Visual Inertial Subsea 3D Reconstruction

For Subsea Model Generation and Real-Time Positioning

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ZUPT's VIEW ON THE APPLICATIONS AND TECHNOLOGY

What do we want?

- We need a way to navigate accurately subsea, within the space we are working.
- We may want to navigate where no external reference are available.

  SLAM lets us work within unknown environments autonomously.

- We need to build an accurate model of the world around us – in real time –no delay to deliverable.
- We need to be able to support the accuracy claims of this model.

  3D Reconstruction allows us to deliver this.

- Any solution has to be aware of the infrastructure and incumbent processes we will compete within.

  Power, size, bandwidth, water depth – probably most important – time to delivery of product!

JUST A FEW OF THE APPLICATIONS?

Positioning:

Under Hull Positioning – Tricky to position free moving targets in the water column.

Metrology – Delivers metrology level accuracy, 30mm over 30m (1/1000)

Out of Straightness (OOS):
Accurate offset determination. Multibeam like deliverable with position solution in the model.

The last few meters:
Precise positioning for autonomous intervention into structures/control panels, etc.

Model:

Pipeline surveys – High resolution free span data, anode depletion volumes possible

As Built – Delivers exactly what is on the seabed and exactly where it is – import into operator GIS

Asset Integrity Monitoring – Facilitates automated change detection, position and feature definition.

Chain/mooring inspection – dynamic structure modeling

Both:

Augmented Reality/Perception – Identify a feature, automatically display metadata and automatically navigate to that specific feature.

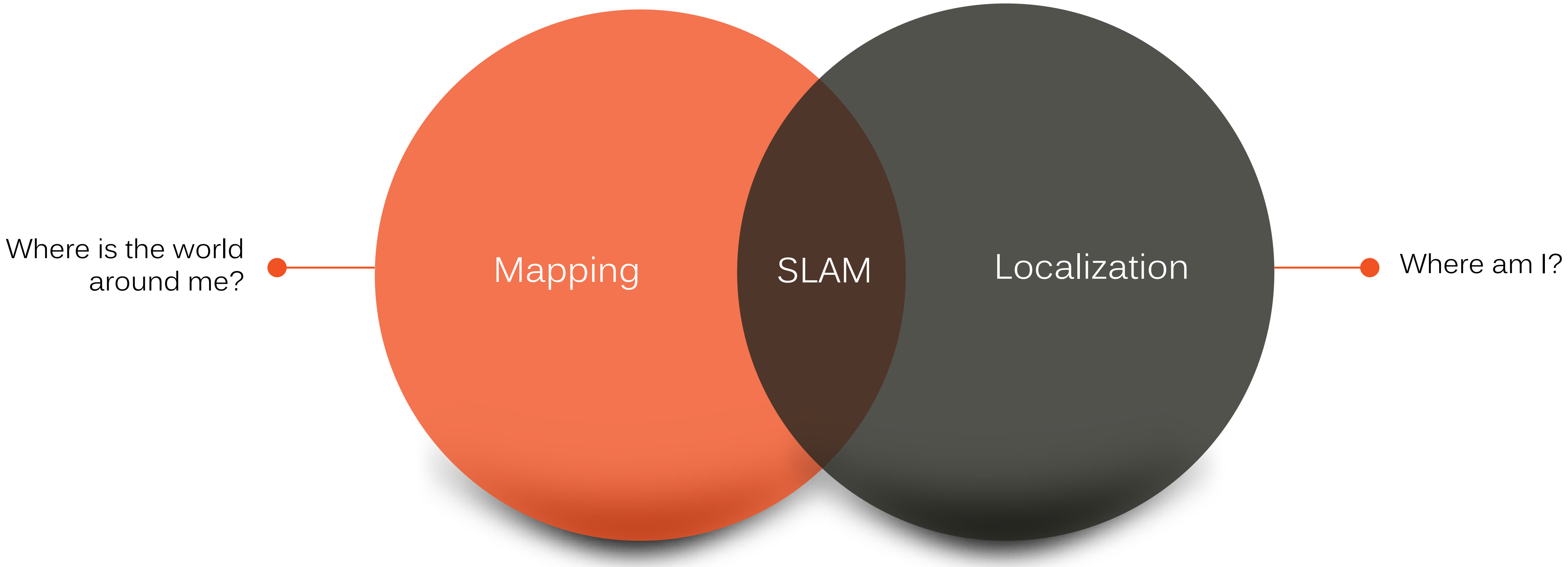
Dimensional Control at Depth – Structure modeling and subsea offset determination

CONTENTS OF OUR TALK TODAY

- An introduction to SLAM
- An overview of our version of Visual Inertial SLAM system - 3D Recon
- The basics of 3D reconstruction
- Why we think you must integrate inertial?
- System design limitations and failure modes
- Integration into current work processes

WHAT IS SLAM?

SLAM provides the ability to position us while developing knowledge of the environment around us.



TOOLS AVAILABLE FOR SLAM

Landmark Sensing (output is relative to sensor frame):

- Lidar – point cloud in local frame
- Structured light- point cloud in local frame
- Monocular Camera – RGB imagery, map and poses only recoverable up to a scale factor
- Stereo Cameras – RGB + point cloud, map and pose

Inertial Sensing (output is relative to NED frame)

- Accelerometers and Gyroscopes- IMU/INS allows for accurate position and attitude estimation when aiding data is not available

- Inertial + stereo gives high rate pose estimation and adds robustness to global data association.

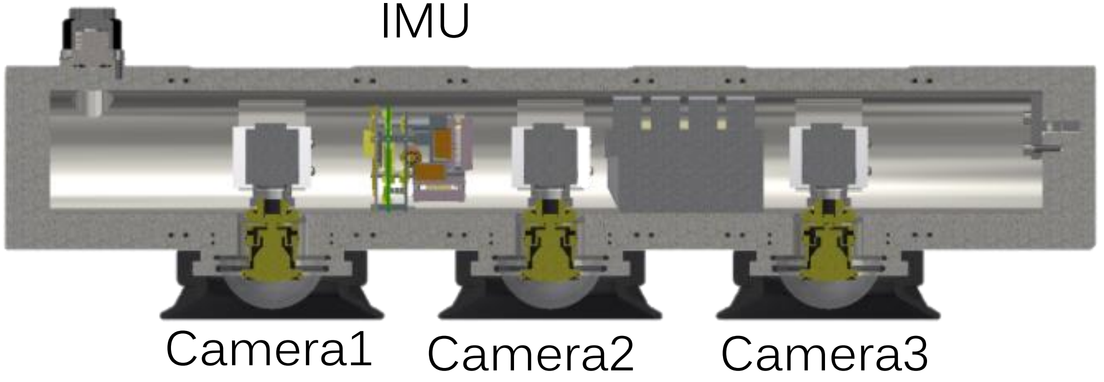
VISUAL INERTIAL SLAM

Multi baseline stereo, lower triangulation error + more image overlap for nearby targets

