Adaptive Exploration and Active Mapping for Forest Environmental Monitoring

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1. The Problem

Climate change induced extreme weather events is among the major causes of degrading and dying forests. Forests are particularly sensitive to climate change due to their limited adaptation skills to changing environmental conditions, in addition to their long lifespan. Since 2018, vast forest areas of Europe have experienced continuous prominent drought. Germany was among the most highly affected with only 21% of the regularly surveyed trees not showing any sign of health degradation or death. Most are dead due to large scale infestation of bark beetles.

In mitigating the effects of climate change, replanting trees aid in reducing soil erosion and reestablishment of forest ecosystems. However, due to financial and logistical limitations, **manual forest replanting measures are no longer feasible**, which suggests shifting the focus to digital replanting methods which are reliable and scalable to large affected forest areas.

As a result, accurate environmental monitoring is needed. Environmental monitoring applications require large amounts of accurate spatial and temporal data. Traditional remote sensing platforms are satellite-based data and manned aircrafts. They are usually not suitable for monitoring forest terrain because:

- Limited spatial resolution of several meters per pixel (0.3-10m per pixel)
- Limited temporal resolution
- Vulnerable to cloudy sky conditions, which attenuate electromagnetic waves and cause information loss and data degradation.

Figure 1: first-person view shows extent of damage to a forest area.

Figure 2: birds-eye view of the forest floor.

2. Objective and challenges

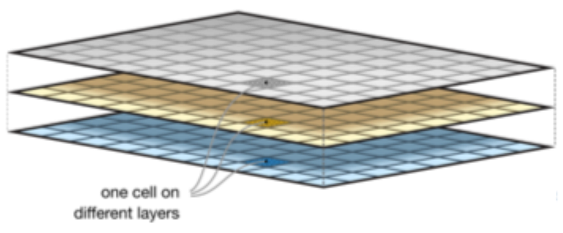

Figure 3: Multilayer structure of map.

