Urban Underground Space 3D Semantic Mapping

Technical Report of 2021 ISPRS Scientific Initiatives

Investigators[1]

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Project Goals

This scientific initiative aims to investigate the methodology of urban underground space 3D semantic mapping and organize a benchmark to evaluate the associated 3D semantic mapping methods. The expected outcome of the proposed scientific initiative is to facilitate interactions between researchers and developers with interests related to urban underground space mapping, and to promote the development of cross-cutting techniques of robot navigation, 3D SLAM, and 3D dynamic mapping.

Activities and Results

The project team designed two LiDAR scanning systems named WHU-Helmet and UGV 3D mapping system, one dataset and three papers to complete the scientific initiative.

WHU-Helmet is a compact helmet-based laser scanning system. Fig. 1 shows the mechanical design of the WHU-Helmet. Four types of sensors are included in this system, which are solid-state LiDAR (Light Detection and Ranging), camera, IMU (Inertial Measurement Unit), GNSS (Global Navigation Satellite System) receiver. This system was applied in urban aboveground and underground 3D mapping successfully as shown in Fig. 2. The paper detailed integration and evaluation of the system for underground 3D mapping has been accepted and will be published in XXIV ISPRS Congress.

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[1] Bisheng Yang is a Co-chair of ISPRS WG II/3. Yiping Chen is a proposer of ISPRS WG for point clouds processing in 2020.

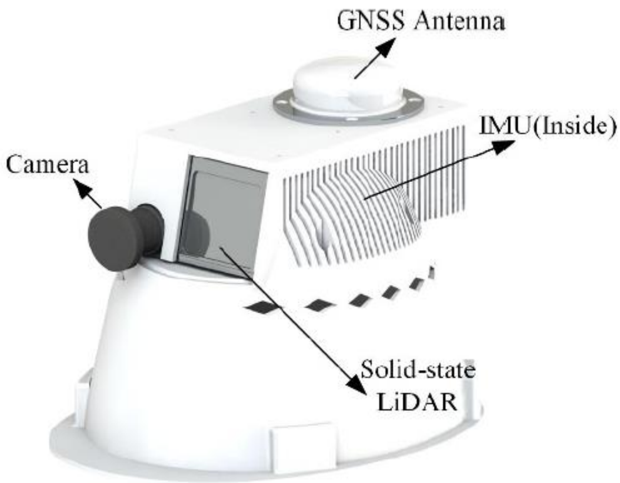

Fig. 1 System overview of WHU-Helmet.

We showed eight point clouds of these four scenes captured by the WHU-Helmet in different urban environments as shown in Fig. 3. Ground truth data used for evaluation of the SLAM algorithm accuracy is captured using a tactical-grade POS (position and orientation system). This WHU-Helmet dataset will be made publicly available via ISPRS website.

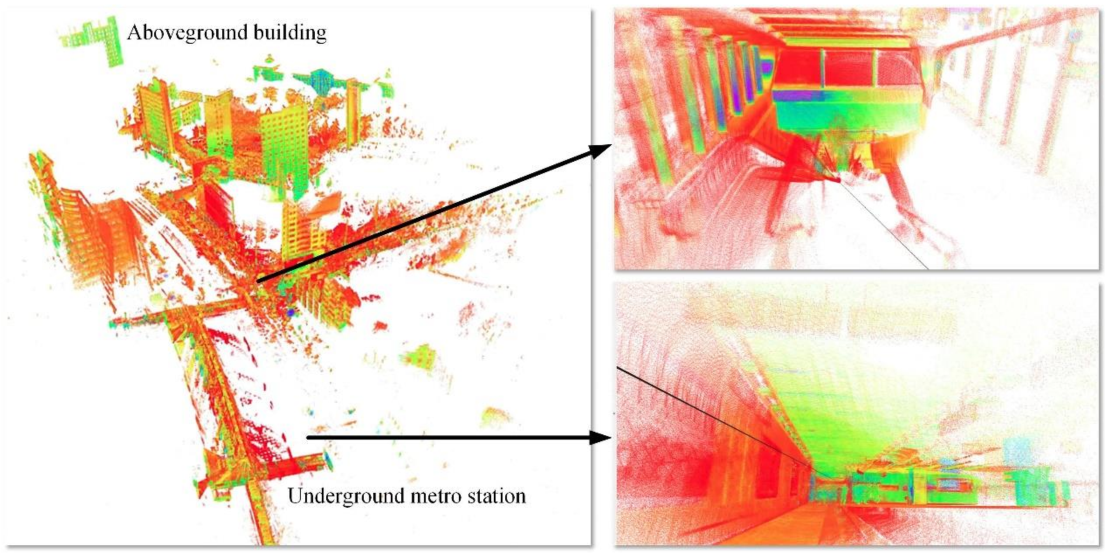

Fig. 2 3D mapping of the urban underground space.

