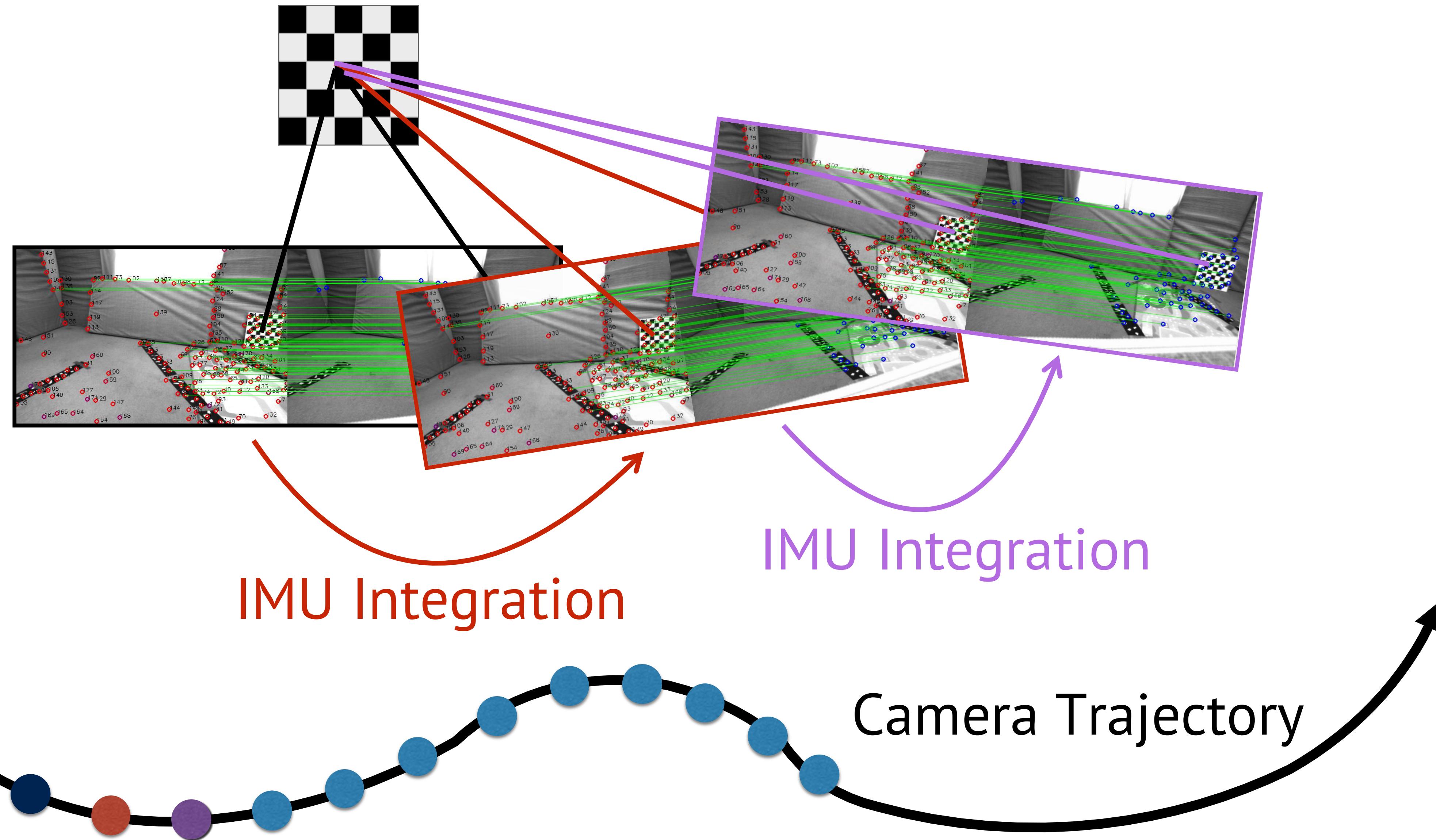
Data Association Frontend



