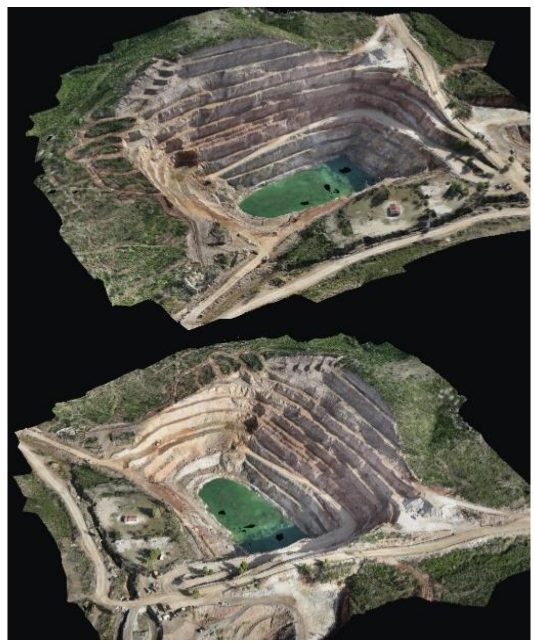
European Mining in the Green and Digital Era

4th Press Release

Advancing mining safety through innovative drones and automation

Over the last six months, the Laboratory of Robotics and Automation at the Department of Production and Engineering, Democritus University of Thrace (DUTH), has dedicated its efforts to the development of the Spatiotemporal Analysis and Semantic Mapping for the AUTOMINE module. The goal of the researchers' efforts has been to create a customized algorithm by deepening their expertise of mining operations. One of the most important parts of this project was visiting TERNA MAG for study. The main objective of the visit was to gather as much information as possible about open-pit and underground mining operations, as well as their topography. This type of data is essential for the team's simulation projects.



The researchers at DUTH were able to investigate the intricacies of mining operations by interacting with TERNA MAG's experts, and this allowed them to get crucial insights that will significantly guide the algorithm development process. They started working on the practical aspect of their research following the visit to TERNA MAG, concentrating on a task that is divided into three main sections. The project's first step is to create a 3D model of the mine, which will serve as the visual basis for processing data overlays. The second task at hand is to train an object detection framework, which is designed to recognize specific things in drone-taken pictures. The last phase consists of incorporating these findings into the three-dimensional spatial framework and combining them with the mine's model to improve the precision and usefulness of the image.

For the initial phase concerning the 3D model creation, the team employs a combination of sensors to achieve an accurate environmental reconstruction. A 3D LiDAR sensor generates a detailed point cloud capturing the geometry of the environment, while a camera sensor adds texture by providing surface appearance details. These sensors are integral components of the DJI Zenmuse L1 module equipped on the drone. Additionally, data from a GNSS receiver, enhanced with IMU readings, are indispensable for pinpointing the precise position and orientation of each observation, ensuring the model's fidelity to the real-world structure.

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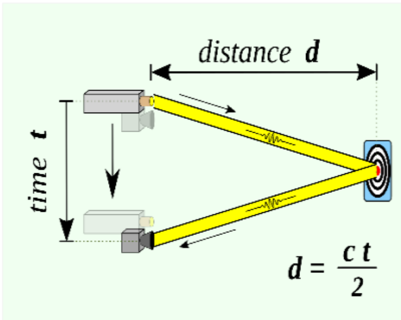

A lidar, which stands for Light Detection and Ranging, measures distances based on the time of flight concept. It emits laser pulses and measures the time it takes for the light to bounce back after hitting an object. By calculating the distance based on the speed of light, LiDAR creates highly accurate 3D maps of the surroundings.

The DUTH team conducted a real-world demonstration by deploying drones equipped with LiDAR sensors to map a selected area. As the drones flew over the region, the LiDAR sensors emitted laser pulses, capturing precise distance measurements. The collected data was then processed to generate detailed and accurate 3D maps of the terrain.

Upon creating an accurate 3D representation of the mining environment, the project advances to its second critical phase: the detection of specific targets within the captured imagery, such as trucks, excavators, and cars. This step employs a deep learning-based algorithm, designed to recognize, and classify these objects. While such algorithms can achieve high levels of precision and accuracy, their effectiveness hinges on the availability of extensive training data. This requirement underscores the necessity for a robust dataset to effectively teach the algorithm how to identify the specified targets accurately. Currently, the DUTH team is working with TERNA MAG to obtain a dataset that includes pictures of vehicles and trucks.

