Technische Universität München

Collaborative simultaneous localization and mapping (CSLAM)

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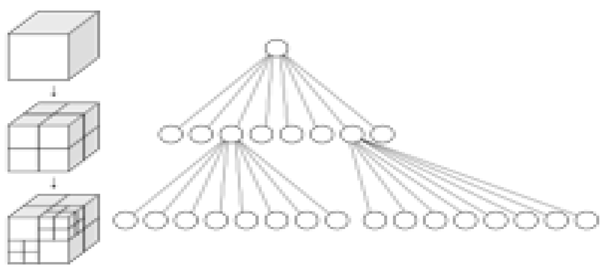
A decentralized approach for collaborative mapping in remote environments using swarms of drones equipped with LiDAR sensors.

Mapping and Localization

These are the main concepts we use for creating the map.

Octree

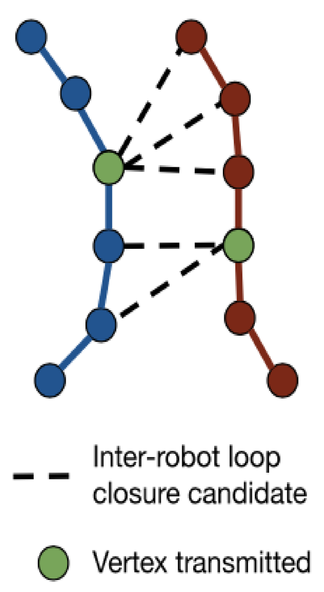
An octree is a tree structure used to describe 3D spaces, where each node has either 0 or 8 children. The drone constructs the map by converting the output from the LiDAR and storing it in an octree.



Source: Wikipedia

Landmark Recognition

Landmark recognition involves identifying prominent features in the 3D map. To achieve this, we initially simplify the tree by identifying larger volumes of matter, essentially creating bigger pixels. Subsequently, the map is analysed for landmarks, such as walls, corners, drones, trees, etc.



Loop Closure Detection

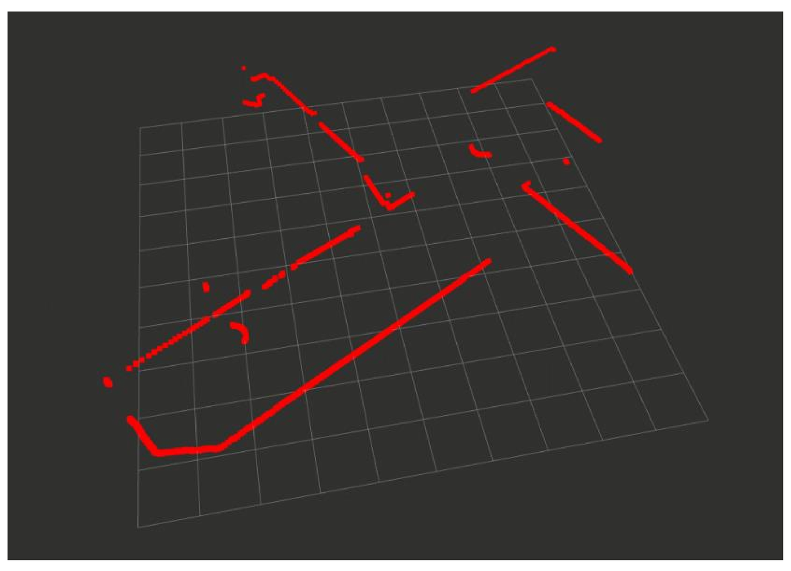
Loop closure detection is the identification of a previously visited location when a drone revisits an area that it or another drone has been to before. The landmarks are then used to find coincidences between two maps when merging them.

Pose Graph

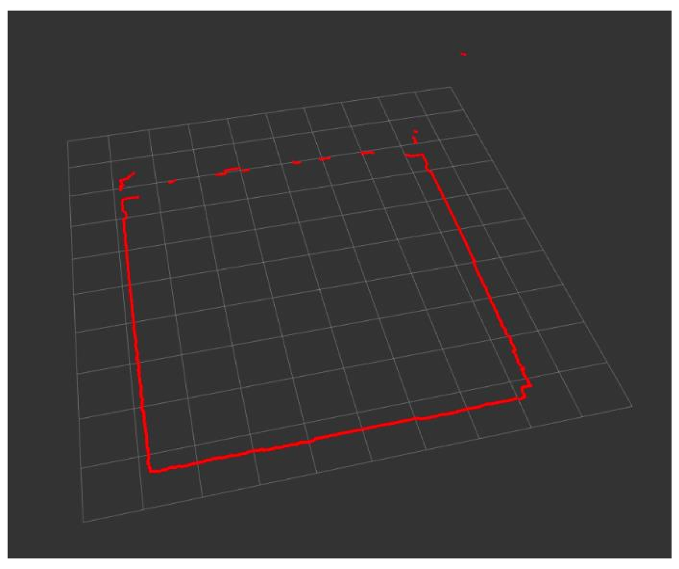
The algorithm uses pose graph to represent the placement of the drones. In this graph every node represents a drone pose (spatial position and orientation of each individual drone in the environment) and connection between the drones can be observed. Neighbour management and loop closures can be achieved by optimizing this graph.