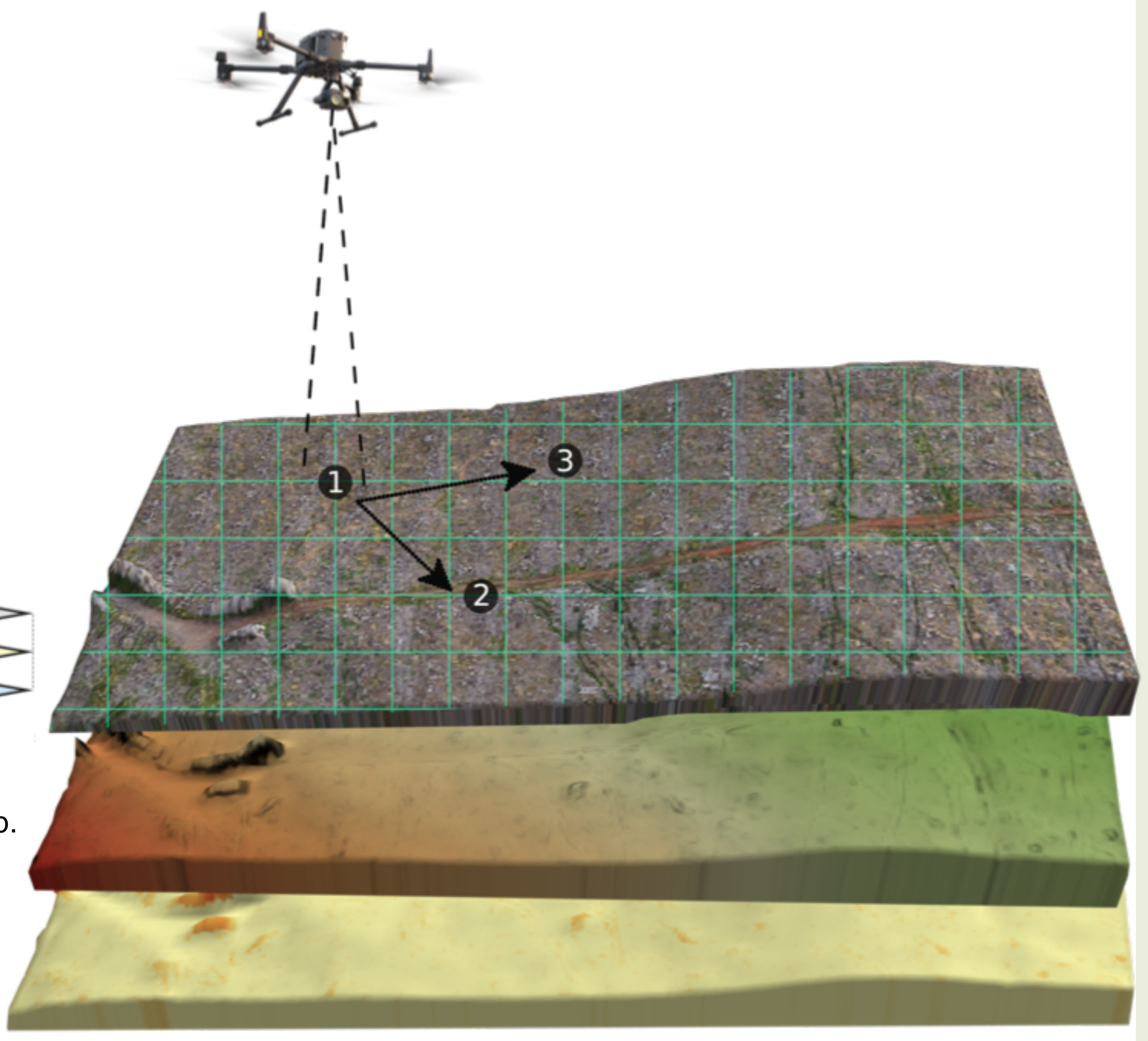

Figure 4: Three layers of forest terrain. Dashed lines is sensor footprint. The possible positions where the UAV can fly next indicated as 1,2 and 3.

The objective of this work is to investigate an adaptive exploration and active mapping problem where a UAV is guided by an information-gain-based controller through an apriori unknown outdoor environment.

Associated challenges include:

- No specific limit or criteria for choosing motion commands and sensing actions.
- Unknown and dynamic environment with no apriori information, subject to change due to wind, rain and other environmental conditions.
- Limited energy resources and reduced payload weight.
- A multi-resolution and multi-scale mapping problem, sensor measurements are inherently noisy.
- Non-uniform spatial distribution of the objects on forest floor, clutter, and occlusions.

3. Proposed methodology

- The mapping module consists of several layers each of which is designed to act as a standalone map.
- Sensors utilized include LiDAR, RGB and multispectral cameras.
- Such a hierarchical and multilayered representation constitutes a highly detailed model of the terrain.
- The model takes into account the visible factors (objects on terrain) and non-visible morphological factors (soil and water information).
- The resulting model including all layers will be a probabilistic terrain estimate including variance and confidence bounds.

A surrogate model is used to extract relevant information needed for an informed exploration and control of the UAV. The surrogate model is a simple analytical and statistical model of the highly detailed terrain model map. The surrogate model is a cheaper and convenient approximation of the underlying model it tries to approximate .