Tactical grade IMU - provides high rate control inputs for dynamic model

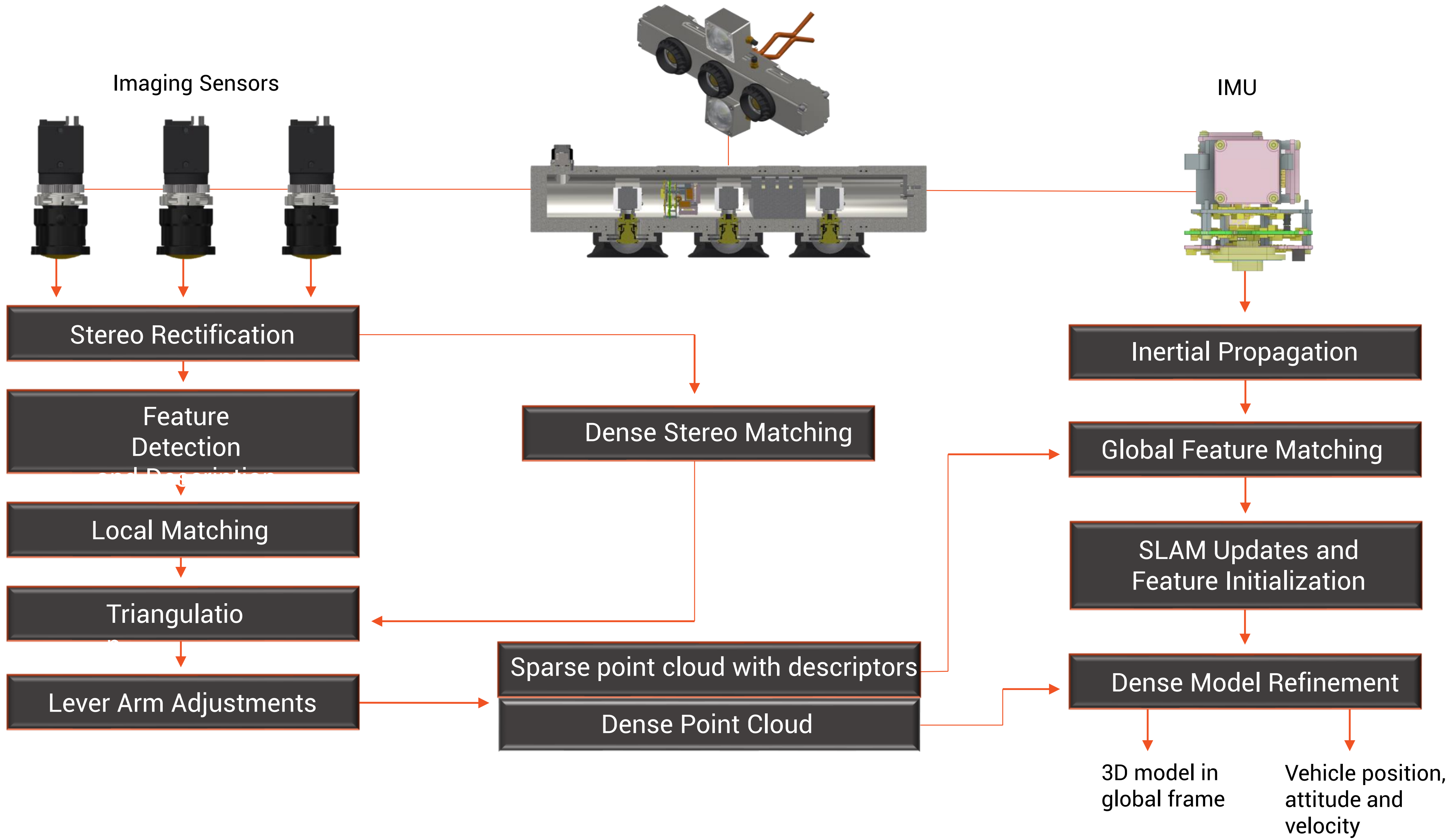
Custom strobed lighting with image feedback controller – change light intensity, not exposure time (blurring and variable time of validity).

