

# Exploration and Mapping of Catacombs with Mobile Robots

V. A. Ziparo  
and M. Zaratti  
Algorithmica Srl

G. Grisetti, T. Bonanni,  
J. Serafin and M. Di Cicco  
Sapienza University of Rome

M. Proesmans  
and L. van Gool  
Katholieke Universiteit Leuven

O. Vysotska, I. Bogoslavskyi  
and C. Stachniss  
University of Freiburg

## I. INTRODUCTION

The conservation of archeological sites and historical buildings is an important goal for both, scientists as well as the general public. Accurate models of such sites is often a prerequisite for conservation, maintenance, restoration, security, and other tasks. Recent technological advancements in information and communication technology as well as artificial intelligence and robotics have the potential to develop valuable tools for mapping and digitally preserving archeological sites.

In this work<sup>1</sup>, we focus on archeological sites that are difficult to access by humans, such as catacombs or similar underground sites. These environments are often not open to public because they are not safe and operation within them is difficult and sometimes even hazardous. Therefore, the application of standard digitization techniques, such as static 3D laser scanners operated by humans, is often not feasible. On the other hand, mapping and digitizing such sites is important for both, enlarging their fruition and for maintenance tasks. In these environments, autonomous mobile robots offer a great potential to support these tasks. Our goal is to develop autonomous mobile robots for mapping archeological sites that are difficult or dangerous to access for humans.

This document describes the recent developments in the FP7 project ROVINA. We report on our first inspection in the catacombs of S. Priscilla in Rome, along with the preliminary analysis of the collected data and on the lessons learned for the design of the ROVINA robot.

## II. THE ROVINA PROJECT

ROVINA project (<http://rovina-project.eu>) is a FP7 project recently funded by the EC that focusses on the exploration, digital preservation, and visualization of archeological sites. Its key objectives are

- developing autonomous robots for creating digital models of hard-to-access environments,
- improving autonomous navigation for robots exploring unknown underground environments,
- building large 3D textured models of poorly structured environments, and

- offering a cost-effective support for performing continuous monitoring of these sites and to enable comparative analysis that will allow to devise better preservation plans.

## III. INITIAL ENVIRONMENT ANALYSIS

The experimental evaluation of the ROVINA system will be performed in S. Priscilla catacomb in Rome and the S. Gennaro catacomb in Naples, Italy. At these sites, the exploration, digitization, and visualization tasks will be conducted and evaluated. The International Council of Monuments and Sites has identified both as the most representative sites for this class of cultural heritage, both in terms of archeological impact and robotic challenges.

Our preliminary analysis of the sites highlights a harsh environment that is similar to the environments faced by rescue robots: there are steep slopes, uneven grounds, challenging obstacles, drifts and debris, dangerous passages, huge unexplored areas, health hazards due to radioactive radon gas, and poor wireless connectivity. In addition, being an archeological environment, the robots has to deal with fragile objects, artifacts, wall paintings, bones, carvings, etc. A detailed analysis of the two sites is available in [1], while the datasets we collected during this run are available on our website <http://www.rovina-project.eu/research/datasets>.

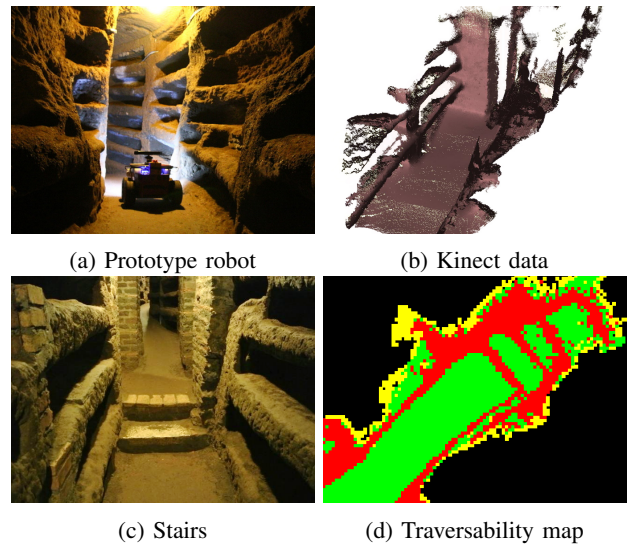


Fig. 2: S. Priscilla catacomb exploration

<sup>1</sup>This work has partly been supported by the European Commission under contract number FP7-600890-ROVINA.