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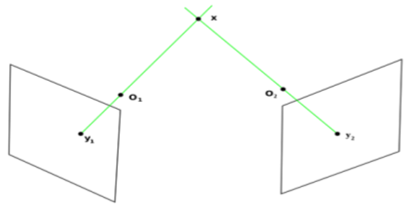
The last part of the researchers' task is the transformation of the detected objects from the image plane into the 3D world.To achieve this, it is necessary to know the camera's pose at the time of capture, the position of the object within the image, and establish correspondences between objects across different images.Then triangulation can be performed to project that object to the 3D world and thus place it onto the previously generated 3D model of the area.



Within the context of the MASTERMINE project, contributions to the advancement of safety in mine environments have been marked by the publication of two significant papers in 2023 at internationally recognized conferences. These works are pivotal in enhancing DUTH's role in MASTERMINE, focusing on the detection of objects and individuals to bolster safety in mining settings.

The first paper, "Multi-criteria Decision Making for Autonomous UAV Landing," co-authored by DUTH team and presented at the IEEE International Conference on Imaging Systems & Techniques **IST 2023,** represents a leap forward in UAV safety. It introduces a novel multi-criteria decision module that evaluates risks from obstacles during emergency landings, using a lightweight detection system to calculate an "occupancy score". This score is based on various parameters, including the sum of detections, average confidence, detection density, and slope, showcasing the system's efficacy through simulations that included dynamic and static human figures. The figures below represent DUTH's proposed framework.

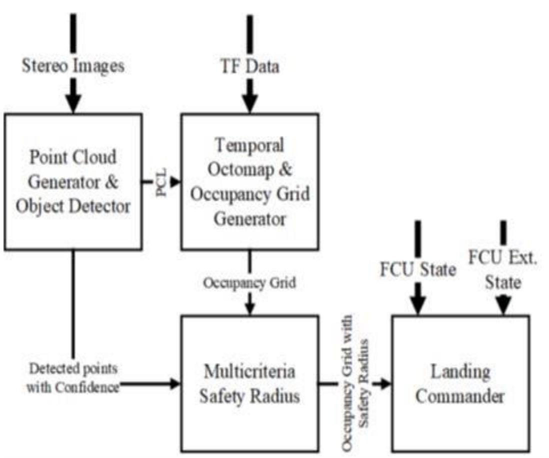


Figure 1: Proposed framework for autonomous UAV landing

Fig. 1. The proposed framework consists of four sub-modules: The first one is based on the object detector; it receives a stereo pair from a camera and outputs a point cloud along with the detections coordinates in the world's frame. The point Cloud is fed to the Temporal Octomap module to insert the spatial information into the Octomap and produce an occupancy grid. The resulting occupancy grid along with the detections and their confidence are inserted into the multi-criteria safety radius module to determine the safety radius for each landing obstacle. Ultimately the landing commander inspects the derived occupancy grid to discover safe spots suitable for landing.

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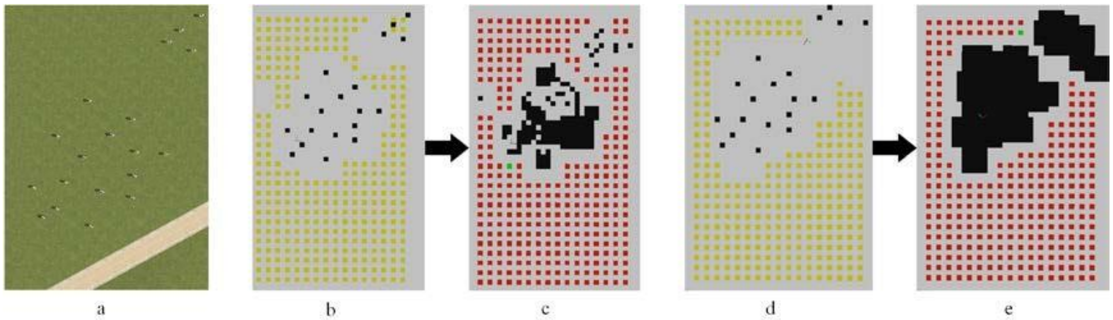

Figure 2: Constant and dynamic safety radius

Fig. 2 This visualization aims to show the difference between a constant and a dynamic safety radius calculated by the proposed module. In **a**, an aerial view of the Gazebo environment is shown. In **b**, we can see the ground truth where each black cell represents a person and thus a landing obstacle and yellow represents every landing point deduced by the pipeline. In case one of those points was occupied, it would be red. In **c,** the points detected by the pipeline, along with their safety radius are presented with black. In this case, the same landing points in b are presented in red. The green is the landing spot closest to the UAV. The same applies to images d and e. The amount of unoccupied landing spots is greater in the case of dynamic safety radius **(b and c)** compared to constant safety radius (**d and e**).

