# Application of laser scanner based on SLAM technology in urban 3D digitization

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**Key words**: SLAM, point cloud, technology application, mobile Laser scanner

**SUMMARY**

At present, there are over 10 thousand institutions conducting SLAM technology research worldwide, but they are mainly concentrated in the realm of robot vision and automatic pilot. The application of SLAM in the field of mobile surveying and mapping is relatively rare. Currently, 3D SLAM based on LiDAR can meet the requirements of mobile mapping for globally consistent positioning accuracy and mapping accuracy.

Mobile mapping systems based on SLAM technology include: Zebedee, a handheld SLAM system developed by CSIRO in Australia; Pegasus backpack mobile measurement system and BLK2GO handheld mobile scanning product from Leica, Switzerland; ZEB Horizon series of GEOSLAM, which has been acquired by FARO Company at present; Heron Series Mapping System of GEXCEL, Italy; Stencil Series of KAARTA Company, USA; BMS3D backpack mobile mapping system from Viametris, France, etc.

With the rapid development of 3D SLAM technology, many researchers have verified the feasibility of applying LiDAR SLAM to urban mobile surveying. It can achieve high-precision three-dimensional reconstruction of complex urban scenes quickly and robustly, and will bring breakthroughs to the construction of digital cities.

目前有上万家机构对 SLAM 技术进行研究，但是大部分研究都集中在机器人视觉或自动驾驶领域。对于 SLAM 应用于移动测绘领域相对较少。当前基于 LiDAR 的 3D SLAM 可以满足移动测量对全局一致性的定位精度和建图精度的需求

基于 3D SLAM 技术的测量系统有：澳洲 CSIRO 研发的手持 SLAM 系统 Zebedee；瑞士 Leica 的 Pegasus backpack 背包移动测量系统及 BLK2GO 手持移动扫描产品；GEOSLAM 的 ZEB Horizon 系列，目前 GEOSLAM 已被 FARO 公司收购；意大利 GEXCEL 公司的 Heron 系列测图系统；美国 KAARTA 公司的 Stencil 系列；法国的 Viametris 的 BMS3D 背包移动测量系统等。

3D SLAM 技术正在快速发展，不少研究者已验证了将 LiDAR SLAM 应用于城市移动测量的可行性，它可以稳定快速的实现城市复杂场景的高精度三维重建，将为数字化城市建设带来新的变革。

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Abstract: The 3D digital expression of cities is an important basis for realizing smart cities and digital twins. At present, there is an increasing demand for cities to realize digital expression of multiple details and levels. SLAM technology can quickly and accurately acquire 3D laser point clouds, panoramic images and trajectories of complex scenes such as indoor and outdoor, aboveground and underground, and can provide data support for indoor positioning, indoor 2D and 3D maps and 3D model production. The portable SLAM 3D laser scanner is characterized by its convenience and accuracy. This paper introduces three cases of using SLAM technology in urban survey, which proved that SLAM based laser scanner can perform well in underground space digitization, can be used as a more detailed and complete supplement to urban 3D data and for analysis of various industries.

## 1. INTRODUCT

With the introduction and development of concepts such as digital twins and smart cities, people's demand for three-dimensional digital representation of cities is increasing. The 3D model with multiple levels of detail is the key data base of digital twins and smart cities.(ZHU,2018)

With the development of computer technology and digital map technology, the accuracy of 3D scene information acquisition and reconstruction is increasing higher, and its application is also more and more extensive. At present, oblique photogrammetry technology, low-altitude remote sensing platform has realized low-altitude digital image acquisition, which can meet the needs of large-scale mapping, high-precision urban 3D modeling and other engineering applications. Airborne LiDAR(Light Detection and Ranging) integrates three technologies: laser scanner, GPS and inertial navigation system (INS), and can directly obtain high-precision three-dimensional coordinate information. Compared with traditional aerial photogrammetric methods, airborne LiDAR technology can partially penetrate the forest shelter and directly obtain high-precision three-dimensional coordinate data of ground points. (HUANG,2018)