UGV 3D mapping system (Fig. 4) was designed for investigating the city space especially for underground space. The system uses the Clearpath Jackal as the motion platform, and consists of a Velodyne VLP-16 laser scanner, a stereo camera, an IMU and a NUC on-board processor. Our system can thoroughly and accurately fuse the point cloud data in favor of the resultant 3D map which can be used for many applications such as autonomous driving and navigation, deformation monitoring of critical infrastructure.

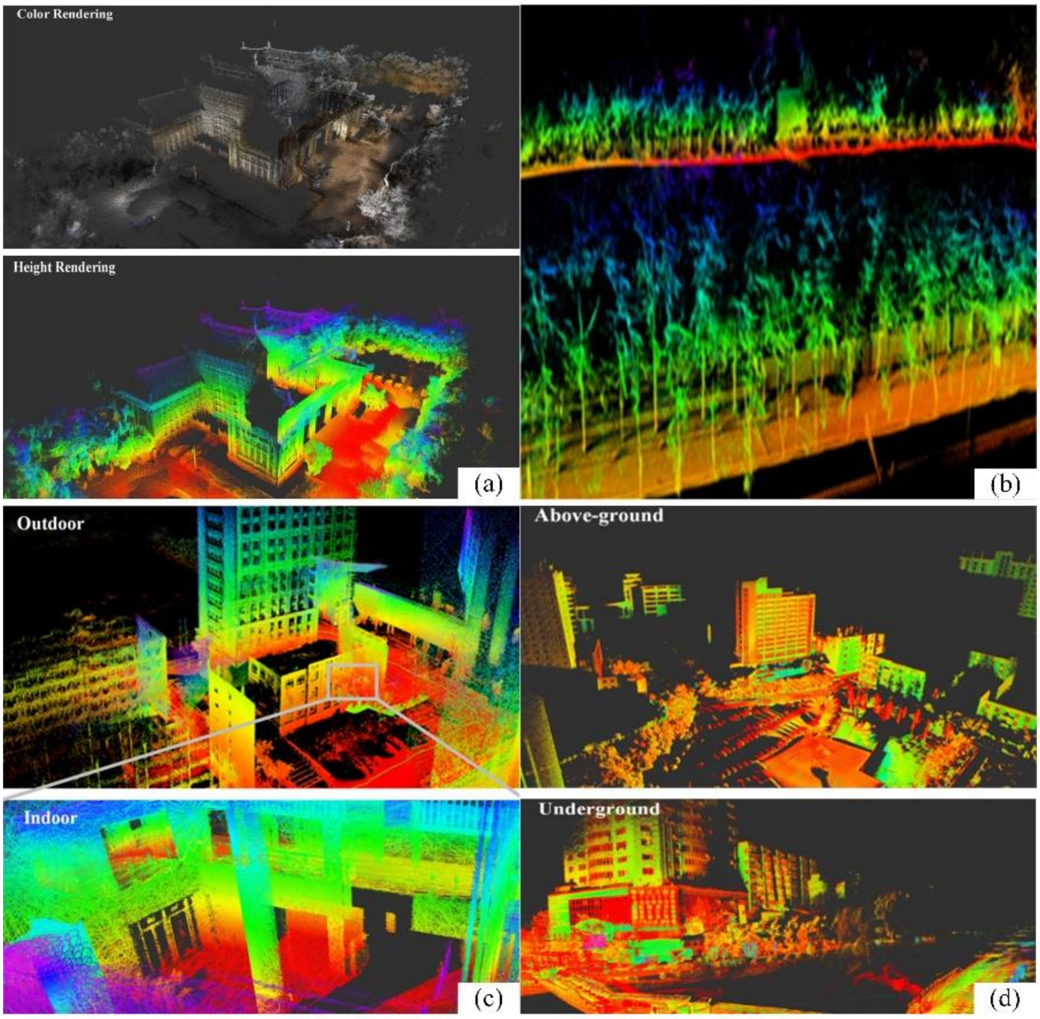

Fig. 3 Point clouds captured by WHU-Helmet. (a) Ancient building; (b) Urban vegetation; (c) Outdoor and indoor 3D mapping. (d) Aboveground and underground 3D mapping.