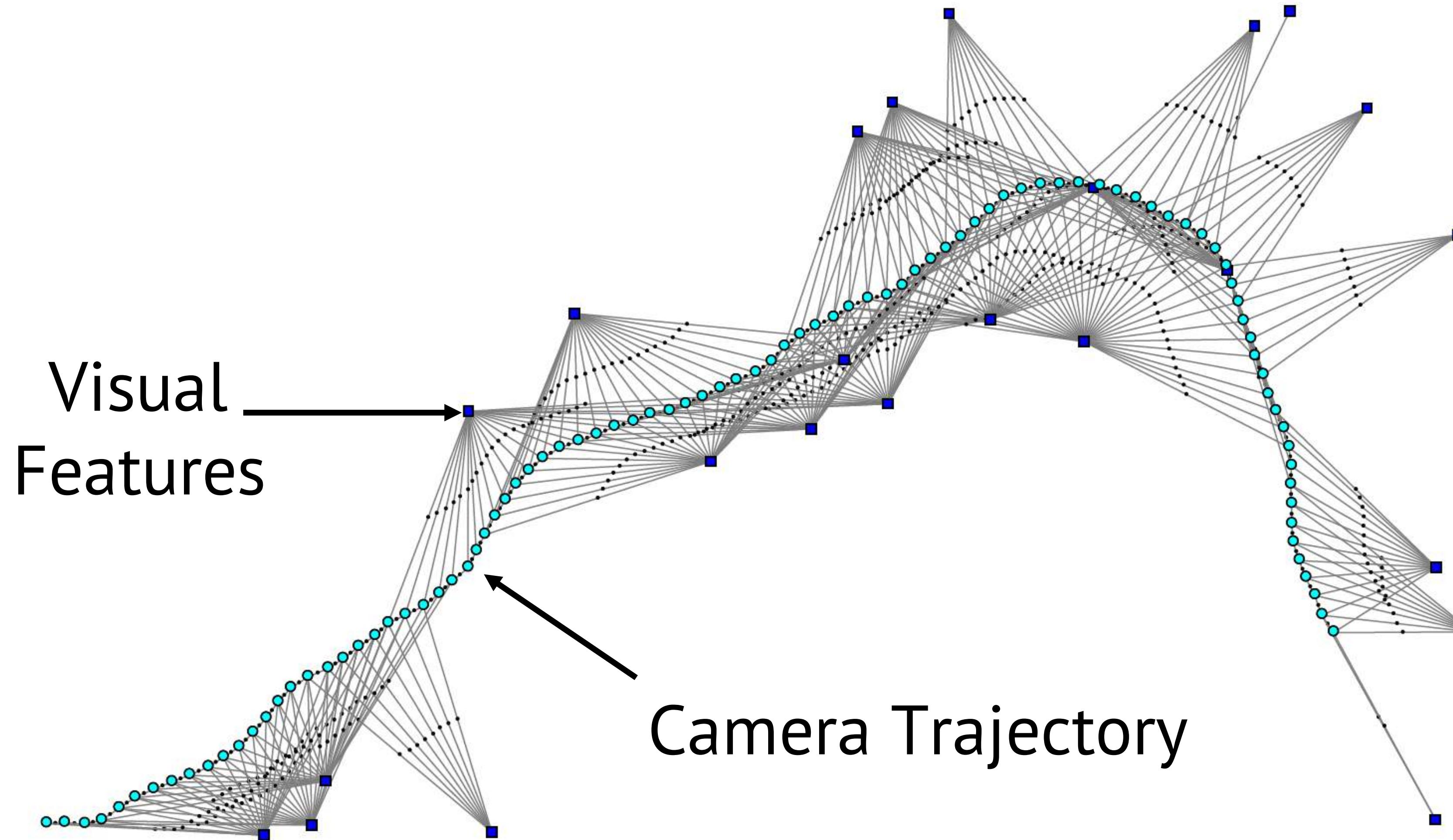
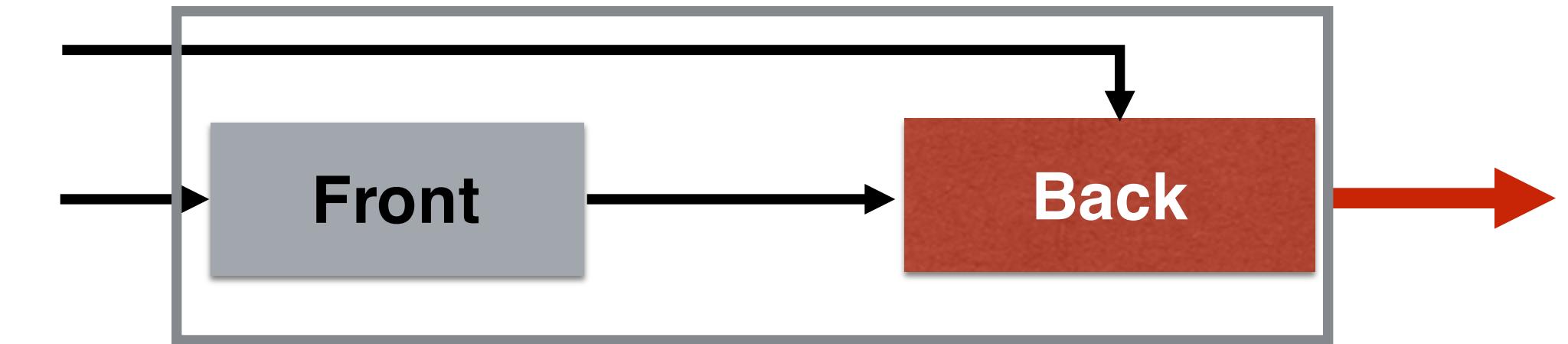
Left Camera Frame

