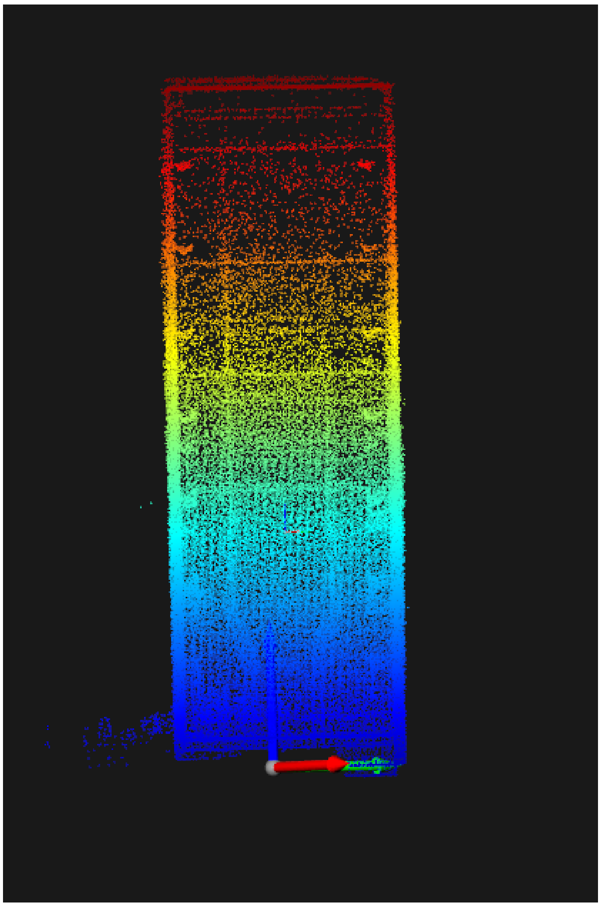
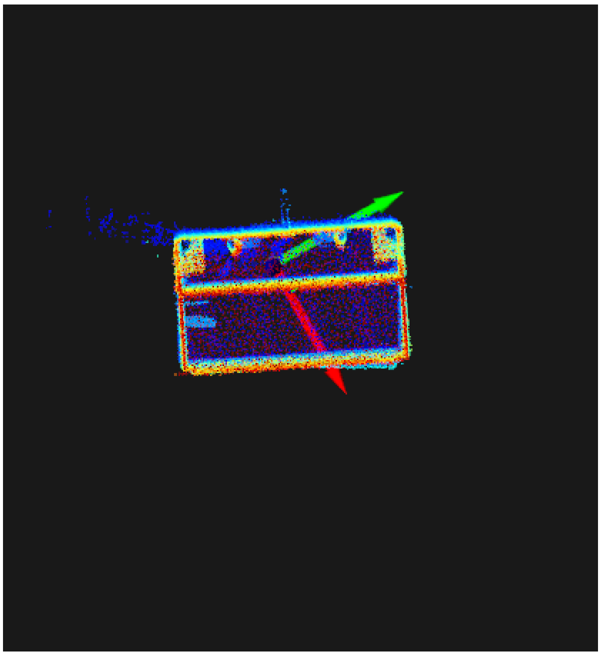
Localization at HRSG Manhole