However, aerial observation technology lacks a lot of ground information, especially in 3D reconstruction, the reconstruction effect at the bottom of the building is poor, so it is necessary to supplement the information reconstructed by the ground surveying and mapping system. The 3D information data acquisition of ground scenes is generally divided into two types: mobile laser scanning and terrestrial laser scanning. The existing mobile laser scanning technology depends on the global navigation satellite system (GNSS) and inertial navigation system, which

can only be used in outdoor environment. For indoor and underground space scenes, traditional mobile measurement methods cannot work. Terrestrial laser scanning(TLS) can be used in indoor and outdoor environments, but complex scenes require multiple stations, and then point clouds need post-process to align, so the efficiency of data acquisition is very low, unable to perform overall 3D reconstruction in real-time and quickly.

SLAM (real-time positioning and mapping) technology does not need GNSS signal, and combined with 3D laser scanning technology, it can quickly, conveniently and low-cost collect 3D point cloud data. SLAM technology can efficiently make up for the data empty caused by the occlusion of aerial remote sensing technology, and can obtain refined ground, underground and indoor structural information which can be used as an important data supplement for urban 3D information digitization.

## 2. SLAM Technology and Handheld laser scanner

### 2.1 SLAM technology

SLAM refers to simultaneous localization and mapping, which is proposed by the robot field. It means that the robot starts from the unknown environment, locates its own position and posture through repeatedly observed environmental features during the movement process, and then builds an incremental map of the surrounding environment according to its own position, so as to achieve the goal of simultaneous positioning and map construction.

The development of SLAM sensor include sonar, 2D or 3D LiDAR, monocular, binocular, RGBD, ToF and other cameras, as well as the integration with IMU and other sensors; The SLAM algorithm has also changed from the filter-based method (EKF, PF, etc.) to the optimization-based method, and the technical framework has also evolved from the single-thread to multi-thread. The filter-based algorithm only uses the measurement data of the current laser sensor for operation. The optimization-based method uses a global optimization matching method, which uses all measured data from the initial time to the current time for its solution. The posture is constantly corrected by new data, so the effect is better.(WEI,2018)

3D SLAM is the development direction of SLAM technology at present. The combination of 3D SLAM and laser and image can carry out high-precision mobile 3D laser scanning for various types of buildings, indoor spaces, squares, mines, tunnels, shopping malls, public facilities, industrial plants and other environments.

### 2.2 Handheld laser scanner

Cygnus handheld laser scanner is the new generation product of SATLAB company, with a weight of 1.5kg, combining the latest SLAM technology with the most efficient and revolutionary algorithms, the relative accuracy of the equipment can reach up to 1 cm. Its appearance is shown in Figure 1. Without relying on GNSS satellites, Cygnus can obtain data in any outdoor, indoor, underground or other heavily obscured area. A wide range of accessories support Cygnus' compatibility with multi-platform situations, such as drones, vehicles, or even

backpacks. The Cygnus can be used in a variety of scenarios and work environments requires 3D modeling such as mining, forestry, underground digitization, construction and more.

The main specification are as follow in Table 1.

**Figure 1 Cygnus handheld laser scanner**

**Table 1 Cygnus handheld laser scanner main technical parameters**

| | |
|---|---|
| LiDAR Sensor | HESAI-16 |
| Laser Class | Class1,Eye Safe |
| Range | 120m |
| Measuring rate | 320,000pts/sec |
| Accuracy | 0.5-2cm |
| FOV | 360°×285° |
| Scanner Weight | 1.5kg, 227×98×98mm |

### 2.3 Advantages of SLAM technology in Urban survey

Because SLAM does not rely on the integrated navigation system (GNSS+INS), it can walk through the urban areas without GNSS signals such as tall buildings and trees to collect data, especially those far away from the main roads, residential areas and other places that cannot be reached by traditional mobile laser measuring vehicles, and then obtain very accurate data results, including high-precision data of outdoor building and its indoor structure.