Right Camera Frame

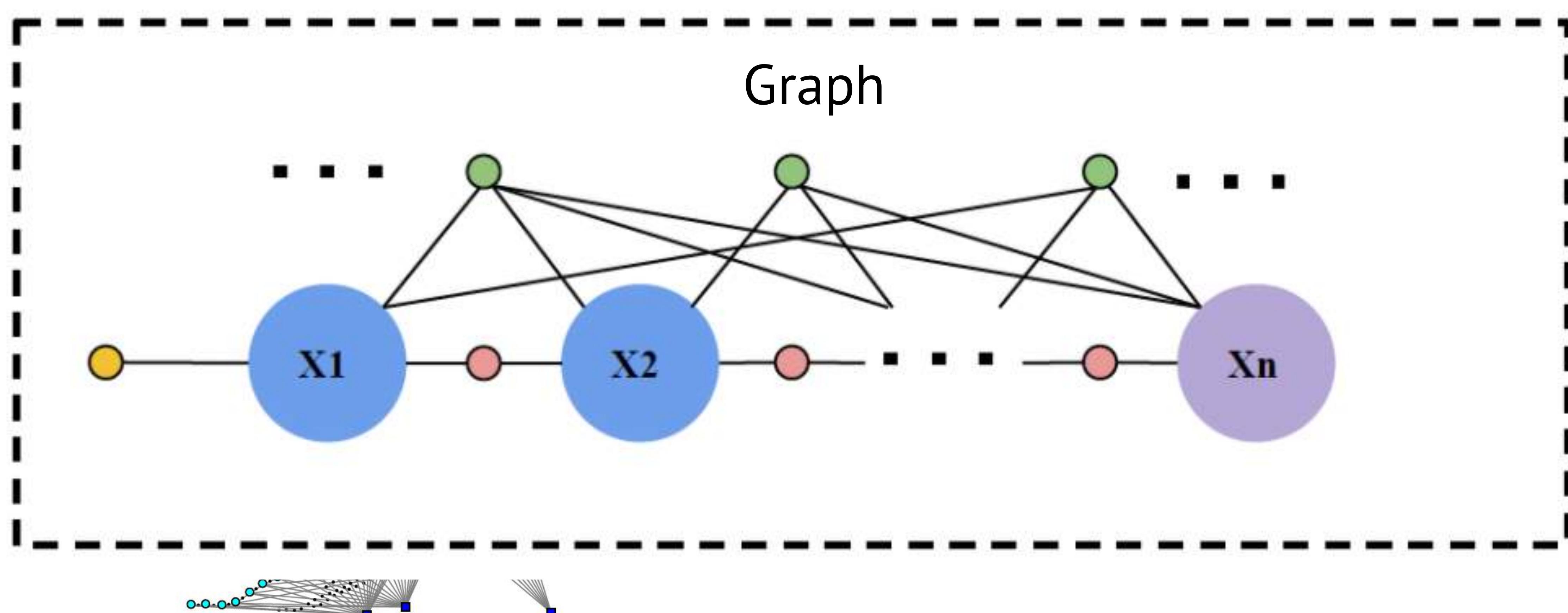
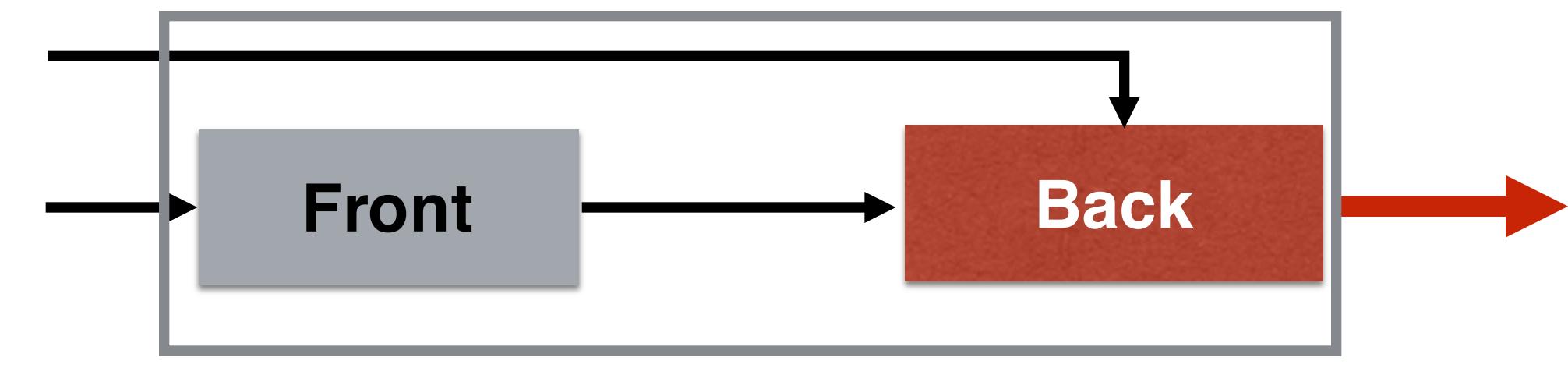
A sequence of camera movements