Specially designed lens for balanced illumination across images

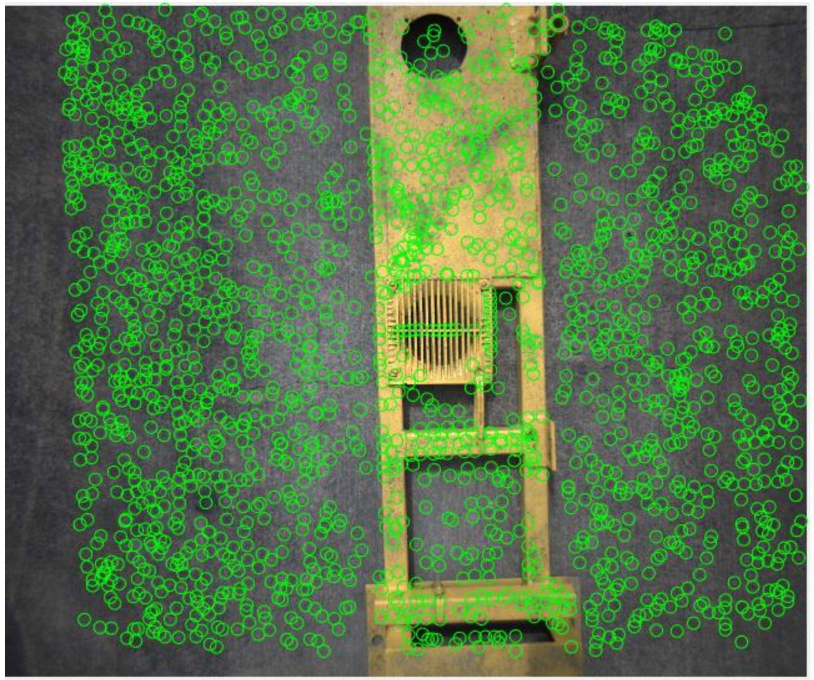


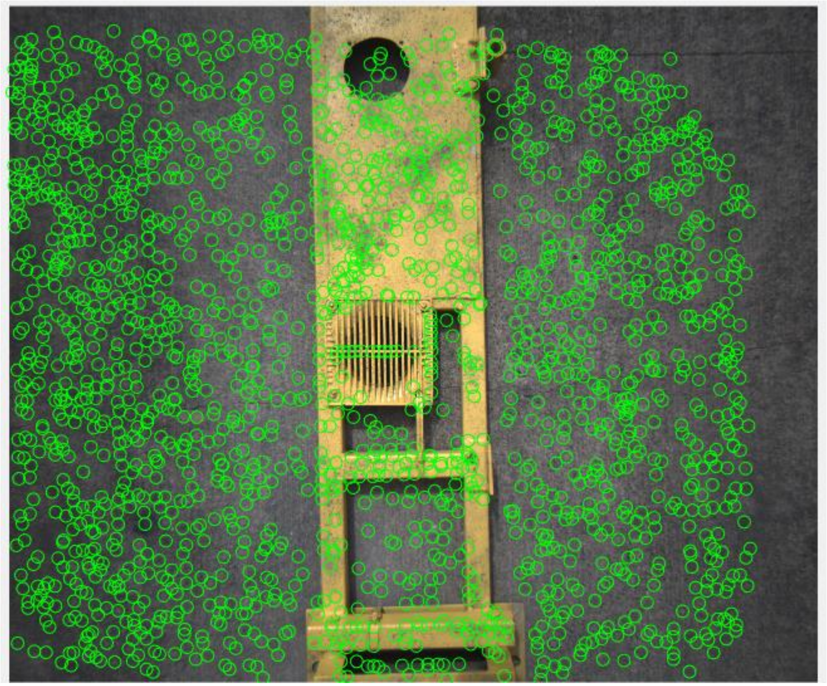
VISUAL-INERTIAL SLAM

OUR IMPLEMENTATION OF A SUBSEA SLAM SOLUTION



FEATURE DETECTION AND DESCRIPTION

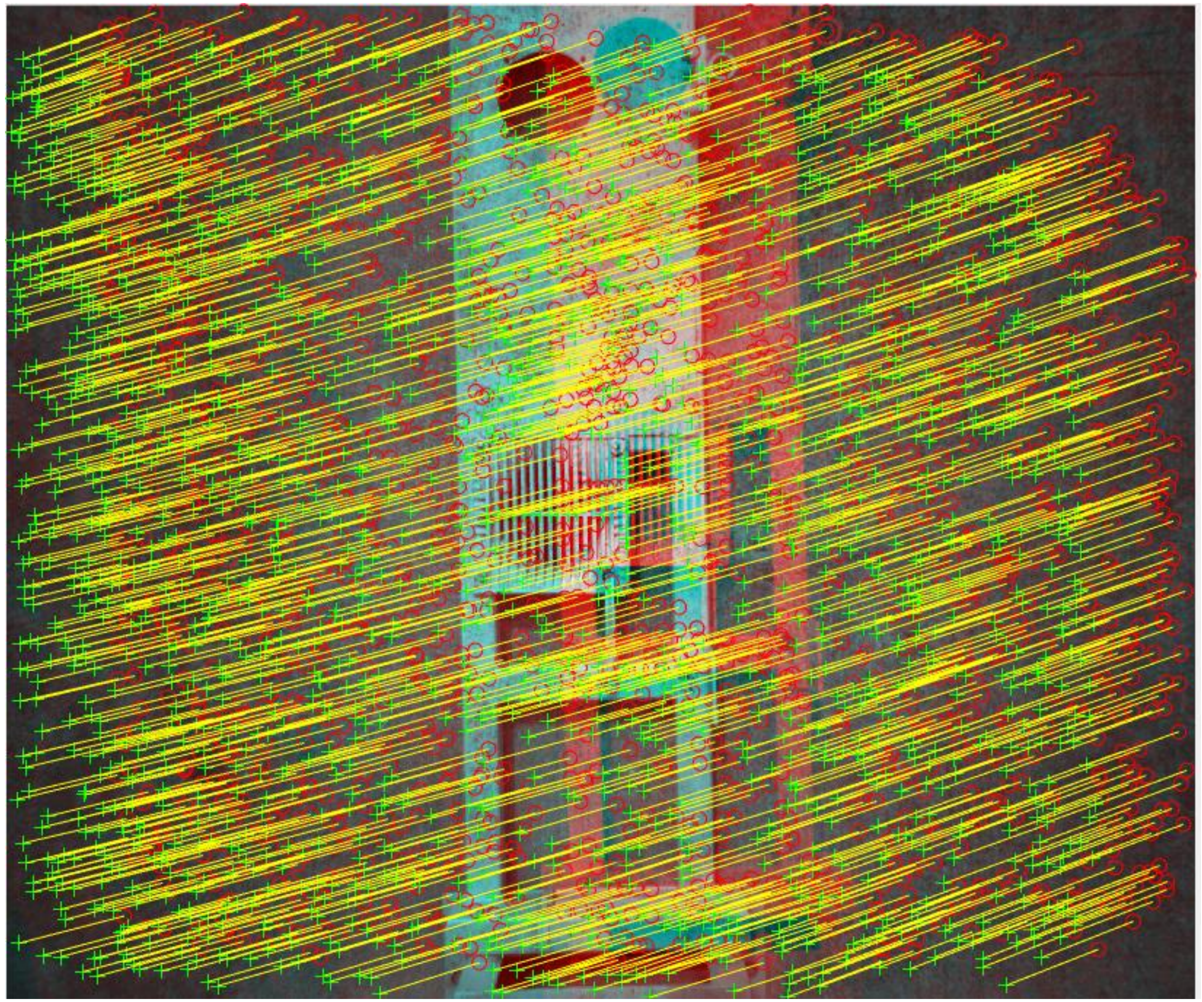




Detection – find unique points in the image. Usually corners or edges.

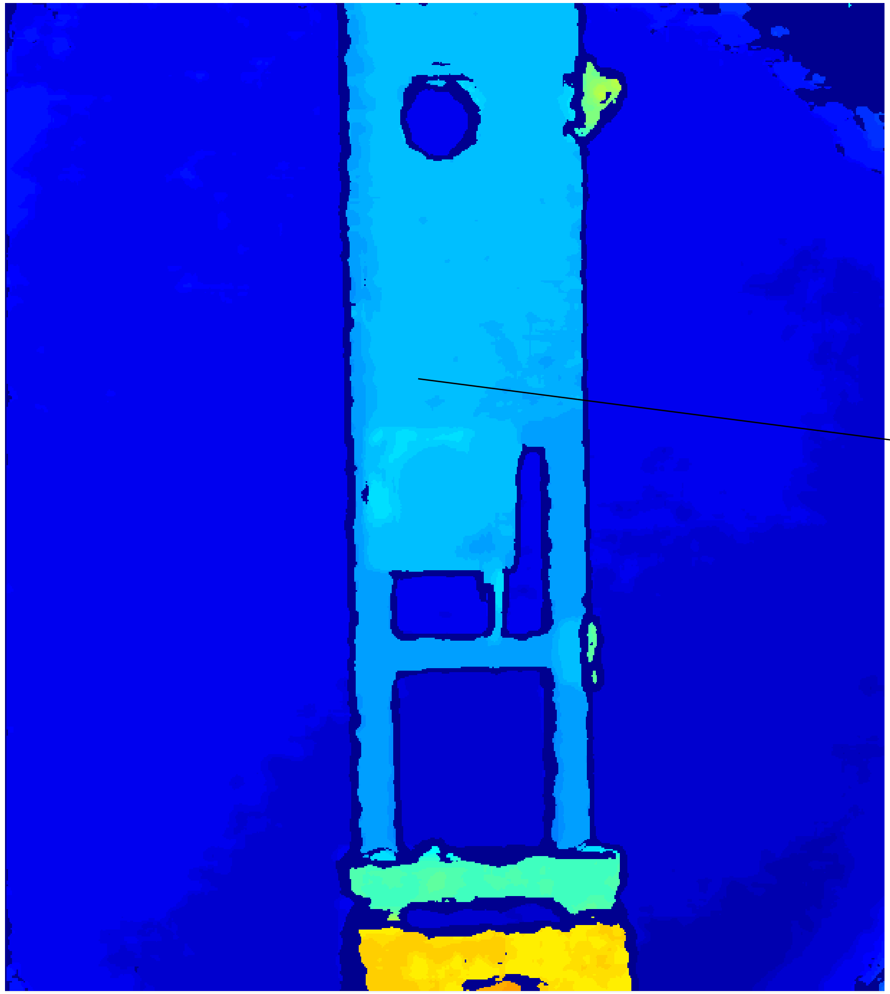
Description – compute a unique descriptor so the features can be matched locally and globally. SIFT, SURF, and ORB are the most common.

FEATURE MATCHING



- Use Euclidean distance or angle between (dot product) descriptors for matching
- Stereo constraint can be used to eliminate outliers

DISPARITY COMPUTATION
DIFFERENCE IN X COORDINATE (DEPTH) IN BOTH IMAGES



- Rectify images and attempt to match every pixel in each row based on intensity.
- Structured light (line laser or pseudo random patterns) can be used to improve accuracy in poorly textured scenes.