Based on the scanning system, the project team acquired several data to evaluate our proposed novel algorithms. We have proposed a 3D-CSTM: A 3D Continuous Spatio-Temporal Mapping method. The 3D-CSTM is a robust LiDAR-based SLAM system separating localization and 3D mapping into two isolated modules which can achieve real-time ego-motion estimation and precise point cloud reconstruction. In order to alleviate the influence of motion distortion and optimization degeneration problems, which are two nonnegligible issues in the system of LiDAR SLAM, we use multi-frame-features within the time-window modeled by B-spline to estimate the 6 DoF poses, as shown in Fig. 5 (a). In the 3D mapping process, spatial and temporal continuity are both considered to make the resultant point cloud map precise and clear (Fig. 5 (b)). This work has been accepted by ISPRS JPRS.

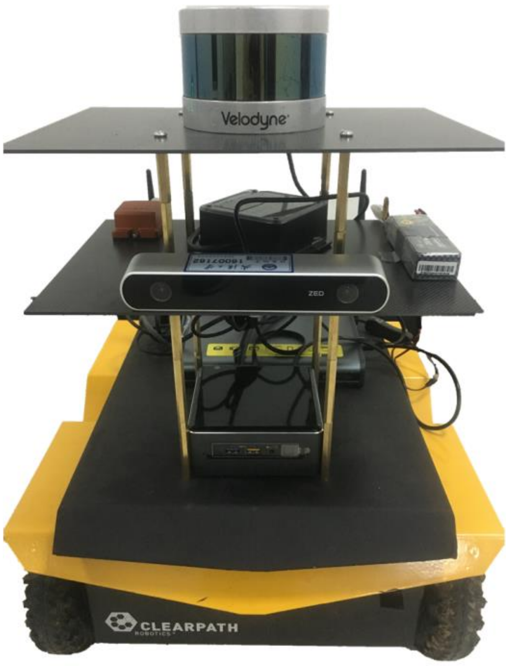

Fig. 4 UGV 3D mapping system.

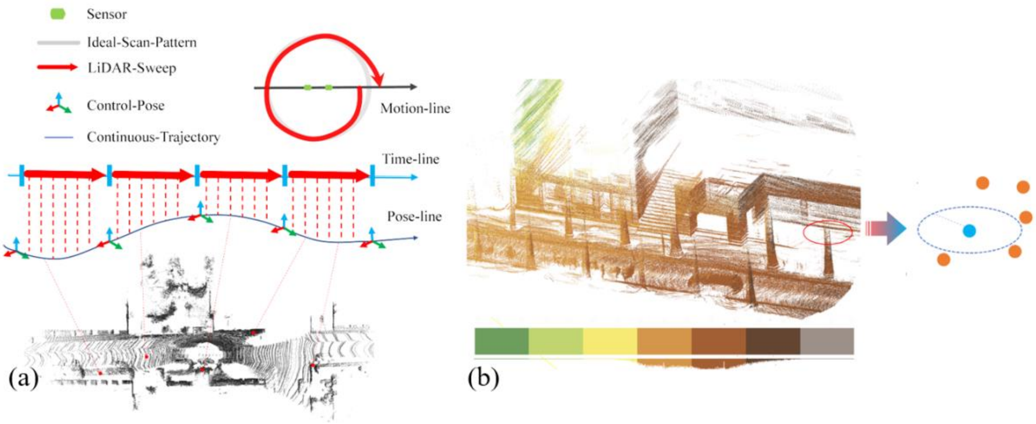

Fig. 5 3D-CSTM system. (a) spline based non-rigid registration; (b) continuous time and spatial mapping (color encodes time-stamp).