Optimisation Backend

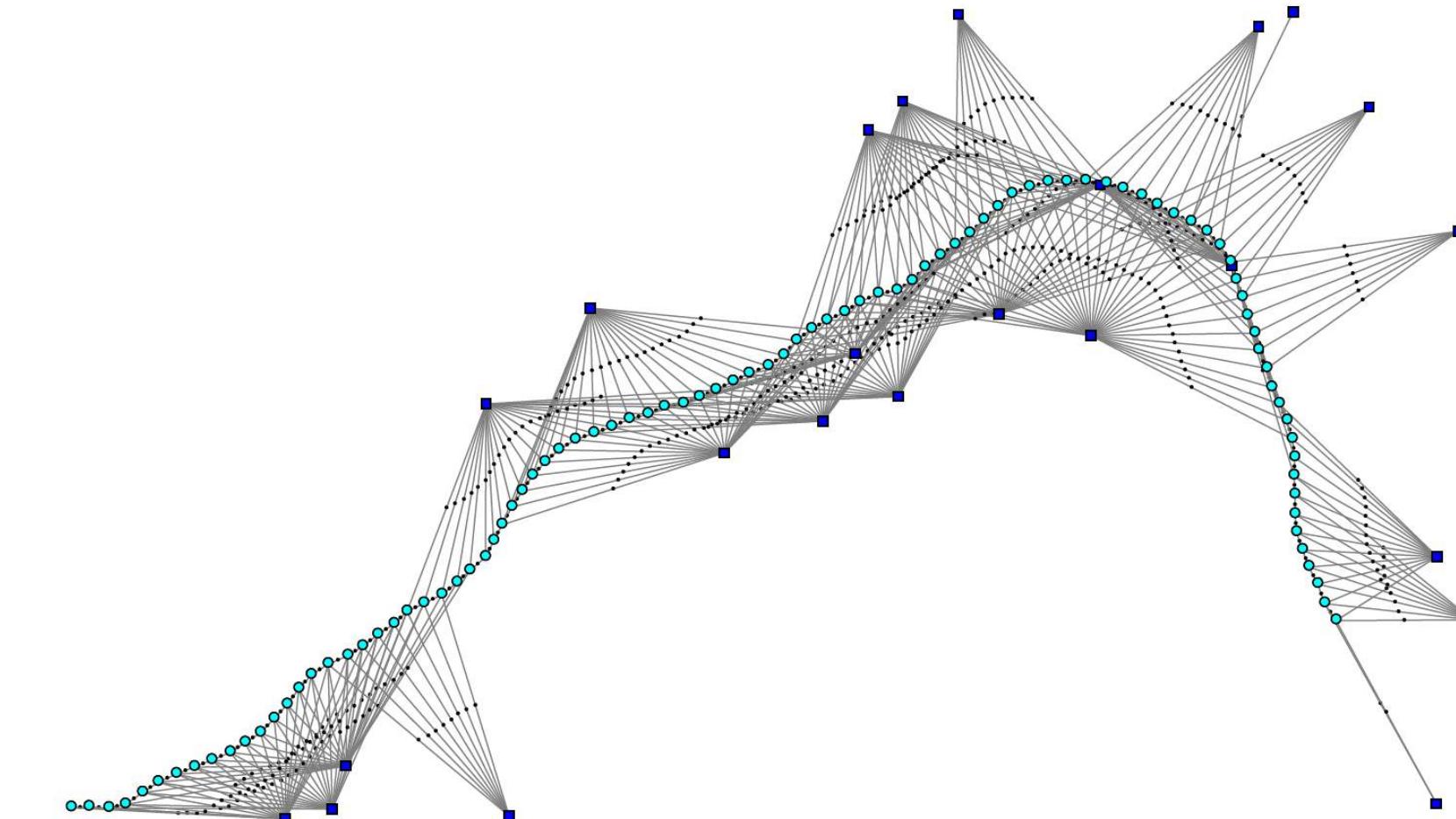


Optimisation Using Graphs

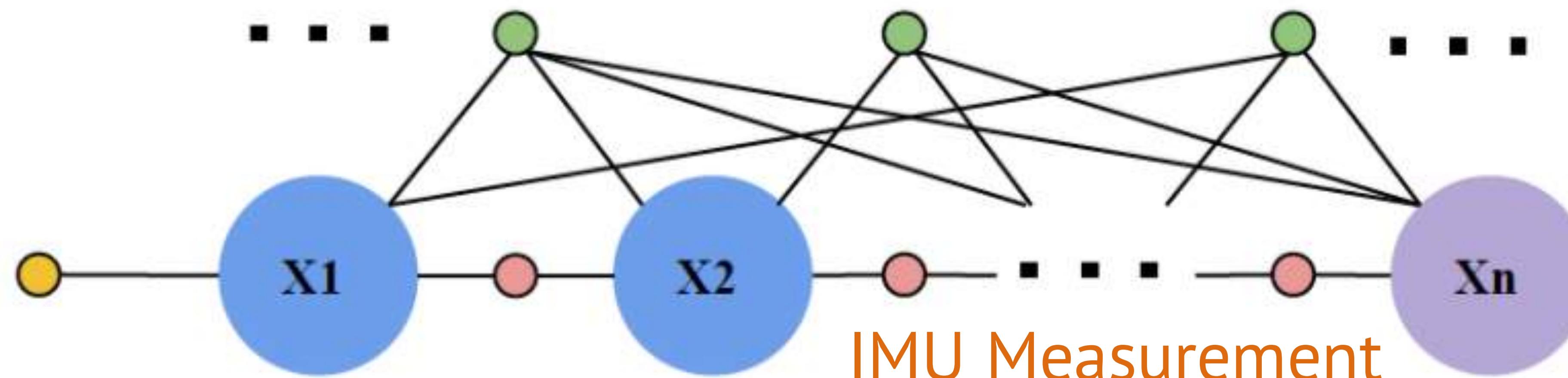


Graph Optimisation

- Specifies the relationships between variables and measurements



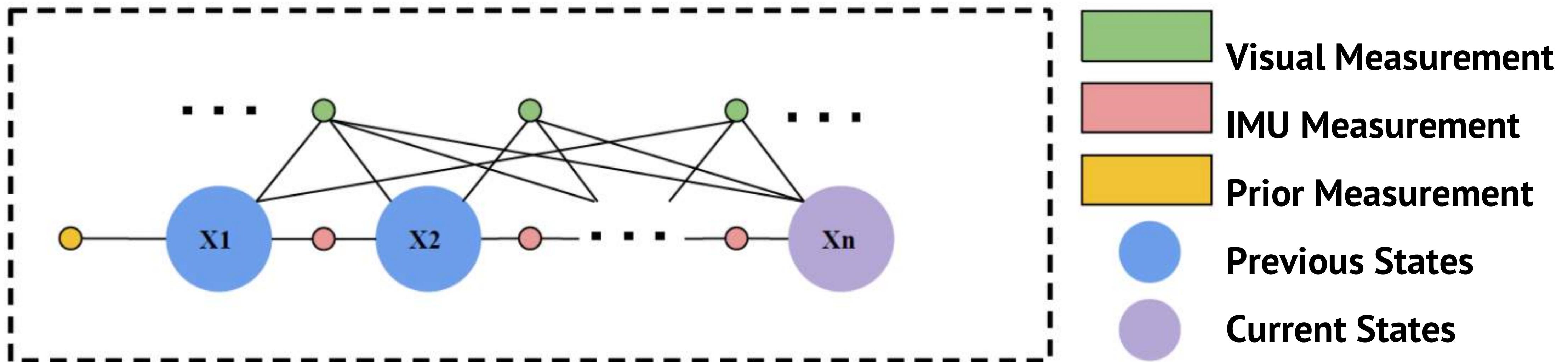