In addition, the control of UAV flight in some cities has brought inconvenience to the use of UAV remote sensing technology. For the three-dimensional measurement of cities, mobile SLAM scanning technology can also achieve considerable efficiency. Nevertheless, the data obtained by mobile SLAM scanning can be used as a supplement to the data hole caused by the obstruction of ground objects and the limitation of field angle of view of UAV remote sensing technology, so as to better express the complete and rich detailed features of the urban.

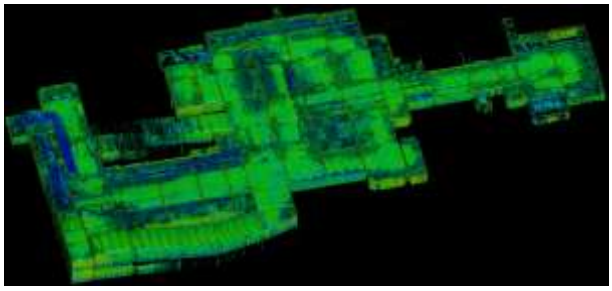
From a data perspective, data acquired by SLAM can directly calculate a complete point cloud without the time-consuming point cloud registration like TLS methods. For the key areas with high accuracy requirements, it can be used with TLS to ensure both accuracy and efficiency.

## 3. Application cases

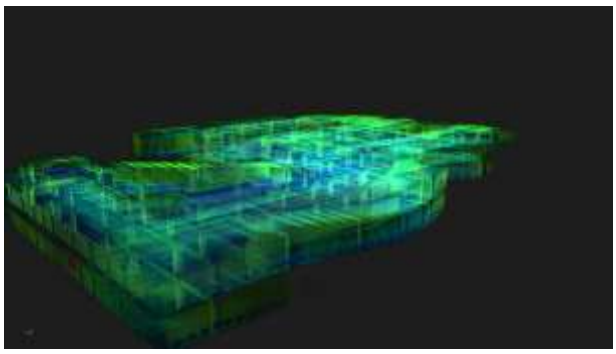
### 3.1 Urban underground space survey

At present, in the process of urban construction, the development of underground space is becoming more and more intensive, and the relevant surveying and mapping work is also increasing.(LI,2020) For large underground public facilities such as urban underground comprehensive pipe gallery, subway station, underground garage, etc., in order to realize the informatization of management, detailed structural drawings need to be mapped. In these areas, there is no GNSS signal inside. Traverse operation is commonly used, which is time-consuming and laborious.

Using SLAM technology, you can easily and quickly obtain the required point cloud data. According to the point cloud data, you can extract the vector line, mapping the façade and plan structure. The following figure shows the effect of 3D point cloud and point cloud slice of the underground parking lot obtained by cygnus handheld scanner.



(a)



(b)

**Figure 2 Point cloud of underground parking lot captured by Cygnus**

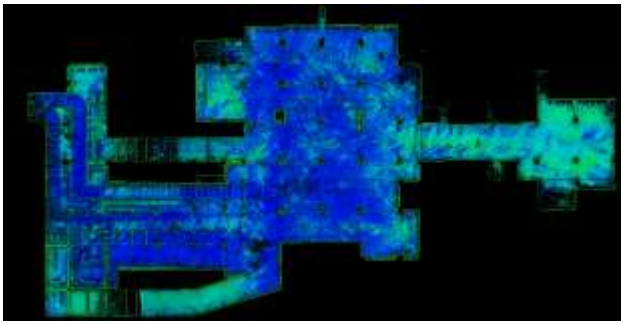


**Figure 3 Point cloud slice effect of underground parking lot**

The thickness of the underground space structure wall in the point cloud reflects the accuracy of the handheld mobile scanning system to a certain extent. By measuring the thickness of point cloud around each column through CloudCompare software, the results are mostly between 2-3 cm, the figure 4 shows the result.