Disparity to XYZ Example Calculation:

$$u = 1267 \quad \text{pixels} \quad , v = 700 \quad \text{pixels} \quad , f = 1126 \quad \text{pixels}$$

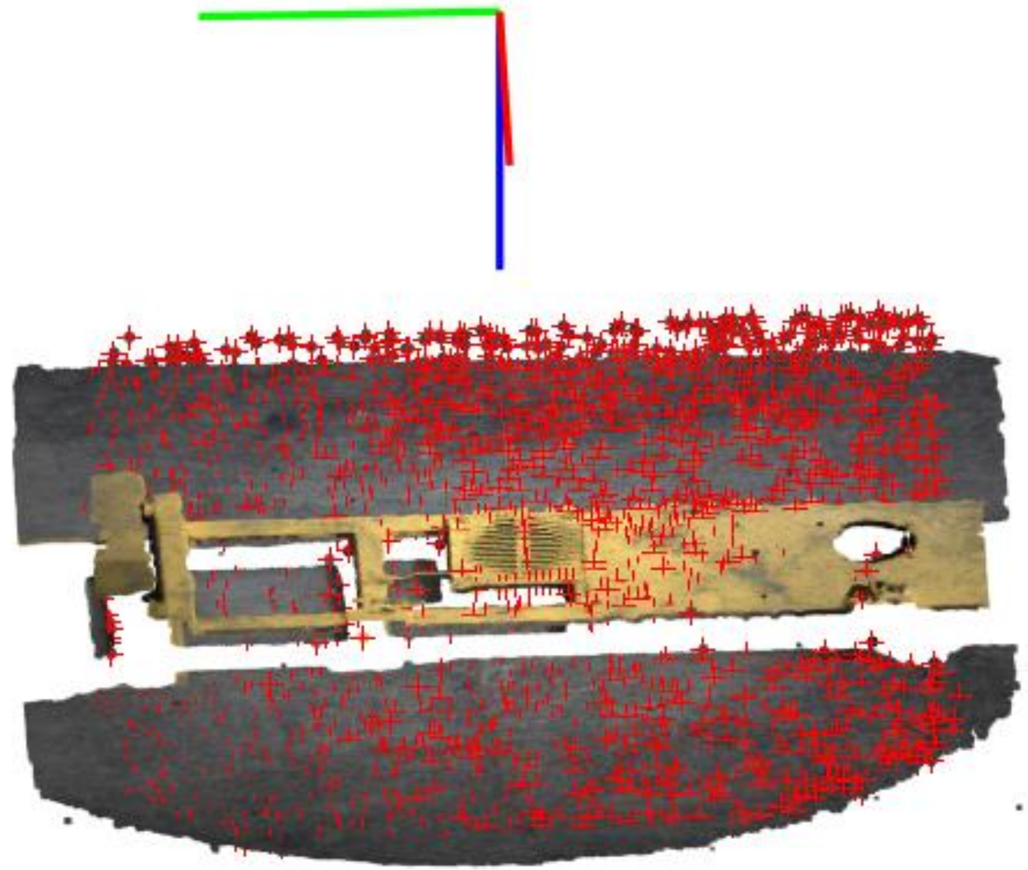
$$b = 0.298 \quad \text{m} \quad , d = 249 \quad \text{pixels} \quad , c_x = 1056 \quad \text{pixels} \quad , cy = 684 \quad \text{pixels}$$

$$x = \frac{(u - c_x)b}{d} = \frac{(1267 - 1056)0.298}{249} = 0.2525\text{m}$$

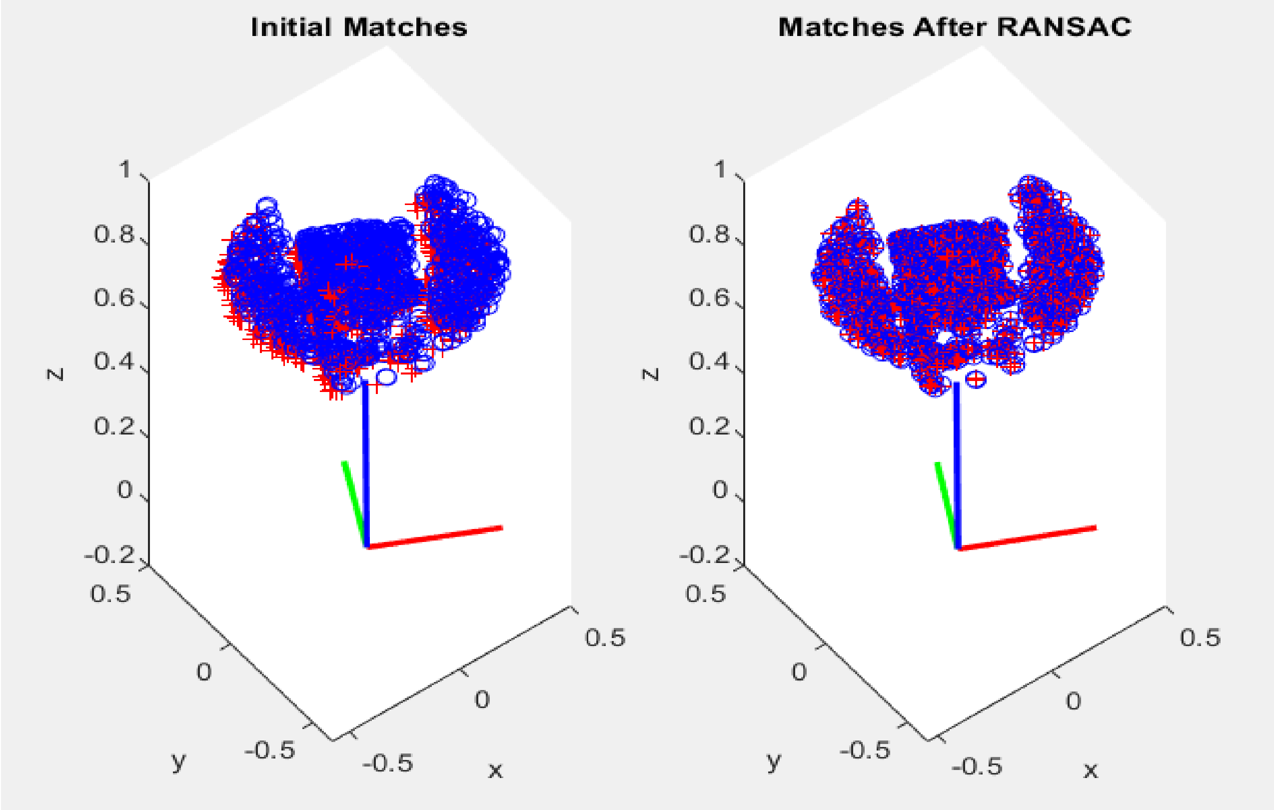
$$y = \frac{(v - c_y)b}{d} = \frac{(700 - 684)0.298}{249} = 0.0191\text{m}$$

$$z = \frac{fb}{d} = \frac{(1126)(0.298)}{249} = 1.3476\text{m}$$

POINT CLOUD GENERATION (SPARSE AND DENSE)



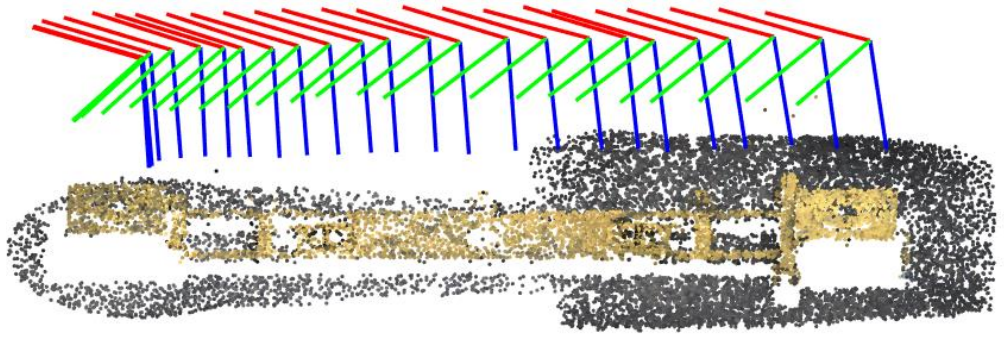
Global Matching and Random Sampling Consensus



- Use current INS solution to project global points into the camera frame.
- Match features based on position and descriptor
- Use RANSAC to remove outliers.