LiDAR Demonstration

These are some examples of room scans we performed using a LIDAR A3M1-R1:



Mapping of a corridor in the TUM MI building



Meeting room with a window wall

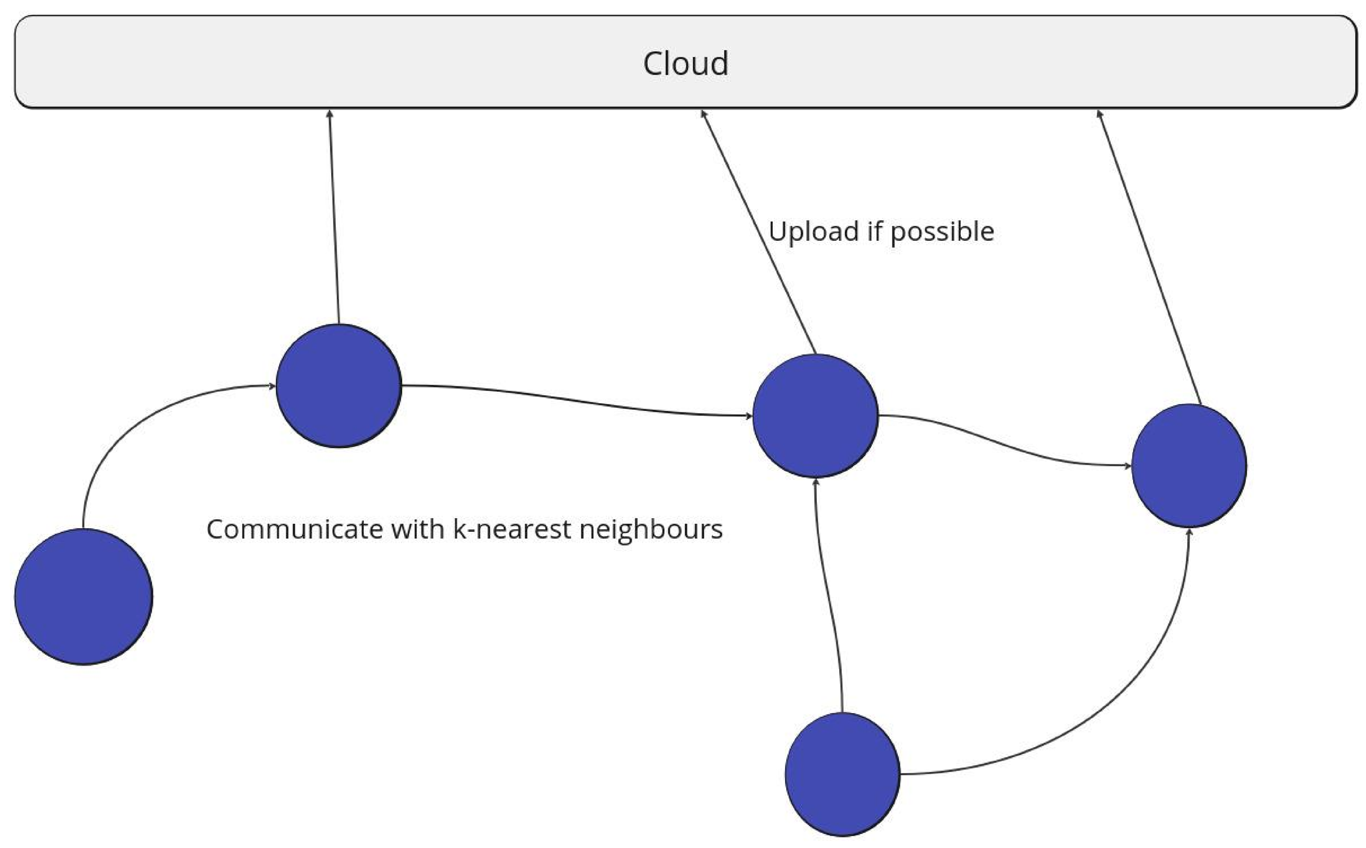
Used programs and libraries:
- OpenCV
- ROS2
- Gazebo