Registration of underground large-scale point clouds remains many challenges in the scenes with symmetric and repetitive elements, the weak geometric features, and dramatically changes in different phases. To address these issues, a novel neural network JoKDNet is proposed to jointly learn the keypoint detection and feature description to improve the feasibility and accuracy of point clouds registration as shown in Fig. 6. This work is published in International Journal of Applied Earth Observation and Geoinformation.

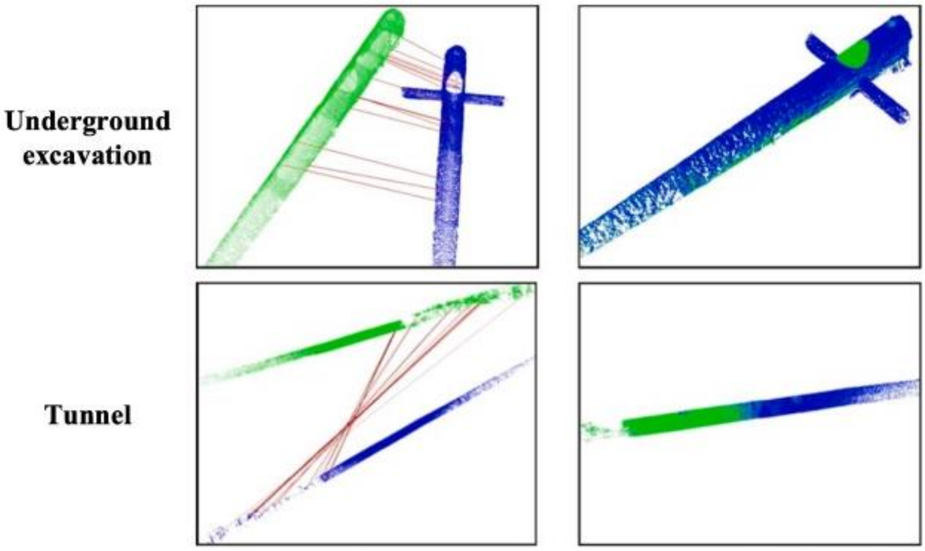

Fig. 6 JoKDNet for registration of underground point clouds.

The completed and submitted project outcomes are list as follows:

Hardware systems:

1. WHU-Helmet
2. UGV 3D mapping system

Papers:

1. Yuan Wang, **Bisheng Yang*, Yiping Chen**, Fuxun Liang, Zhen Dong, JoKDNet: A joint keypoint detection and description network for large-scale outdoor TLS point clouds registration, *International Journal of Applied Earth Observation and Geoinformation*,104,102534,2021.
2. Jianping Li, **Bisheng Yang***, **Yiping Chen**, Weitong Wu, Yandi Yang, Xin Zhao, Ruibo Chen, Evaluation of a compact helmet-based laser scanning system for aboveground and underground 3D mapping, *XXIV ISPRS Congress*,2022.
3. Yangzi Cong, Chi Chen, **Bisheng Yang**, Jianping Li, Weitong Wu, Yuhao Li, Yandi Yang, 3D-CSTM: A 3D continuous spatio-temporal mapping method, *ISPRS Journal of Photogrammetry and Remote Sensing*, 186, pp.232-245, 2022.

Dataset:

1. WHU-Helmet Dateset: A large scale ground truth of multi-sensor fusion SLAM using a compact wearable helmet for underground space 3D mapping. Submit to ISPRS JPRS in May 2022.

Project Expenses

The total grant received from the ISPRS for this project was Swiss Francis 9,800.00. Table 1 is the project actual expenditure.

Table 1. Project actual expenditure.

<table>
<tr><td></td><td colspan="2">Total</td><td>9800 CHF</td><td>Budget statement</td></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Equipment development hardware fee</td><td>Laser scanner</td><td>3053</td><td></td></tr>
<tr><td>Positioning and orientation system</td><td>5525</td><td></td></tr>
<tr><td>Connecting wire and circuit board</td><td>102</td><td></td></tr>
<tr><td>2</td><td colspan="2">Open access publication</td><td>434</td><td>434 is the part cost for JAG publication total 2250$=2066CHF (Automatic registration for underground space scenarios)</td></tr>
<tr><td>3</td><td colspan="2">Administrative fee， 7%</td><td>686</td><td></td></tr>
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