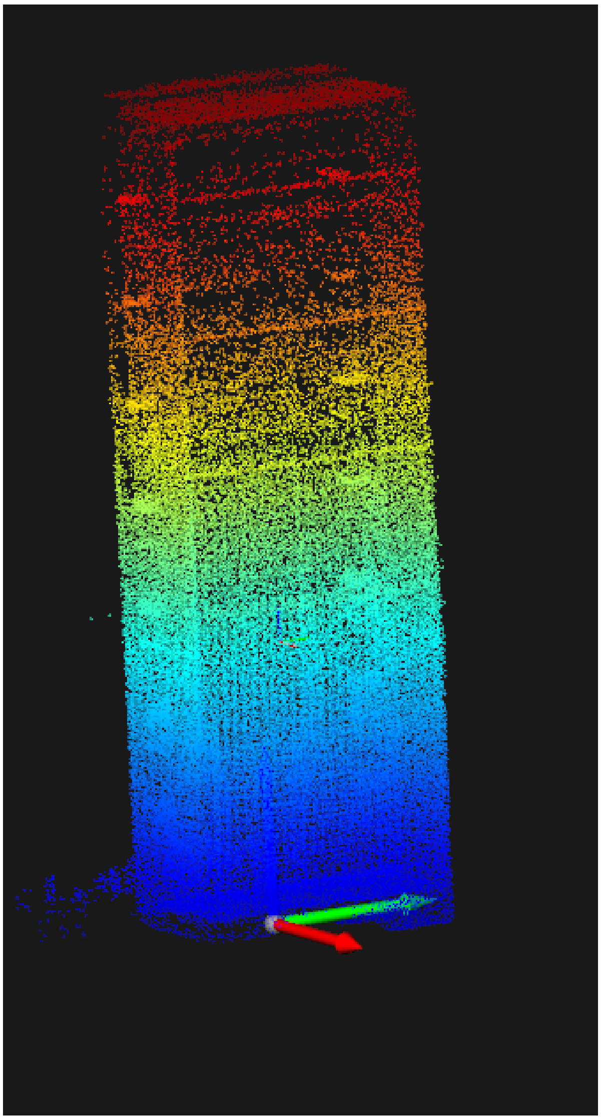
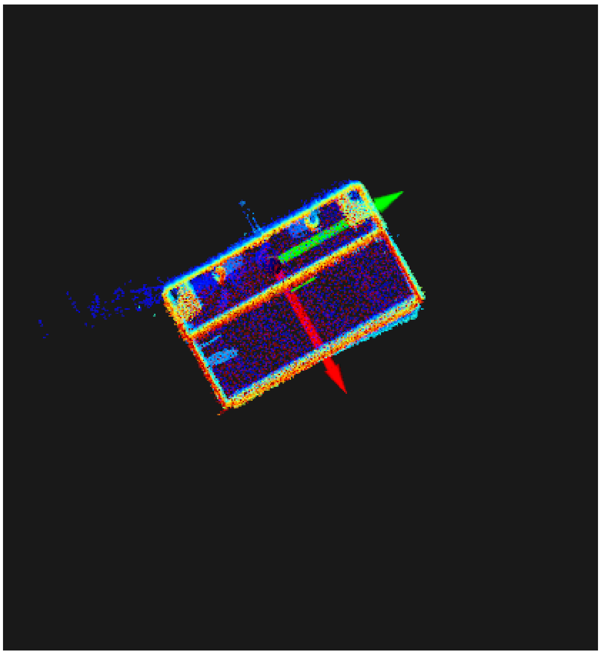
Perception Pipeline

1. (offline) **COLLECT LiDAR and IMU data**, sweeping inside each manhole: field experiments
2. (offline) **BUILD MAP** and postprocess:
    1. identify the floor and level the map





    2. manually rotate the map (yaw) so that axes are aligned (parallel) to the real world

3. while building map, **construct NODE GRAPH**
    1. node: important (key) pose
    2. which involves LiDAR-inertial odometry (LIO) internally
4. (online) **LOCALIZE** drone
    1. initially by providing **INITIAL POSE**: where drone takes off (depends on the experiment), probably where **station** should be
    2. then consecutively:
        1. by identifying similar & revisited node (constructed offline, see 3)
        2. and applying LIO & fixed window smoothing (factor graph optimization)

Problems of HRSG Manholes

there were two problems:

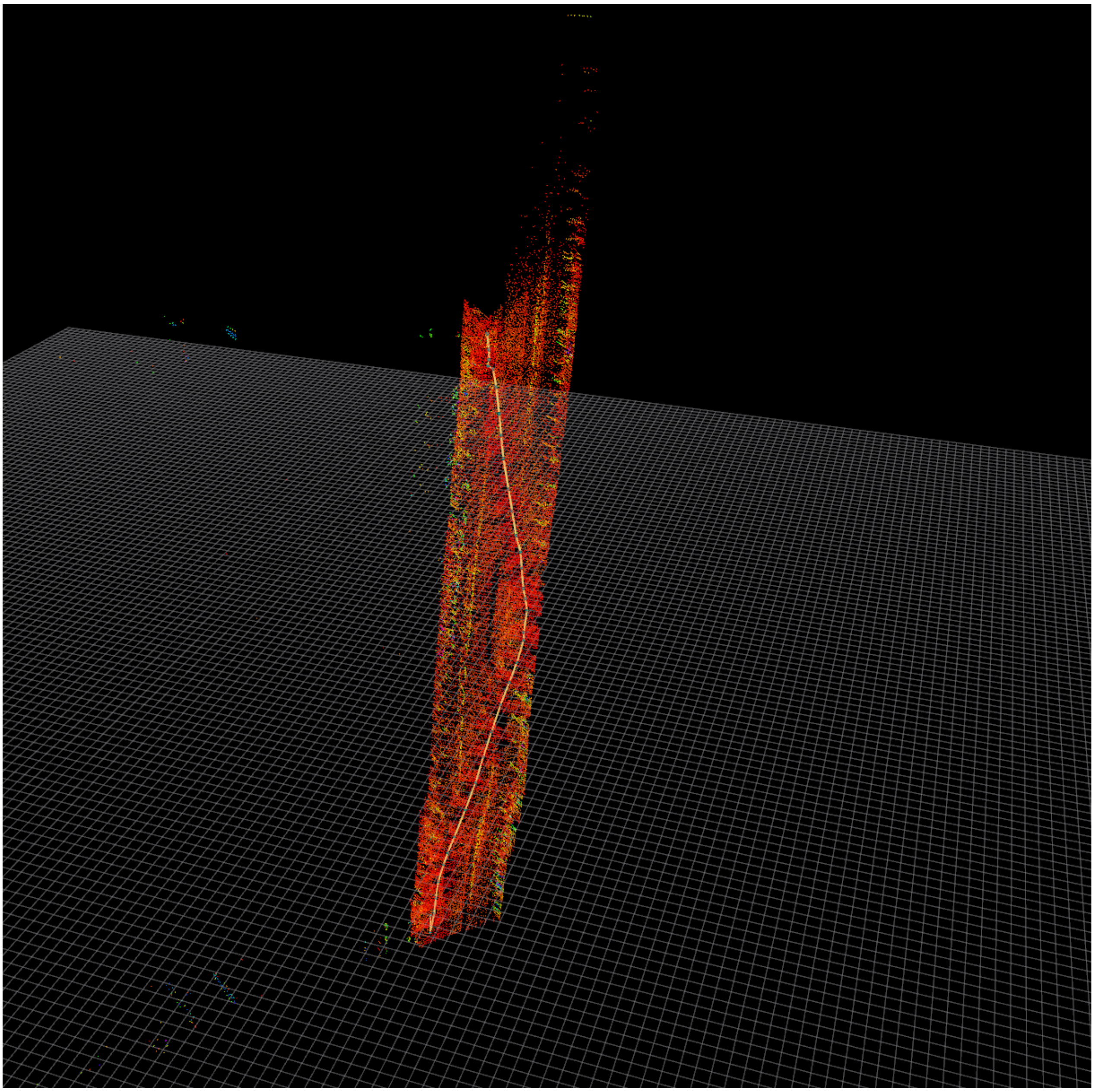
1. while building map, internal LIO continuously failed

    - correspondence are hard to secured, due to the repeated feature

        - **correspondence**: where are the points (of current LiDAR scan) mapped to the built map?