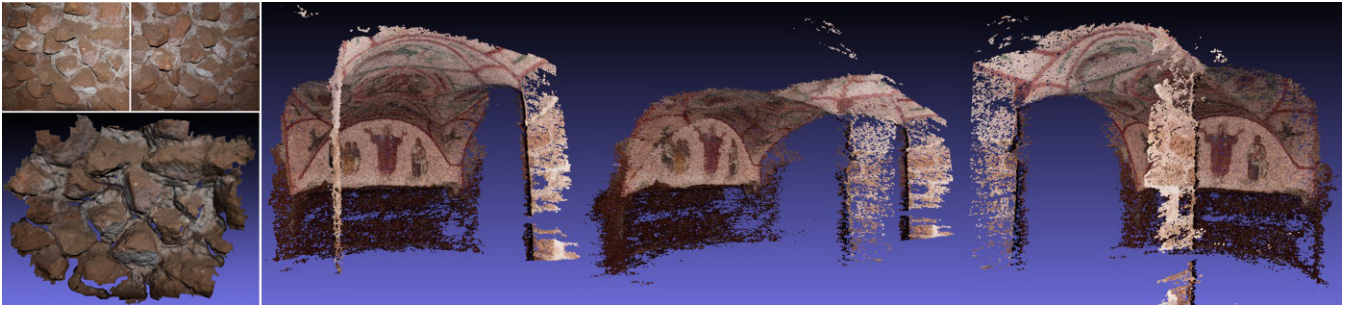


Fig. 1: 3D reconstruction from photos: a wall fragment and a decorated room

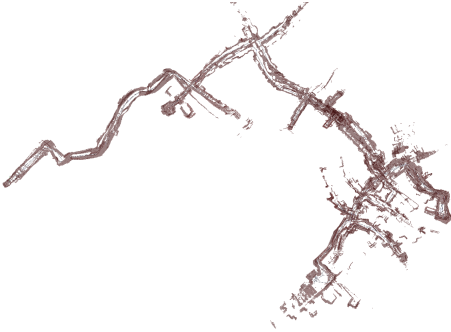


Fig. 3: First mapping results during the preliminary acquisition

Given that the ROVINA robot is not available yet, we performed the data collection with a test setup: a Pioneer AT with two planar laser scanners, one facing forward and the other one backward, a Microsoft Kinect RGB-D camera, and an XSens MTi IMU. In addition, we used a standard digital camera with which we manually took pictures of the environment.

The catacombs environment has a rich but repetitive 3D structure (see Figure 2a) that has been captured by the Kinect sensors (see Figure 2b). We evaluated the quality of this data for navigation and, in particular, for traversability analysis. Indeed the results were promising. For example, the traversability map in Figure 2d shows in green the traversable areas from Figure 2c.

Figure 3 shows the path of the robot during this preliminary mission. The reconstruction was done by integrating the IMU and aligning incrementally the 3D data from the Kinect. In addition, large rotational drifts are compensated by the compass on the IMU and the contours of the laser scans are sharper due to the incremental alignment. The reconstruction is challenging for state of the art approaches so we enriched it by adding some manual loop closures.

Finally, based on the camera images, we performed a preliminary reconstruction based on a structure from motion (SFM) pipeline. Starting from individual features detected in the each of the images, the system identified the correspondences based on which the system determines both, the external and intrinsic camera parameters as well as the 3D structure. Figure 1 shows some of these preliminary results.

#### IV. PRELIMINARY HARDWARE ANALYSIS

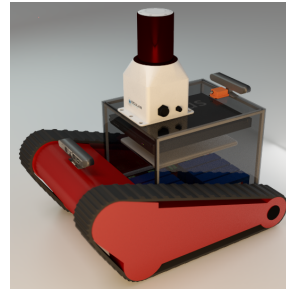


Fig. 4: Virtual robot

Our first inspection made clear that the Pioneer AT is not an option for navigating in such a harsh terrain. There are slopes, debris, uneven terrains, stairs and all sort of other mobility challenges. Moreover, there is the need of a long range 3D laser sensor and pictures should be taken at high frequency and from different points of view

to support the reconstruction.

In order to improve mobility, we decided to adopt the tracked robot Mesa Element. While to improve the long range sensing capabilities, we decided to add the Ocular RE05 3D laser (30m range). Figure 4 shows a 3D reconstruction of the robot based on a simulation during the design phase. Our pre-development simulations show that this configuration is not able to sense inside the niches that are over a certain height (see Figure 2a). For this reason, we are planning to include a linear actuator capable of raising the sensors on demand.

In order to have a better coverage of images, the robot will carry an array of Allied Manta industrial cameras arranged in a way that the robot can take multiple pictures of the same area from different points of view.

The robot should also be dust and humidity proof (IP65). It will host two on board computers, one for all intensive tasks and the other for data logging. It will have an extra power system ( $\sim 300W$ ) for computers and sensors for a planned system autonomy of two hours.

#### V. CONCLUSIONS

In this document, we have summarized on our preliminary analysis of the ROVINA project. Our inspection shows that the environment is challenging and that it is comparable to a rescue scenario, albeit having more demanding sensing requirements due to the nature of the addressed task.

#### REFERENCES

- [1] "Rovina deliberable 1.1: Environment analysis, hardware requirement analysis and data collection," <http://rovina-project.eu/del/del-1-1.pdf>.