If you follow the link in the QR code you will find a video demonstration of what a drone would "see" using a LiDAR

https://youtu.be/W9U-EuIumio

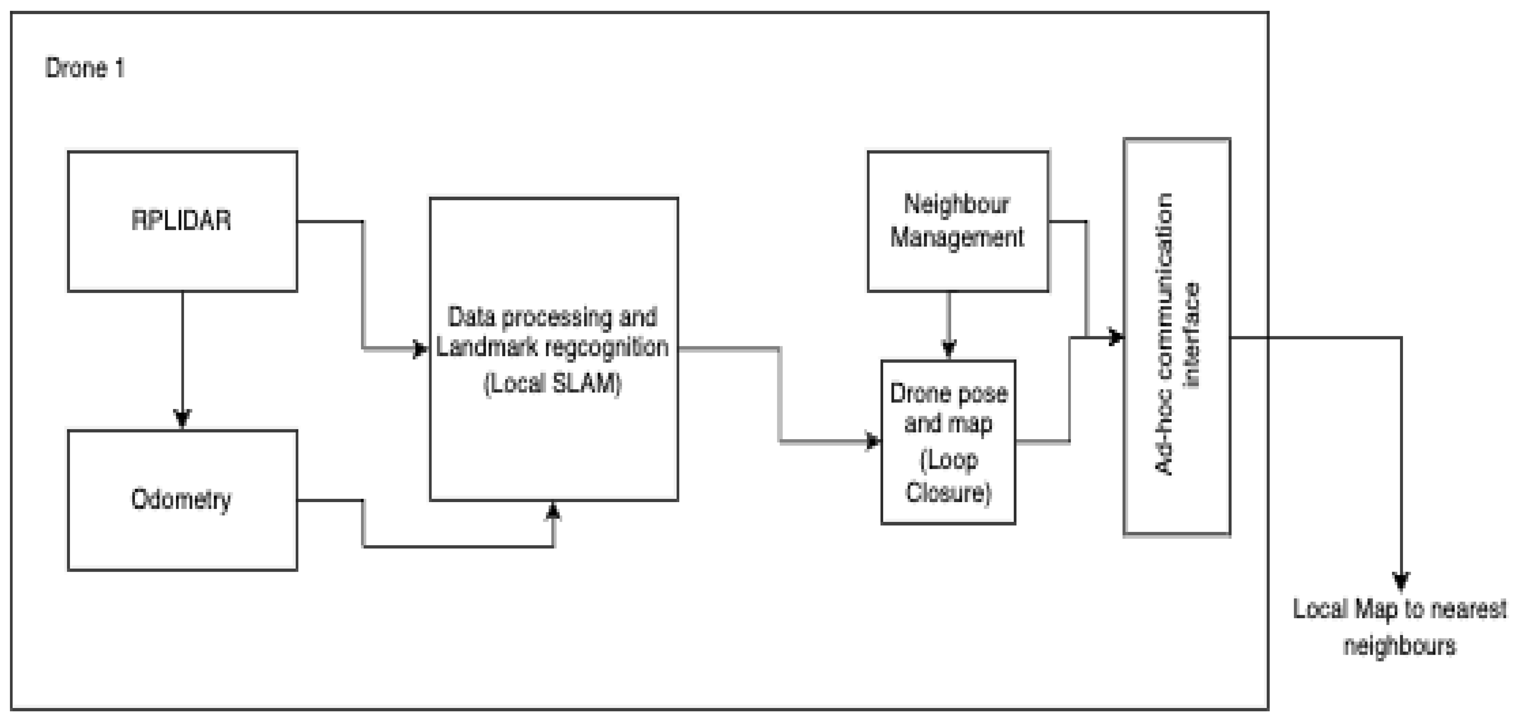
Architecture

System Architecture



We employ a swarm of n drones to explore and scan an unknown area where GPS is assumed to be unavailable. Each drone in the swarm stores its own map. A drone's map is generated by combining its measurements with the measurements it receives from its nearest neighbours. Drones can operate without the need to communicate with each other or with a server. However, they will attempt to exchange information with their neighbours and upload their map to a centralized server for storage when possible. This approach enables the drones to operate in circumstances where establishing communication with other drones and servers might be challenging.

Software Architecture inside the drone



Each drone is equipped with a LiDAR sensor to scan its surroundings and an Odometry unit to determine its position. During the data processing and Landmark Recognition phase, it combines these measurements to compute its map, consisting of a compressed octree representation of the point cloud (the map) and a list of landmarks with their positions. At the same time, it tries to connect to its n nearest neighbours (Neighbour Management or NM) and collect parts of their maps to combine them with its own (Drone Pose and Map), in order to gain information about its surroundings.

The NM module continuously tracks which drones are in its communication range (i.e., neighbours that can be reached reliably). Drones send heartbeat messages regularly, ensuring that network connectivity can be periodically evaluated. To reduce the amount of message exchange between neighbours, NM will always try to get the most updated map (i.e., the map that includes updates from other neighbours that are also within its reach) without having to directly contact these neighbours. The process of retrieving the maps from other neighbours can also be optimized by asking only for unknown parts of the map instead of retrieving redundant parts of the map.

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Links & References
- Demonstration video:
- Pose graph image: Retrieved from "**Swarm-SLAM : Sparse Decentralized Collaborative Simultaneous Localization and Mapping Framework for Multi-Robot Systems**"