The second paper, "Light-weight Approach for Safe Landing in Populated Areas,", which was accepted in the 2024 IEEE International Conference on Robotics and Automation, proposes a streamlined pipeline for UAVs to safely land in populated zones. This innovative approach employs cutting-edge object detection and OctoMap for point cloud generation and analysis, pinpointing safe landing areas amidst obstacles. Optimized for low- weight embedded systems like the Nvidia Jetson Nano, this method ensures real-time application viability, proven through simulations with different densities and movements of people, highlighting its potential to significantly enhance UAV autonomy and safety in emergency landings within human-populated environments.

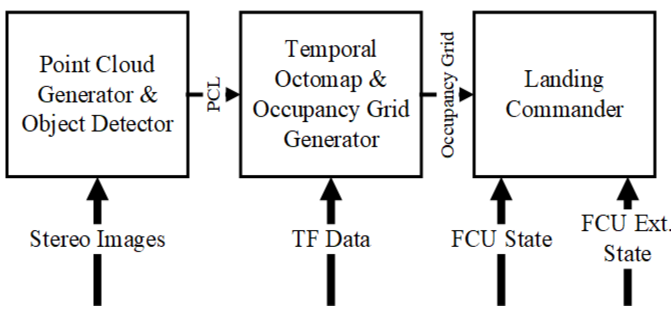

Figure 3: Light-weight approach for safe UAV landing in populated areas

Fig. 3 The proposed framework consists of three sub-modules: The first one is based on the object detector; it receives a stereo pair from a camera and it outputs a point cloud, which is then fed into the second pipeline stage. The second module along with the point cloud receives transformed data necessary to register the point cloud onto an OctoMap.

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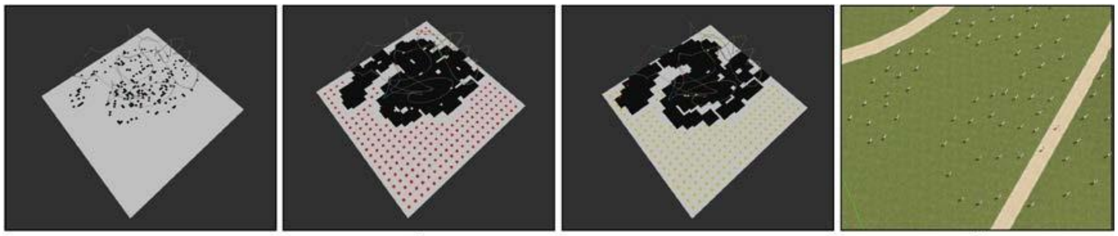

a b c d

Figure 4: Visualization of the output of each sub-module

Fig. 4 This is a representative visualization of the output of each sub-module along with the aerial picture of the densely populated environment. Shown in **a** is the occupancy mesh produced by the TOM module after importing the Point Cloud into OctoMap. In **b** the safety margins are applied to each landing obstacle. The available landing points are presented in red while the active landing point is highlighted in green. In Fig. **4c** the output of the evaluation module is shown. Every correct land point (not Occupied) is presented with yellow while every landing point that has been mistakenly considered as unoccupied is presented with red. The actual simulated world is depicted in Fig. **4d**

These contributions underscore the project's commitment to leverage advanced technologies for safety enhancements in mining operations. Through the integration of sophisticated object detection mechanisms and decision-making frameworks, the research not only advances UAV safety protocols but also sets a new standard or autonomous vehicle operation in challenging environments. The collaborative effort behind these publications reflects a broader initiative within MASTERMINE to develop and implement technologies that safeguard human life and optimize operational efficiency in mine settings.

About the project

MASTERMINE is a 4-year Horizon Europe co-funded project which aspires to become the go-to ecosystem for mines that envision digitalisation, environmental sustainability, productivity monitoring and public acceptance within their strategic goals. The focus will be on an Industrial Metaverse (IM) approach to build a digitalized copy of a real-world mine.

The project will demonstrate its applicability in 4 EU demo cases and one replication demo in South Africa. The mining partners offer access to a total of 10 mines around Europe, producing 10 different raw materials, including 4 CRMs (Cobalt, Coking Coal, Phosphate Rock and Platinum).

MASTERMINE consists of six high-level modules:

- CYBERMINE: Leading the digital transformation of EU mines.
- AUTOMINE: Establishing autonomous and electric operations along with smart monitoring and maintenance.
- GEOMINE: Ensuring safety and stability in critical structures.
- GREENMINE: Enhancing the environmental sustainability of the mines.
- METAMINE: Building the first mining metaverse of the EU mines.
- OURMINE: Connecting the mining industry with the surrounding community to build trust and foster social innovation.

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Project title: European Mining in the Green and Digital Era
Project ID: 101091895
Start Date: 01/12/2012
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Project Consortium:

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