Urban underground space is a valuable natural resource. Its development and utilization has become the trend of urban development in the world, which is necessary to urban modernization. Compared with the traditional total station methods, collect underground space data with hand-held mobile 3D laser scanner is labor saving and more efficient. The spatial information of underground space structure can be collected efficiently while walking and scanning. By adding the control point, the point cloud of underground space can be given absolute coordinates. By processing point cloud slices and importing them into CAD, the mapping of underground space survey can be completed. More than this, the acquired point cloud data can be directly modeled for BIM application.

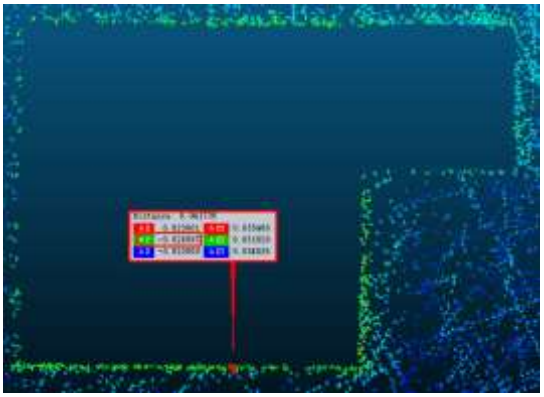


**Figure 4 Thickness of wall column measured in CloudCompare**

### 3.2 Urban topographic survey

For urban topographic mapping, in some areas where the permission of flight cannot be easily apply, ground mobile surveying is an ideal solution for its flexibility and less restrictions.

(WANG,2023) In addition, using aerial remote sensing technology such as photogrammetry and airborne LiDAR for urban topographic mapping is unable to obtain complete 3D information of the city, data empty hole happens due to the occlusion of ground objects.

In the following case, we use the multi-platform application of SLAM to collect 3D information of urban viaducts and space under bridges, roads and tunnels, as the supplement to ALS(Airborne Laser Scanning) data. In addition to handheld mode, SLAM laser scanners can also support backpack carrying, vehicle-mounted and airborne.

3.2.1 Case overview

We have the original ALS data of the expressway and its surrounding areas, however, there is a lack of complete information about roads, bridges, tunnels. In order to better express the completed data of this area, we use the mobile laser scanning based on SLAM to capture more detailed and completed point cloud data. The original ALS data is shown in Figure 5.

First, the bridge area was surveyed, and many preparations such as the point cloud data pre-acquisition experiment were carried out. According to the field environment and technical method validation, two scanning methods including vehicle-mounted and backpack were selected for this point cloud data acquisition to obtain high-precision point cloud data in a more efficient and flexible way. For the overpass and the space under the bridge, we use the backpack laser scanning method. For the information collection of roads and tunnels, we put the SLAM scanner on the vehicle for scanning.

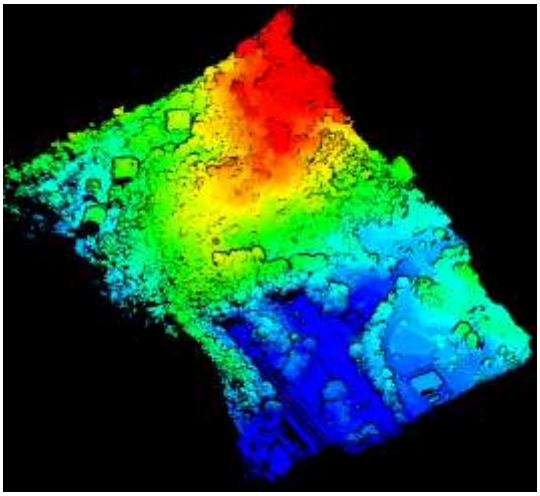


**Figure 5 The origin ALS point cloud data**

3.2.2 Backpack mobile laser scanning system

In the outdoor scene, users can use backpack mobile laser scanning system with RTK involved. The backpack mobile laser scanning system is light and solid, and can obtain point cloud data where the area restricted to people. By converting the RTK observation and SLAM trajectory,

users can obtain the point cloud with absolute coordinate. RTK observations can be used as ground truth values to verify the absolute accuracy of SLAM. RTK observations can be added as global observation value (similar as closed-loop constraint) to correct the SLAM cumulative error. The following picture is Cygnus backpack mobile scanning system with RTK.