Visual Measurement



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

Time

Graph Optimisation

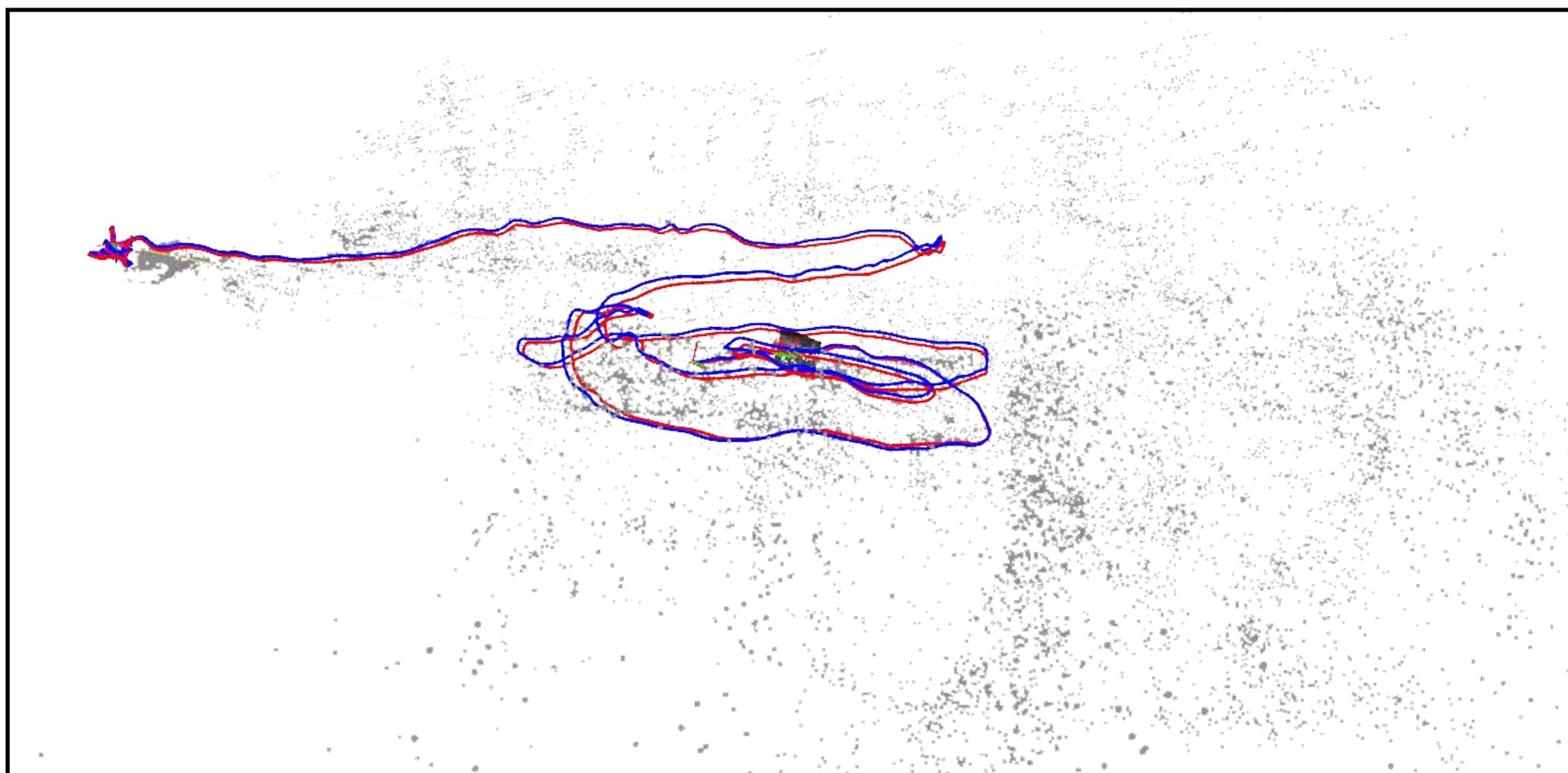


$$\chi^* = \underset{\chi_k}{\operatorname{argmin}} \left(p(\chi_0) \prod_{(i,j) \in