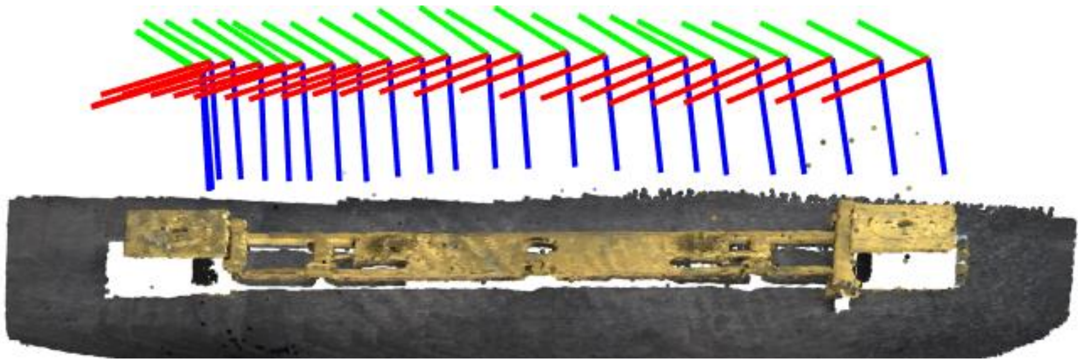
SPARSE (positioning) / DENSE (model) POINT CLOUD GENERATION

Sparse SLAM Map and Vehicle Poses



Each feature point has XYZ, RBG+descriptor.
Descriptor distance + XYZ distance are used for global matching for SLAM updates

Dense Point Cloud Projection using SLAM Poses



Each feature point has only XYZ,RBG.
Down-sampling and refinements are made to further align projected point clouds.

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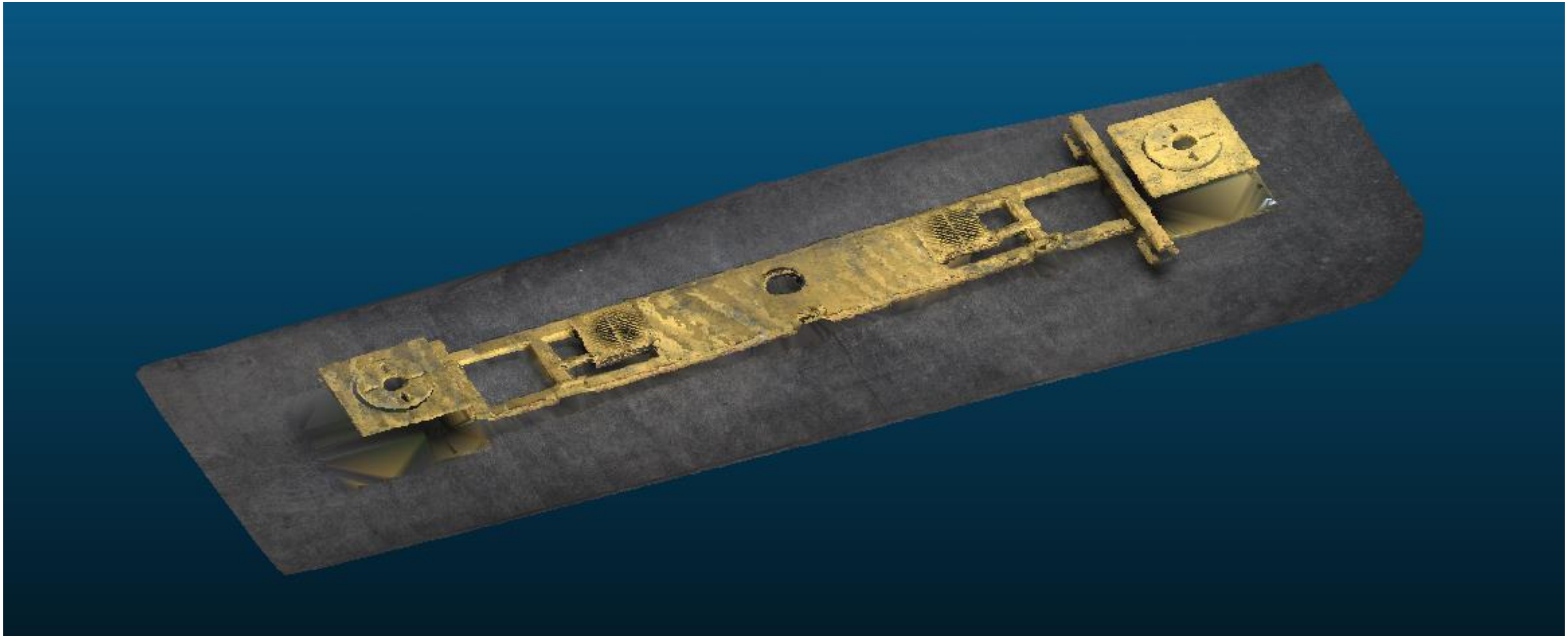
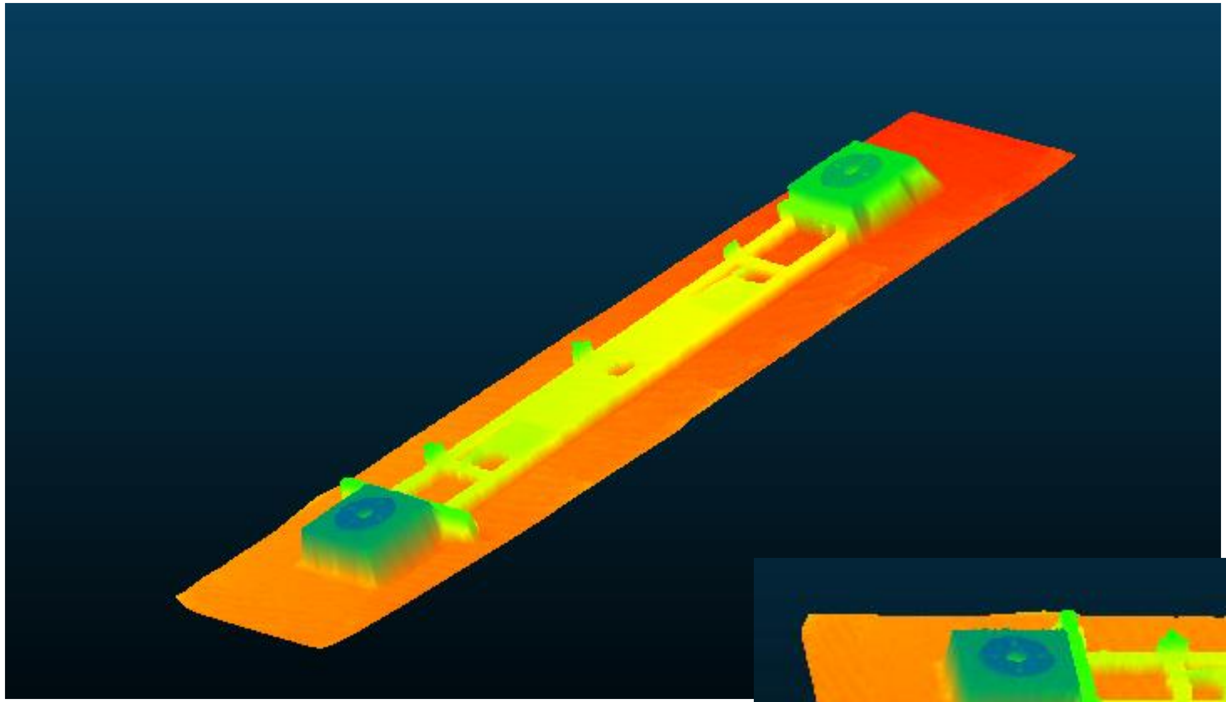
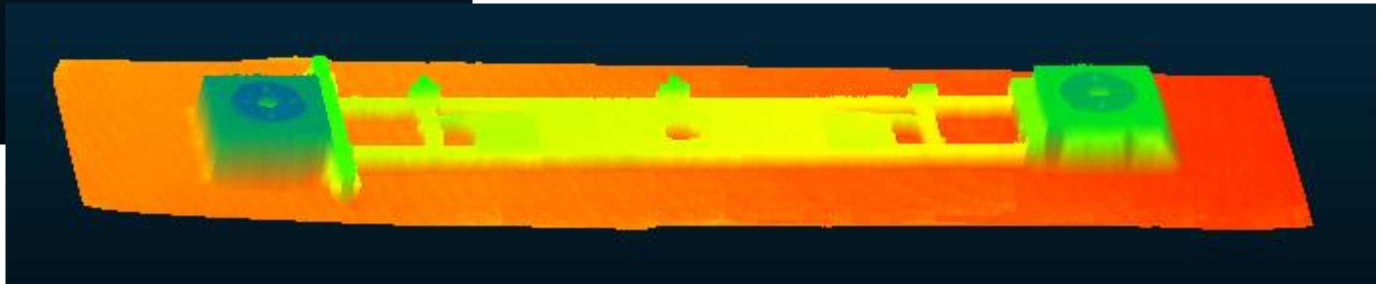
DE-NOISING AND MESH GENERATION