**Figure 6 Cygnus backpack mobile laser scanning system**

We use the Cygnus backpack mobile laser system with RTK to capture the bridge area. The overview of backpack scanning point cloud data is shown in Figure 7 and the detail of the space under the bridge is in Figure 8.

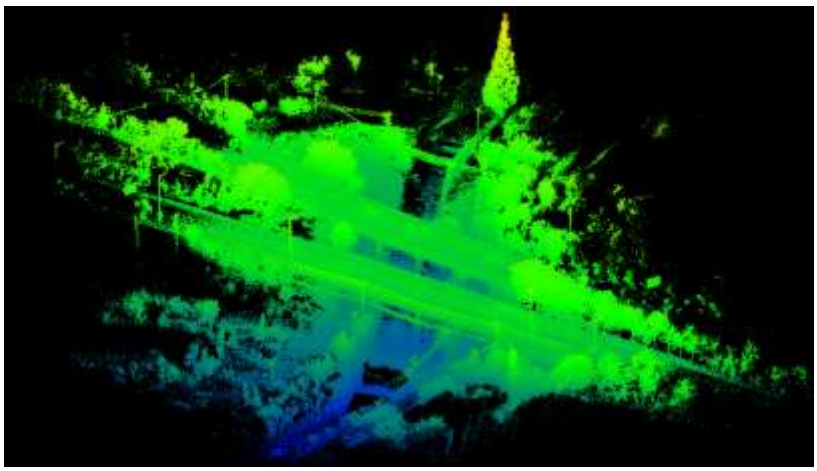


**Figure 7 Backpack scanning point cloud data**

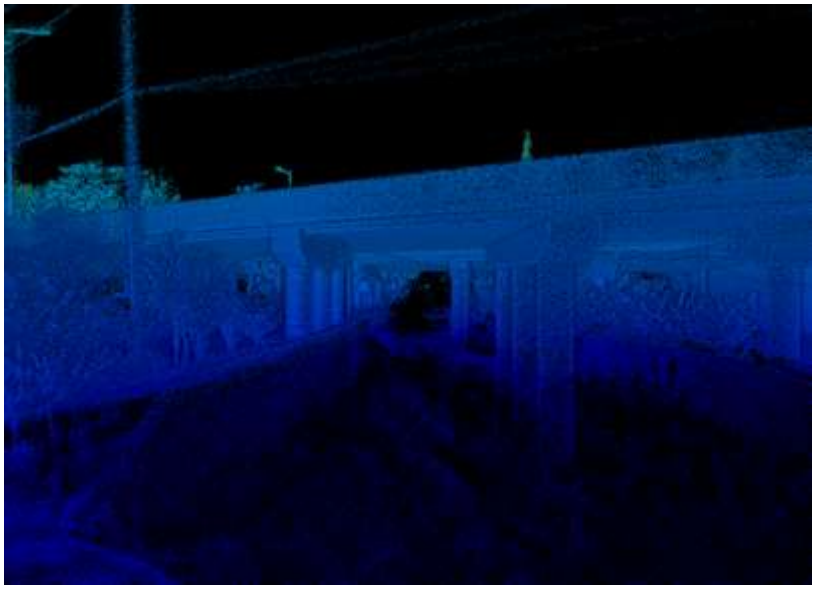


**Figure 8 The local point cloud data of bridge pier**

3.2.3 On-board SLAM scanning system

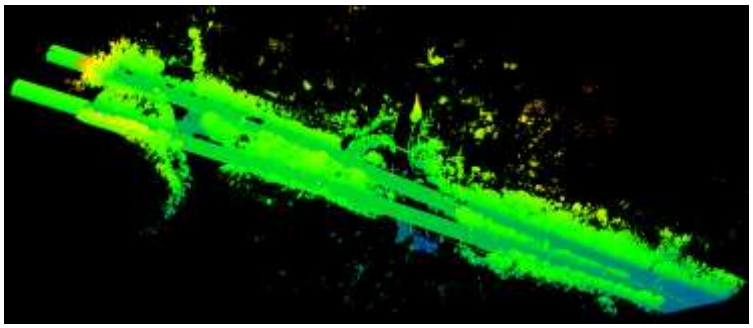
SLAM scanners can also be extended to vehicular applications. In terms of the corridor scene like roads and tunnels, mounting the SLAM scanner on the car and dynamically collects data during one-way or two-way travel along the road, which greatly reduces the scanning time instead of walking. For the measurer, it is also relatively physically friendly.