I_k} p(z_{ij}^{imu} | x_i, x_j) \prod_{i \in I_k} \prod_{l \in C_i} p(z_{il}^{cam} | x_i) \right)$$

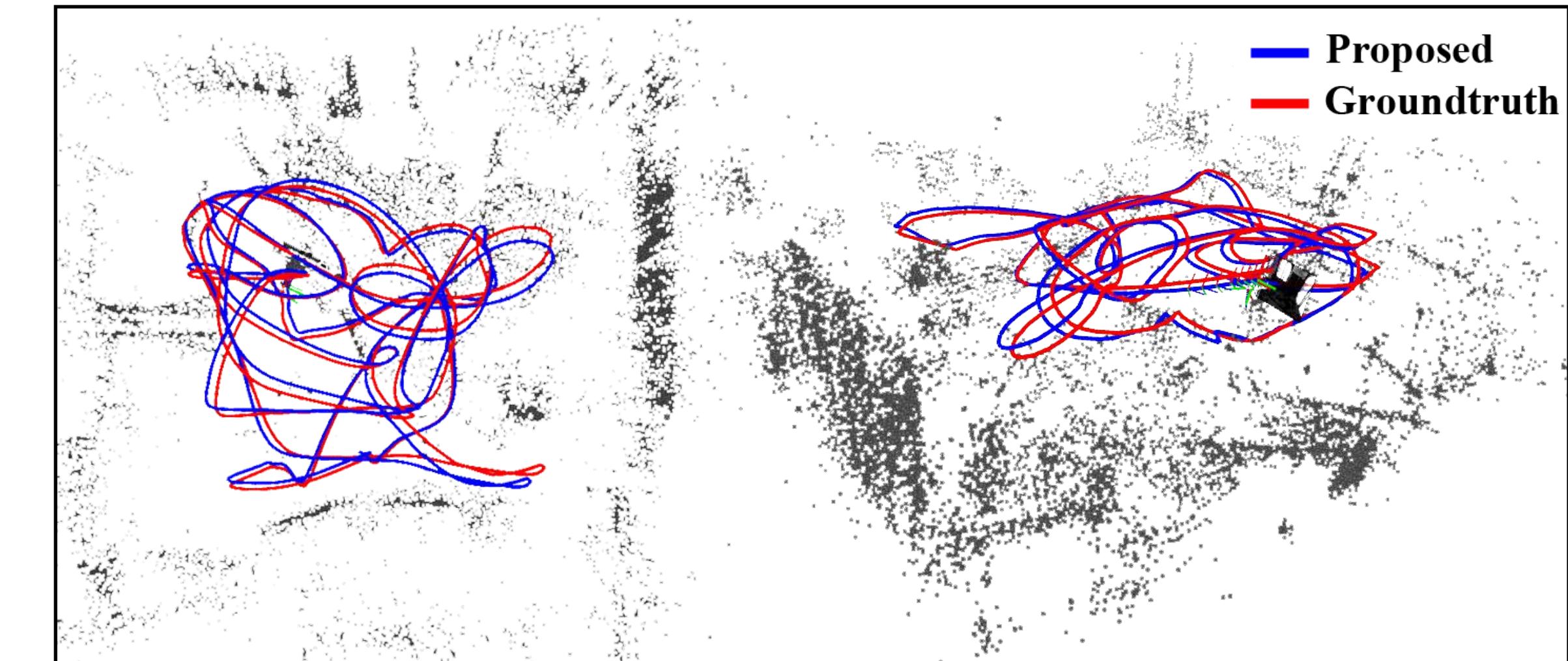
- › Solution is given by the optimal estimate that best explains all sensor measurements
- › Also known as **Maximum a Posterior Estimate (MAP)**

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
	Translational (m)	0.037	0.032	0.027	0.020	0.001	0.164
Relative Pose Error (RPE)	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



rpl

Carnegie
Mellon
University