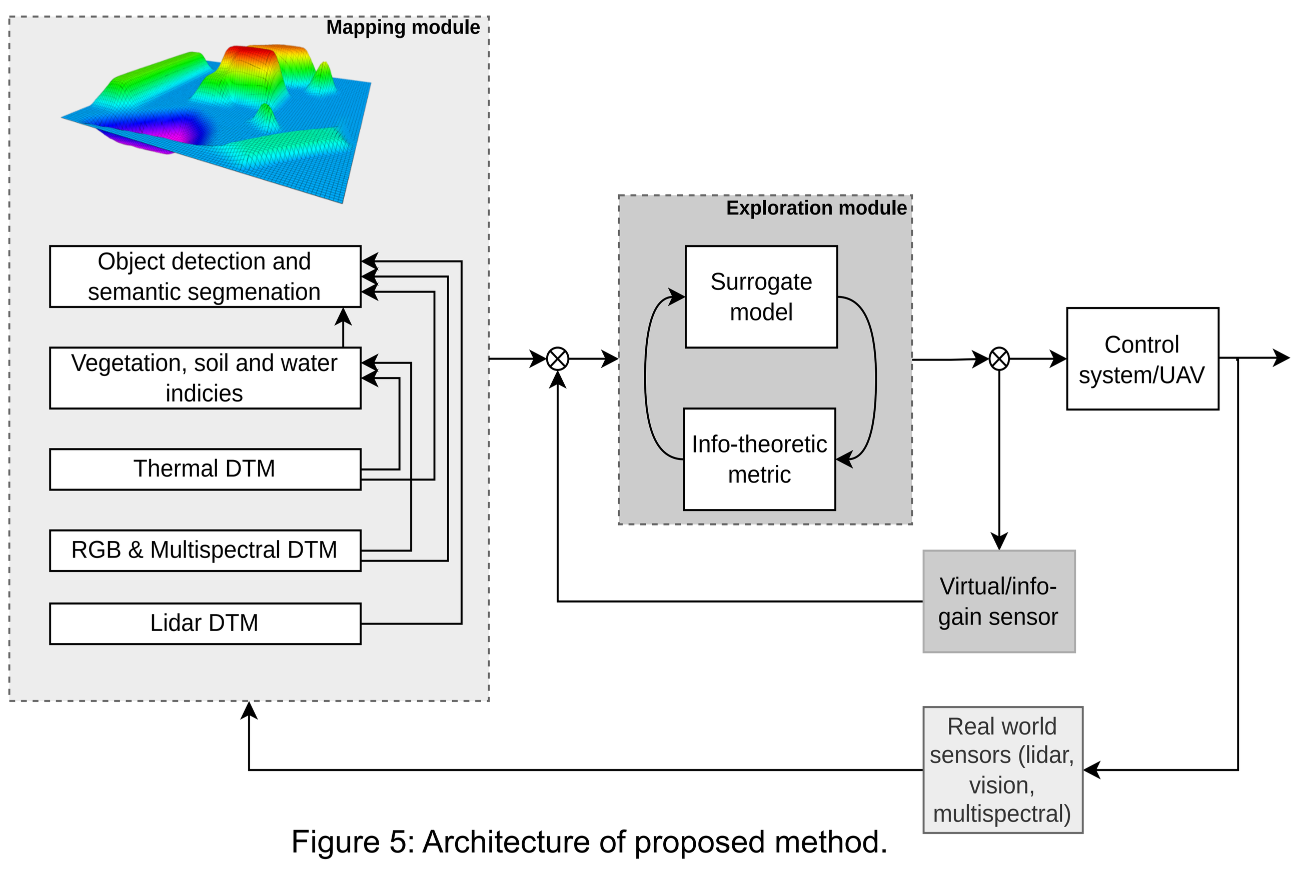

Figure 5: Architecture of proposed method.

4: Current state

Developed a custom sensor payload with LiDAR, high-rate IMU, RTK GPS, and multispectral camera. An SBC is utilized to store and process the captured data. Another off-the-shelf sensor package is also used that captures RGB and thermal images. The data is initially filtered and then processed. As an example, Figure 8 depicts a 3D point cloud of a forest calamity area in Germany, that has been registered and aligned. The RGB and multispectral images are processed to create high quality orthomosiacs and digital terrain models. In addition, several vegetation indices were calculated to detect and classify the different growing vegetation.

Figure 7: Surveying UAV with custom sensor payload.

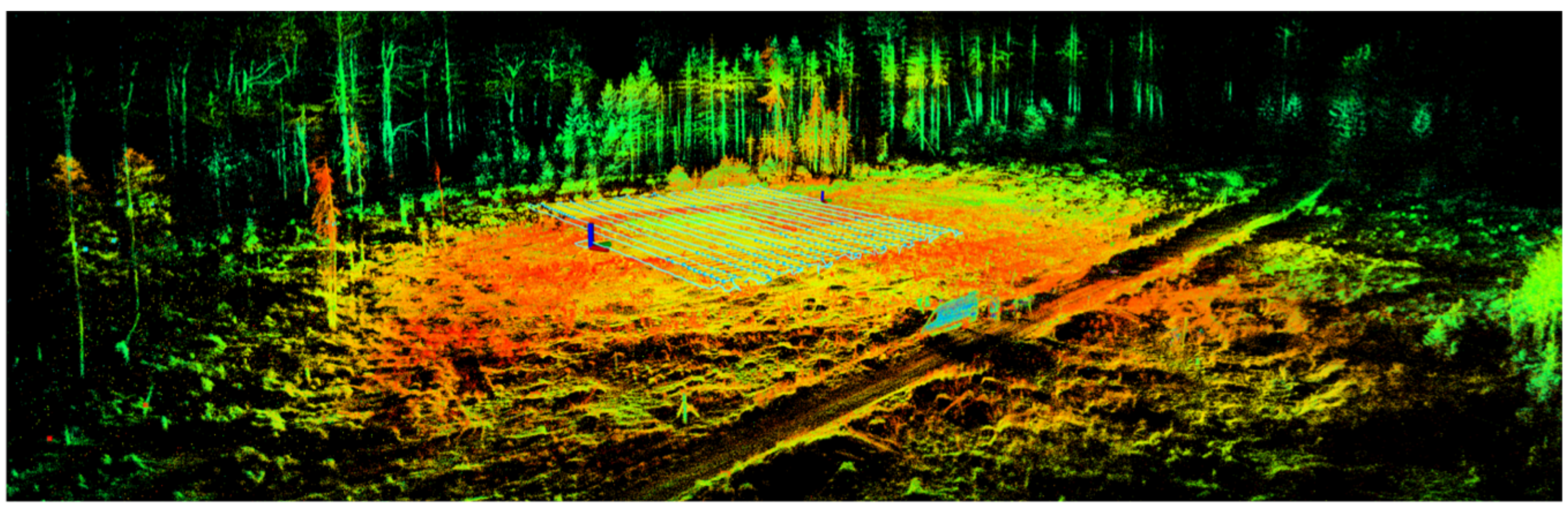

Figure 8: 3D point cloud from LiDAR mapping of forest area..

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