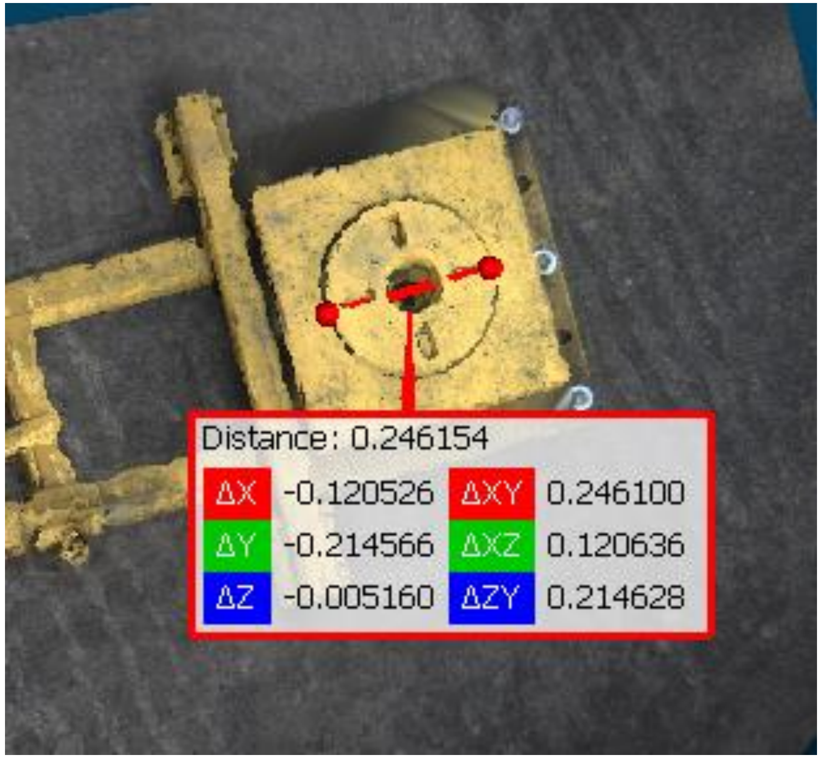


ANALYZE STRUCTURE DEPTH





ACCURACY OF THIS DATA SET <+/-2MM



WHY AN IMU IS A CRITICAL COMPONENT

When compared to pure image alone based solutions:

Lower image frame rate required, less uplink bandwidth, less storage

Continues to work in very degraded visibility – ignore particulate matter in water column:

INS + RANSAC can deal with false features. Fallback to free inertial in total blindness.

INS allows us to lose imagery and still estimate position and attitude between valid poses

Enables much faster real time (nearly real time) processing to dense point cloud.

A very precise and separate "aid" to constrain any image calibration issues – significantly removes scaling errors seen in image only based linear model deliverables.

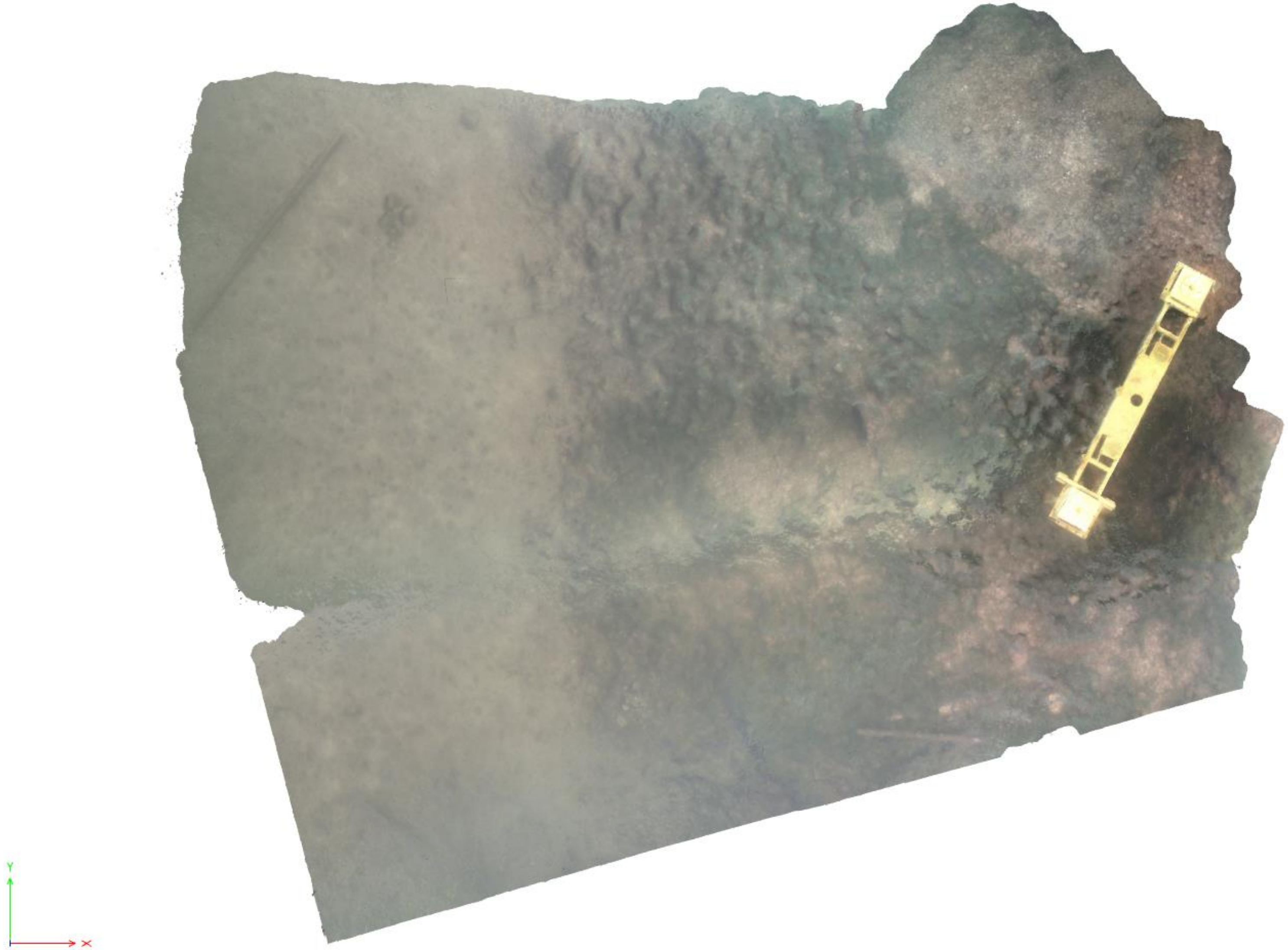
SYSTEM DESIGN LIMITATIONS AND FAILURE MODES

- Distance to target – decreases relative accuracy, beyond 4m a larger baseline than 30cm is needed.
- A solution for chain link/mooring surveys would define shorter baseline – 5cm to 10cm.