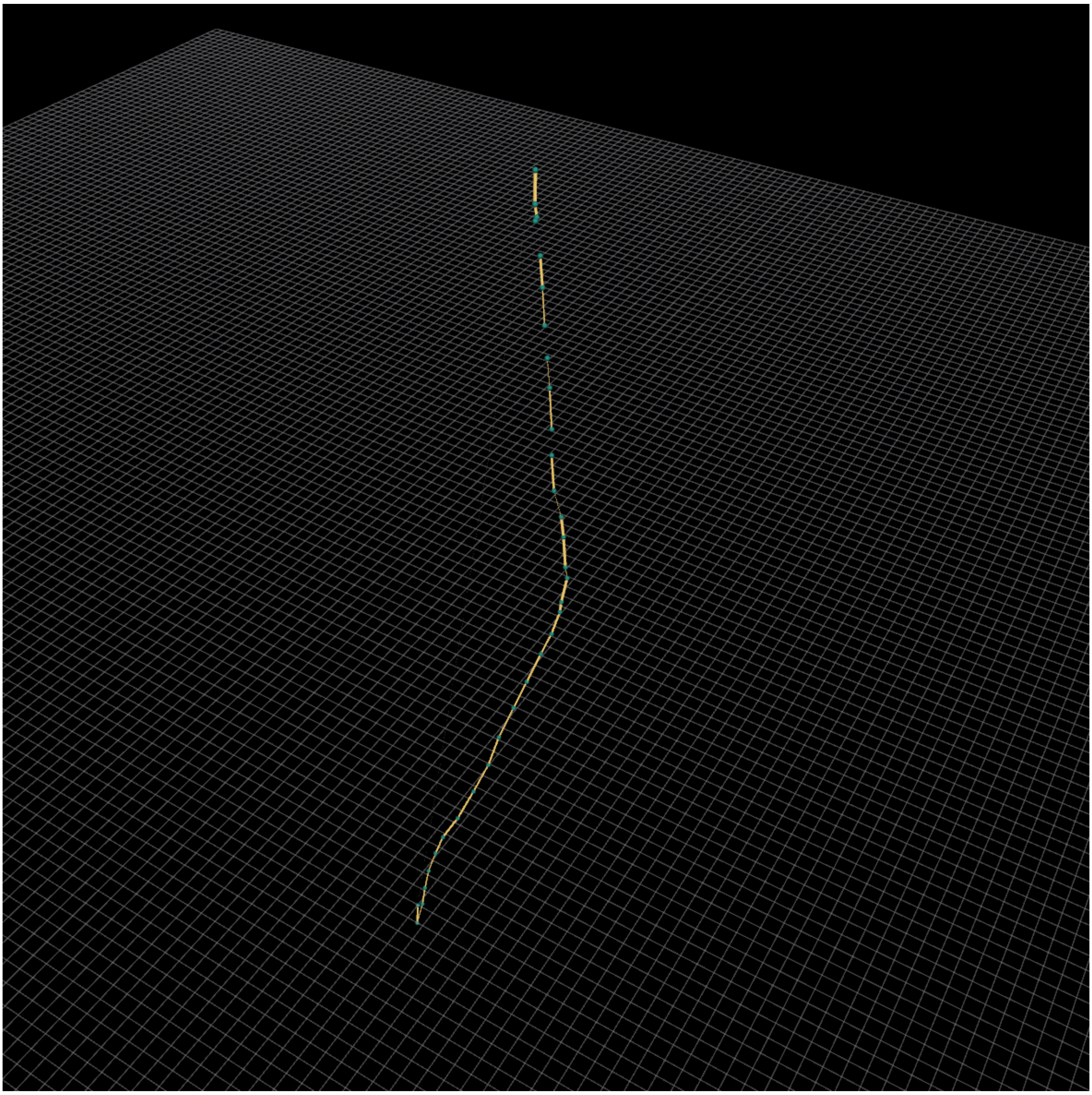
    - basically **tunnel-like & featureless** structures are harsh environment for LIO

- an example of problematic map:



2. identifying node(s) and initial pose
   - basically all nodes are similar
   - the manhole structure was narrow and repeated, thus, there are many (multimodal) wrong localization solutions

- an example of node graph under ill-conditioned situation (where no vertical movements were involved in real world):



Solution Approaches

respective approach per problem is:

1. relax the correspondence checking condition

   - there are basically tons of parameters:

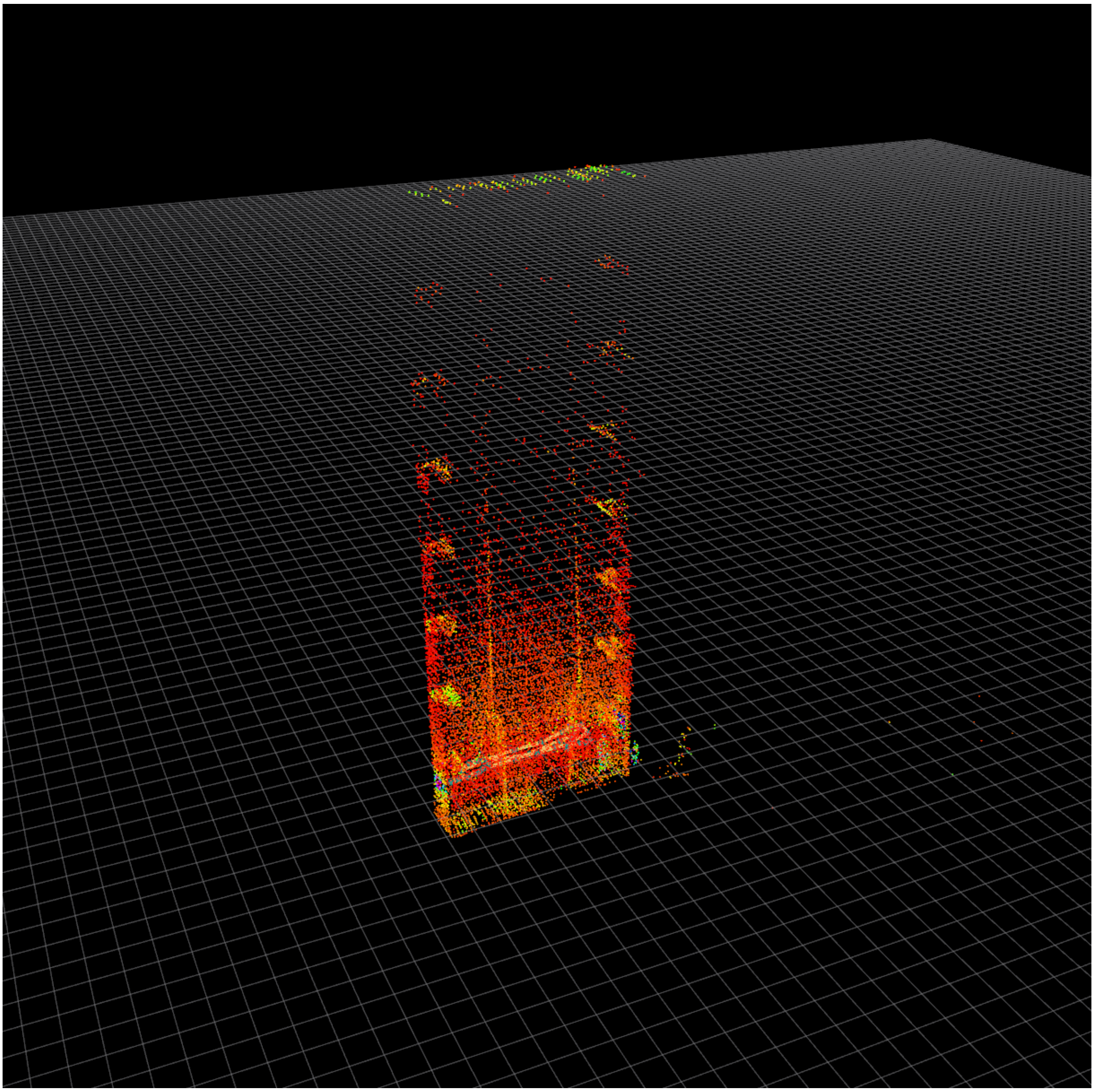
   -
     ```
     /**:
       ros__parameters:
         bag_file: "" # absolute path of bagfile
         odometry_type: "fast_lio"
         keyframe_detection:
           max_range: 40.0 # maximum detection range
           max_time_diff: 60.0 # maximum time difference to maintain the latest keyframe
           motion_threshold: 5.0 # motion triggered keyframe generation
         loop_detection:
           nearby_frames: 3 # nearby keyframes to loop registration
           search_radius: 1.5 # search radius for loop candidate
           min_time_diff: 30.0 # minimum time difference to be a loop pair
           registration:
             resolution: 0.125 # loop registration sampling resolution
             max_iterations: 20 # maximum iteration
             k_corrs: 10 # nearest k
     ```