The car kit is shown in Figure 9-a, and the overview of the car application for SLAM scanner is shown in Figure 9-b

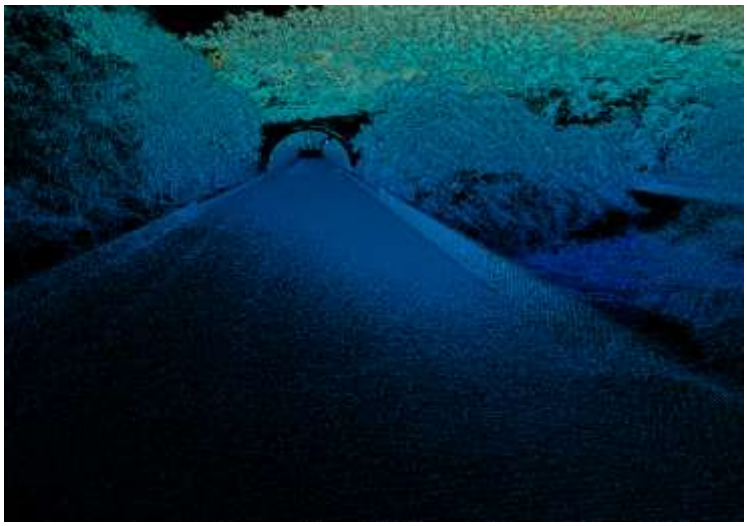
(a) (b)

**Figure 9** Car kit of the Cygnus SLAM scanner

We mount Cygnus SLAM scanners on the car and also RTK involved. To get better quality result, we set several control points in case of the GNSS signal is unlocked. In addition, the round-trip scanning operation to make the trajectory close-loop ensuring the more reliable data. The On-board scanning point cloud data is shown in Figure10-a, and the Point cloud of tunnel entrance reflects in Figure 10-b.



(a)

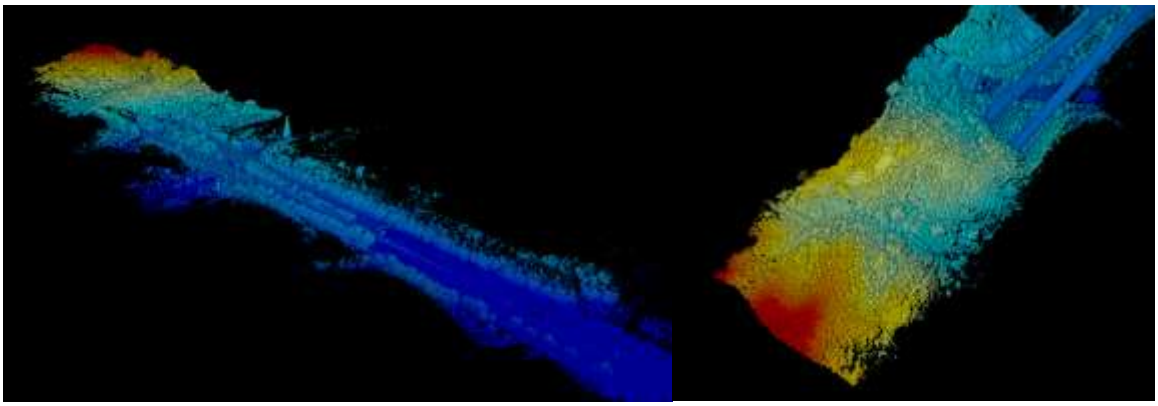


(b)

**Figure 10 On-board scanning point cloud by Cygnus**

3.2.4 Multi-source point cloud data

Both types of data are automatically solved with one key through the control of Cygnus's SLAM Manager APP. Without too much manual intervention, it can greatly save manpower and time in actual production. And Point cloud data fusion is to unify vehicular, backpack and original airborne data into a consistent coordinate system and export *.las point cloud format. The fused point cloud data ensures the integrity of the bridge and its surrounding environment, and avoids the data "hole" to the maximum extent. The whole data is shown in Figure11.