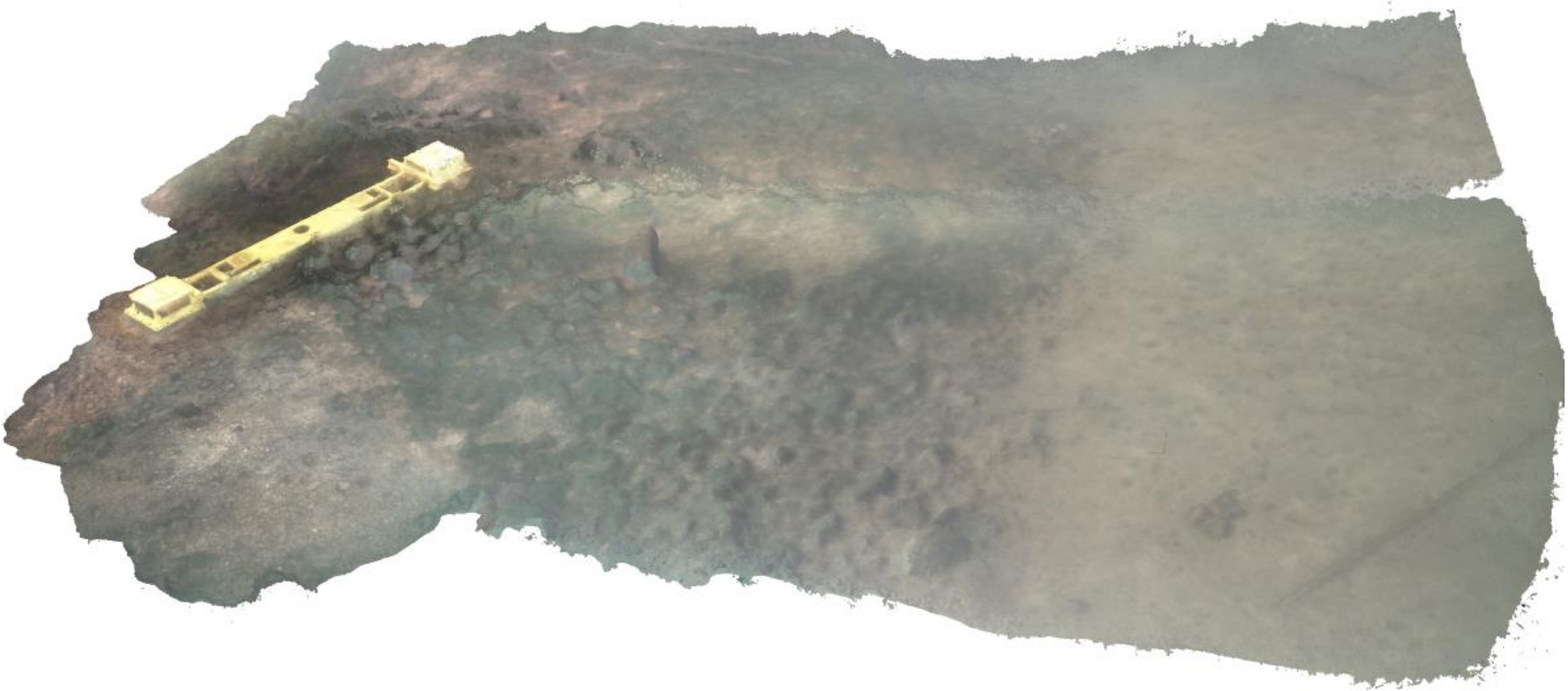
- If we cannot see it – we cannot build a model.
- A reflective surface (mirror like finish or high gloss surface) – dense matching on reflective surfaces can be inaccurate. Testing is in progress with polarized cameras to alleviate this.

- Shadows, in frame/view ROV fixtures have to be blocked from processing solution.
- Lighting is critical – balanced illumination across the scene is critical.
- Zupt developed our own lights/diffusers to ensure optimal lighting.