```
        kernel_sigma: 1.0 # m-estimator constant
        convergence_epsilon: 0.001 # convergence criterion
    graph_optimization:
      max_iterations: 10 # maximum iteration
      abs_error_epsilon: 0.000001 # absolute residual epsilon
      rel_error_epsilon: 0.000001 # relative residual epsilon
      prior_orientation_noise_sigma: 0.000001 # rotational noise sigma for prior factor
      prior_position_noise_sigma: 0.000001 # translational noise sigma for prior factor
      odom_rotation_noise_sigma: 0.001 # rotational noise sigma for odometry factor
      odom_translation_noise_sigma: 0.01 # translational noise sigma for odometry factor
      loop_rotation_noise_sigma: 0.003 # rotational noise sigma for loop factor
      loop_translation_noise_sigma: 0.03 # translational noise sigma for loop factor

    base_frame: "ids" # body frame name
    map_size: 100.0 # edge length of local map
    init_period: 0.5 # system initialization period
    gravity_scale: 9.81 # scale of gravity vector
    base_to_lidar: # base-to-lidar extrinsic params (for visualization)
      rotation: [1.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 1.0]
      translation: [0.0, 0.0, 0.0]
    imu_to_lidar: # imu-to-lidar extrinsic params
      rotation: [1.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 1.0]
      translation: [0.0, 0.0, 0.0]
      fixed: true
    preprocess:
      skip_stride: 2 # resampling stride
      resolution: 0.125 # downsampling resolution
      range:
        min: 0.5 # nearest range
        max: 40.0 # farthest range
    registration:
      use_feature: true # use only planar neighbor points
      plane_threshold: 0.05 # planarity threshold
      k_corrs: 10 # nearest k to search neighbor points
      max_corr_dist: 1.0 # maximum correspondency distance
      min_corrs: 100 # minimum correspondency number
    ikd_tree:
      resolution: 0.25 # downsampling resolution
      alpha_deletion: 0.5
      alpha_balance: 0.7
      min_size_rebuild: 10 # minimum subtree size to rebuild
      min_size_async: 1500 # minimum subtree size to async worker
    ivox_map:
      resolution: 0.25 # downsampling resolution
      nearby_search: 4 # {1, EXACT}, {2, Nearby7}, {3, Nearby19}, {4, Nearby27}
      max_points_per_voxel: 5 # maximum points in single voxel
      max_decay: 60.0 # maximum decay time in seconds
    ikf:
      max_iterations: 4 # maximum iteration
      convergence_epsilon: 0.005 # convergence criterion
      lidar_noise_sigma: 0.03 # sigma of point noise distribution
      imu_noise_sigma: [0.01, 0.03, 0.0001, 0.0001] # [gyro, accel, bias_gyro, bias_accel]
```

  - by adjusting these parameters **PER-MANHOLE** : `loop_detection::registration::k_corrs`, `preprocess::resolution`, `registration::k_corrs`, `registration::resolution`, `ikd_tree::resolution`, successful maps were obtained

- an example for manhole 6 (with node graph) would be:



- yet, no consistent parameters were found that universally apply for all manholes: different manhole should use different set of parameters

2. fine-tune the parameters related to LIO and (re)localization

- however, still not solved: unstable solution
- a different set of parameters set is used here:

-
  ```
   map_path: "/home/junwoo/ids_mmu_workspace/src/perception/navigation/assets/mh6_rev"
  keyframe_detection:
      max_range: 30.0            # maximum detection range
      max_time_diff: 30.0        # maximum time difference to maintain the latest keyframe
      motion_threshold: 5.0      # motion triggered keyframe generation
  relocalization:
      period: 10.0
      search_radius: 5.0
      registration:
          num_threads: 1
          resolution: 0.25            # loop registration sampling resolution
          max_iterations: 64          # maximum iteration
          k_corrs: 5                  # nearest k
          kernel_sigma: 1.0           # m-estimator constant
          convergence_epsilon: 0.001  # convergence criterion
  fixed_lag_smoother:
  ```

```
    window_size: 30.0                 # smoother lag in seconds
    prior_orientation_noise_sigma: 0.01  # rotational noise sigma for prior factor
    prior_position_noise_sigma: 0.1      # translational noise sigma for prior factor
    odom_rotation_noise_sigma: 0.001     # rotational noise sigma for odom factor
    odom_translation_noise_sigma: 0.01   # translational noise sigma for odom factor
    relo_rotation_noise_sigma: 0.003     # rotational noise sigma for relo factor
    relo_translation_noise_sigma: 0.03   # translational noise sigma for relo factor
lidar_topic: "/livox/lidar"  # point cloud topic
imu_topic: "/livox/imu"      # imu topic
base_frame: "ids"              # base frame
num_threads: 5                 # maximum number of threads for tbb
map_size: 100.0                # edge length of local map
init_period: 0.5               # system initialization period
gravity_scale: 9.81            # scale of gravity vector
base_to_lidar:                 # base-to-lidar extrinsic params (for visualization)
    rotation: [  1.0,  0.0,  0.0,
                 0.0,  1.0,  0.0,
                 0.0,  0.0,  1.0 ]
    translation: [ 0.0, 0.0,  0.0 ]
imu_to_lidar:                  # imu-to-lidar extrinsic params
    rotation: [  1.0,  0.0,  0.0,
                 0.0,  1.0,  0.0,
                 0.0,  0.0,  1.0 ]
    translation: [ 0.0110, 0.02329, -0.04412 ]
    fixed: true
preprocess:
    skip_stride: 1             # resampling stride
    resolution: 0.125           # downsampling resolution
    range:
        min: 0.5               # nearest range
        max: 40.0              # farthest range
registration:
    use_feature: false          # use only planar neighbor points
    plane_threshold: 0.05      # planarity threshold
    k_corrs: 5                # nearest k to search neighbor points
    max_corr_dist: 10.0         # maximum correspondency distance
    min_corrs: 100             # minimum correspondency number
ikd_tree:
    resolution: 0.25            # downsampling resolution
    alpha_deletion: 0.5
    alpha_balance: 0.7
    min_size_rebuild: 10       # minimum subtree size to rebuild
    min_size_async: 1500       # minimum subtree size to async worker
ivox_map:
    resolution: 0.5            # downsampling resolution
    nearby_search: 4           # {1, EXACT}, {2, Nearby7}, {3, Nearby19}, {4, Nearby27}
    max_points_per_voxel: 5    # maximum points in single voxel
    max_decay: 30.0            # maximum decay time in seconds
ikf:
    max_iterations: 4          # maximum iteration
    convergence_epsilon: 0.005 # convergence criterion
    lidar_noise_sigma: 0.05    # sigma of point noise distribution
    imu_noise_sigma: [ 0.03, 0.3, 0.001, 0.01 ] # [gyro, accel, bias_gyro, bias_accel]
```

- by adjusting these parameters **PER-MANHOLE** :`relocalization::resolution`, `relocalization::k_corrs`, `ikd_tree::resolution`, `ikf::imu_noise_sigma`, `ikf::lidar_noise_sigma`, **ONLY FEW** cases were able to correctly estimate poses.
- below are some examples of successful and failed cases (videos):
    - successful, failed1, failed2
    - note: initial jump was intentional, by feeding true initial pose (by operator)
- common feature of failure cases:
    - it seems to track correctly but out of sudden **the solution jumps** to other nodes that was accidently more fitted to current scan
    - repeated and hard-to-distinct feature of manhole yields **unstable** pose solution
    - **of course we can TRY FLYING drones**, but safety (stability of accurate solution) should be secured first