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Overcoming the challenges of 3D modeling in harsh, confined, underwater environments: A case study

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It is estimated that there are more than 8000 abandoned, flooded mines in Europe, many of which lack any information on their status and layout. Accurate and detailed 3D modeling plays a key role in fully understanding these complex environments and determining their remaining hidden potential. However, acquiring the needed data is a challenging task since these environments are extremely hazardous for traditional methods such as human diving. Additionally, human divers can reach only a limited depth range, much smaller than that of a standard mine. Therefore, underwater vehicles appear as a natural alternative for overcoming the disadvantages of direct human exploration. The UX1-Neo is a semi-autonomous underwater robotic system built precisely for this use. This small spherical robot with a 0.7m diameter has a 500m depth rating and various sensors for surveying the environment, such as multibeam and scanning sonars, structured light projectors, and multispectral cameras.

The unfavorable properties of the water medium, such as light scattering and attenuation, pose additional difficulties for data acquisition in these complex environments. Furthermore, mine tunnels are a GPS-denied environment, which makes the modeling system rely entirely on the robot's inertial navigation system, which is prone to error due to the dead-reckoning drift. Conventional methods for correcting this drift, such as SLAM, face additional challenges in these repetitive environments (shafts and tunnels) due to their highly symmetric structures and lack of distinctive features. Additionally, during the exploration of a salt mine, Solotvyno (Ukraine), we faced a new challenge, a refraction of the sonar data due to the salty water, which required further processing in order to create an accurate 3D map of the mine.

Rapid developments in the field of underwater photogrammetry are producing impressive results; however, they still have difficulties with the environments with low light, which causes blurring of details, low image contrast, and in general, lack of features needed for image matching. Also, underwater images are prone to contain an excessive amount of blue light, making the features even less visible. Moreover, photogrammetry technology struggles with repetitive environments due to the same reasons as SLAM.

In this work, we demonstrate the challenges faced during our exploration of the Solotvyno salt mine with the UX1-Neo robot and how we overcame them in order to produce a detailed 3D model. In particular, we illustrate that sensor and data redundancy is vital during operations and post-processing. Each UX1-Neo sensor contributes to a complete, coherent picture of the environment. However, using many sensors produces an enormous amount of data that require further filtering: hundreds of millions of points are reduced to a few million using both automated and manual methods. Images also require processing due to the aforementioned reasons: using CLAHE contrast enhancement together with white balancing algorithms, we produce suitable images for photogrammetry. Additionally, data gathered from multiple missions need to be combined for a complete model: we show the importance of robot orientation initialization and external surveying of the robot's launch location to correctly align scans of different missions.