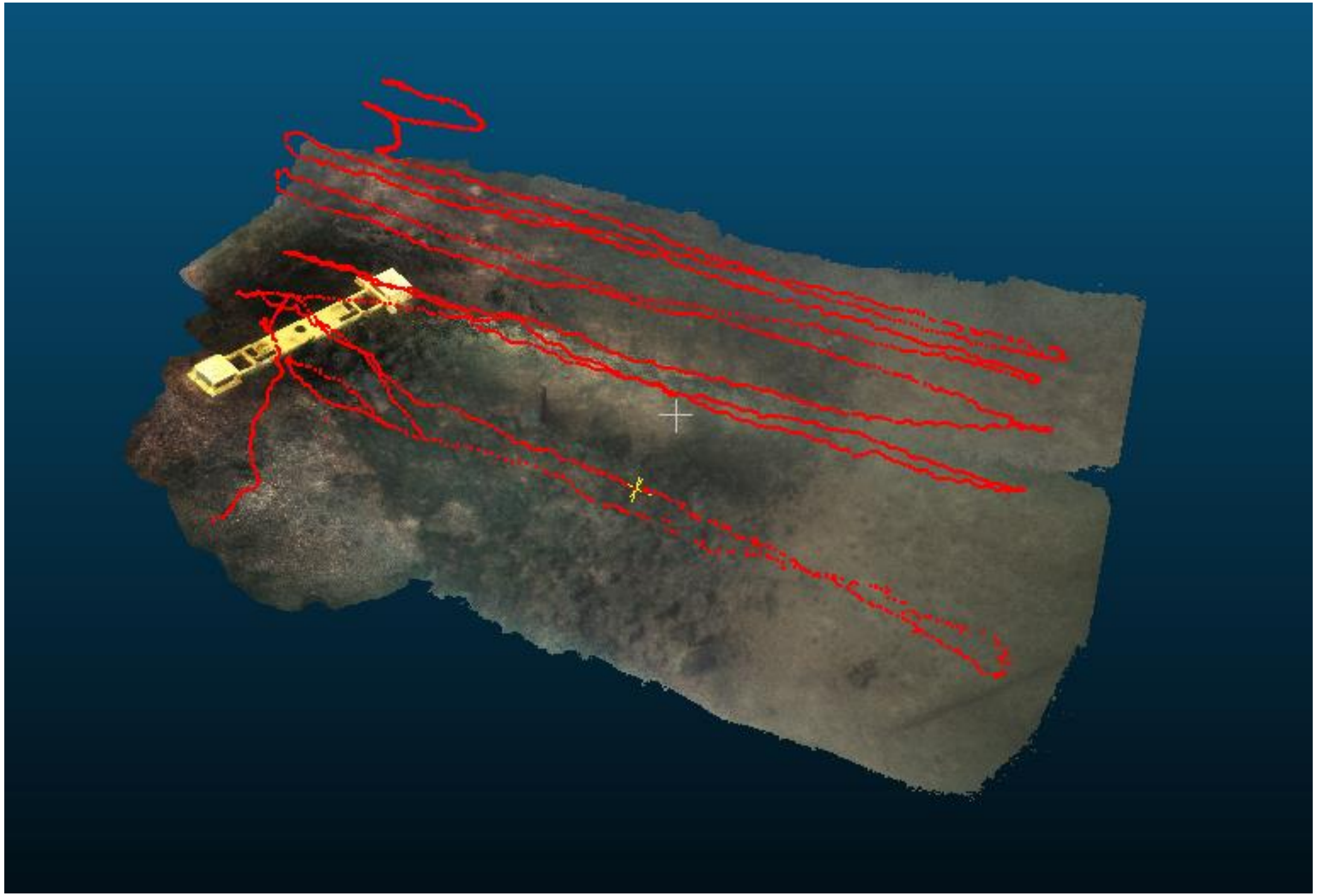
LAKE TEST DATA EXAMPLES - DENSE PLAN VIEW



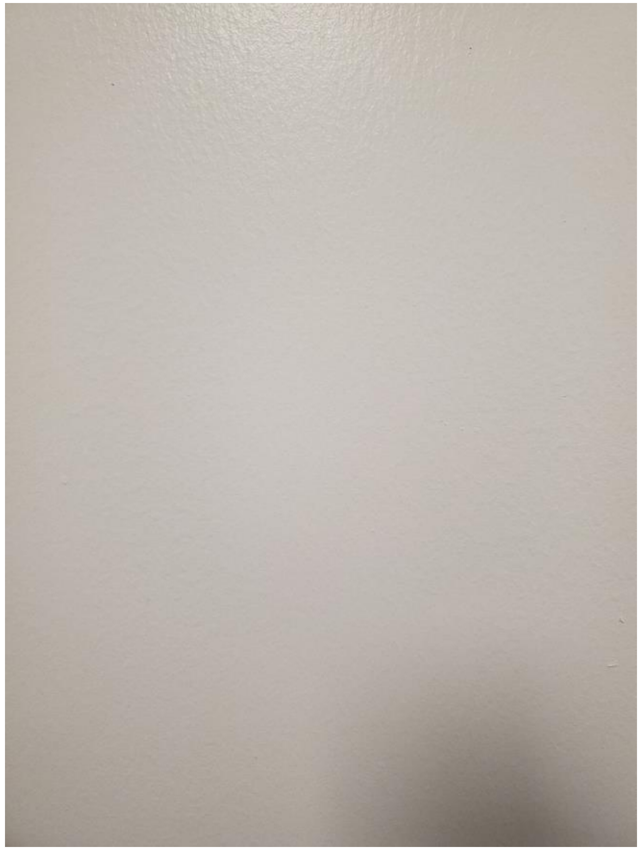
LAKE TEST DATA EXAMPLES – ISOMETRIC VIEW



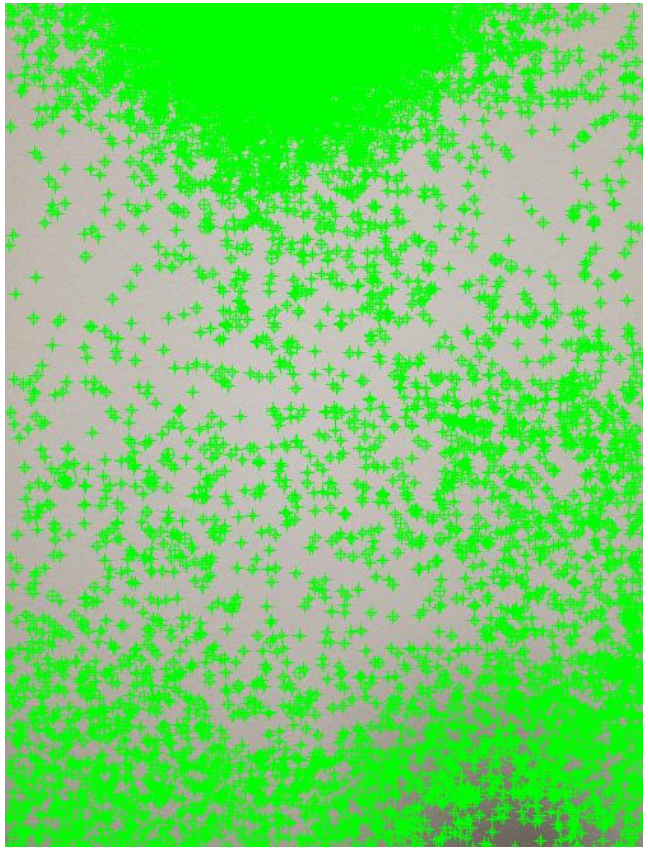
POSITIONING TRAJECTORY OVERLAY



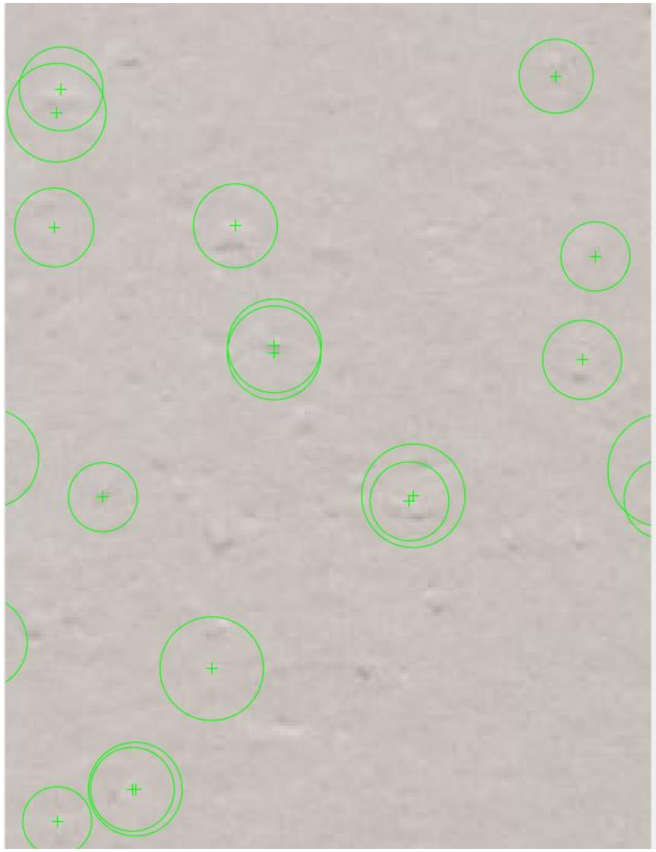
AN ENVIRONMENT WITH NO FEATURES?



Original Image



Detected Features



Close Up

Features are still present, but their descriptors wont be as strong

INTEGRATION INTO CURENT WORK PROCESSES?

DIFFICULT TO GET ANSWERS?

- Who is the real customer for the deliverable?
- What deliverable is really wanted?
- To what level of resolution?
- How do these deliverables merge into the operators, enterprise wide, systems?

DISRUPTIVE TECHNOLOGIES

- How do these next generation solutions “fit” into incumbent processes that primarily insist upon video/DVR based data sets?
- Eventing and Classification will be from very different data sets?
- Have to collect a baseline data set to enable automated change detection
- Some sort of standardization might need to exist to allow the baseline data to be used by many – i.e. competitively bid
- Data management - much larger data sets, full data set transfer still has to be physical, not via bandwidth.

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COMPLIANCE WITH INCUMBENT PROCESSES

Just some of the demands from the incumbent processes, historically delivered by video:

- Operators IM platforms – Risk Based Integrity (RBI) management software
- Practically a hierarchical task list that glues video or screen grams to an event:

  Aker ix3 COABIS ™

  Wood Group Nexus (IC) ™ Integrity Center

Very integrated into such conventional applications as Visual Soft

Process driven IM demands are inherent in operators procedures – drive existing methods:

- CSWIP 3.3u/3.4u- certification required during surveys – purely a video eventing

Summary

- Our goal is to have the ability to autonomously navigate, while simultaneously generating high resolution models in real time
- We're utilizing a combination of online and full SLAM algorithms to enable accurate, but real time navigation.
- By using multi-baseline stereo, we're able to increase image overlap close-up, while decreasing triangulation error for far away objects. There is no need for scale bars.
- Furthermore, by incorporating high rate acceleration and angular velocity, we are able to navigate during instances of poor visibility.
- The IMU also enables us to extend our platform to other tightly coupled INS solutions (LBL, beam level DVL).

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