(a) (b)

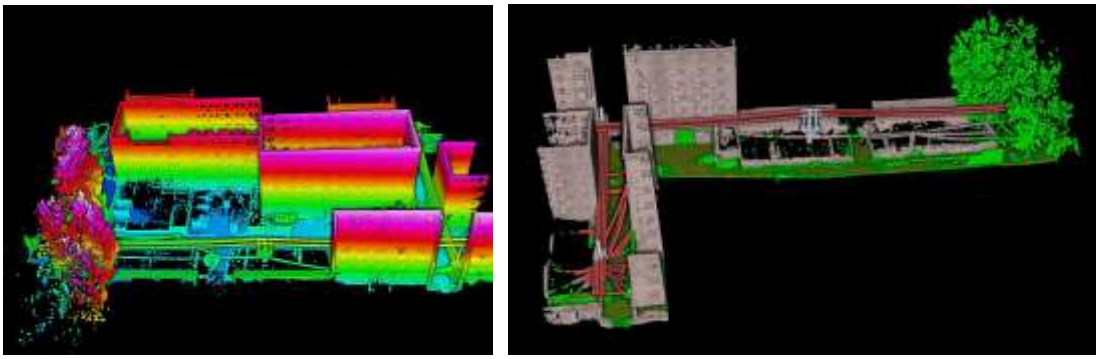
**Figure 11 Multiple point cloud data**

### 3.3 Urban electricity application

With the rapid development of the national economy, the demand for electricity, especially for high-power and long-distance transmission, has significantly increased. Whether in the city or in the rural, the geographical environment where the transmission line crosses are complex and the line direction is chaotic, and its operation and maintenance is becoming increasingly difficult. At present, the 3D handheld laser scanning system is very suitable for 3D information acquisition in narrow areas, buildings and complex terrain areas. For the environment with too much occlusion, it can be flexibly adjusted according to the conditions and scanned from multiple different angles. Moreover, it can be mounted on the UAV, perform overhead scanning from higher altitude.

In this case, we use Cygnus Handheld laser scanner to collect the transmission lines in the narrow residential area. After collecting the point cloud data, we classify the point cloud into serval classes, the original laser point cloud can be automatically segment and delete the irrelevant data , extracted as vegetation points, building points, tower points, traverse points, ground points, etc., which is for post analysis and application, provides strong technical support for digital power grid construction and line safety inspection.

The Figure 12-a shows the whole point cloud of the residential area, and the Figure 12-b display the segmented and classified point cloud.



(a) (b)

**Figure 12 Original point cloud and split point cloud in residential area**

## 4. Conclusion

The characteristics of 3D SLAM laser scanner include high-speed data acquisition, high-precision data processing and point cloud modeling, independent of GNSS signal and inertial navigation constraints, suitable for all terrain environment including indoor, outdoor, underground, aboveground, etc.

In this article, three typical cases of urban 3D information digitization are illustrated, which has certain representative significance. The point cloud obtained by SLAM technology can be sliced and imported into CAD for mapping or directly modeled. We take advantage of the SLAM Laser scanner's versatility such as the backpack and vehicle-mounted to perform a better data collection, and Combining SLAM solution with other aerial remote sensing technologies to obtain more complete and detailed three-dimensional urban information.

With the SLAM algorithm becoming more mature and robust, urban 3D information acquisition using SLAM technology will tend to be more real-time and reliable. SLAM-based laser scanning will provide better technical support for the acquisition of smart city and digital twin data base.

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