FAST CONTINUOUS 360 DEGREE COLOR 3D LASER SCANNER

Aiwu Zhang [a, *], Shaoxing Hu [b], Yulin Chen [a], Haiyun Liu [b], Fan Yang [a], Jia Liu [a]

[a] Key Laboratory of 3D Information Acquisition and Application of Ministry of Education,
Capital Normal University, Beijing 100037, zhangaw163@163.com
[b] School of Mechanical Engineering & Automation, Beijing University of Aeronautics and Astronautics,
Beijing 100083, husx@buaa.edu.cn

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ABSTRACT:

There are many needs for the ability to fast acquire 3D data from environmental surroundings, such as navigation, mapping, localisation and robot mobility, fire and police planning, urban planning, but the technology for acquiring dense, wide ranging, accurate 3D data is too expensive to be used widely. A low-cost, 360^0 continuous scanning, portable 3D laser scanner is presented. The accuracy of the portable laser scanner was analyzed in detail, and an algorithm of systematic measurement error compensation was given. On the other hand, a sequence of images was captured by a hand-held digital camera, and then 2D images were fast mapped on 3D point cloud by a method proposed based-on multiview geometry. The experimental results show that the portable laser scanner has higher measuring accuracy and better data quality. Its max range of the scanner is 80m, and its accuracy can achieved 6 mm. The portable laser scanner can measure black objects, it well suit tunnel measurement. The weight of the portable laser scanner is less than 6kg, it can be installed on unmanned aircrafts.

1. INTRODUCTION

3D laser scanner is a new active remote sensing system developed in the last ten years, and it can scan thousands of points to a point cloud of 3D data of the object and be operated at night. To a certain extent, 3D laser scanner meets the data demands of some applications such as city planning, fire and police planning, underground mine measurement, tunnel measurement, and so on. 3D laser scanners have a huge application market. Unhappily, up to now, there is still no homemade 3D laser scanner on Chinese market. The foreign commercial 3D laser scanner has a high price, the terrestrial 3D laser scanner is about ￥1,000,000, and airborne 3D laser scanner is about ￥15,000,000. In this case, we developed a low-cost, 360^0 continuous scanning, portable 3D laser scanner. The portable laser scanner can collect no less than 8000 points every second to meet the needs of fast acquiring 3D data from indoor and outdoor scenes, but it only costs about one fifth of the price of the foreign commercial 3D laser scanner.

In practice, foreign commercial long-range or mid-range 3D laser scanner manufactures are not too many. There are six main manufacturers: Callidus, Leica, Mensi, Riegl, OpTech and I-Site. I-Site does not produce its own laser sensor and the laser sensor employs Riegl's. Callidus, I-Site, Mensi and Riegl use the mirror to complete vertical scanning, which the horizontal scanning depends on a servo motor rotating to complete, and so their laser scanner can scan 360^0.

Some laser scanners measure distances with the flight time and some others use a phase-difference method. By computing the angles the coordinates of the point in the space are obtain, for example, Leica HDS6000 is phase-based laser scanning. We employ the flight time method to measure distances from sensor to arbitrary points on the object surface. As basic scanning device a time-of-flight 2D SICK laser scanner (LMS291 or LMS200) is used, and which is combined with an additional servo drive to reach the third dimension. For our laser scanner design, accurate synchronization of the laser measurement and the scanning device is very important, and the compensation of systematic errors is also a key task. Moreover, we also discuss an approach to map 2D images from a hand-held camera onto 3D laser points.

The paper includes four main sections: (1) Design of the 360^0 continuous scanning, portable 3D laser scanner, (2) Error correction of the 3D laser scanner, (3) Fast mapping the images onto the point cloud, (4) Analysis of experimental results.

2. DESIGN OF THE PORTABLE 3D LASER SCANNER

2.1 Structure Design

The key components of the 3D laser scanner are a 2D SICK laser scanner (SICK LMS291 or SICK LMS200) and a rotating platform driven by a servo motor.

The line scanning of the 2D SICK laser scanner can form the two modes with 180 ° and 100 °. The sampling resolution in the modes can be set at 0.25^0, 0.5^0 and 1^0, the max scanning range is 80m, and the scanning accuracy can be up to mm, the scanning baud rate can be set at 9600, 19200, 38400 and 500k. SICK LMS200 or SICK LMS 291 communicates with the computer by serial interface, whose maximum speed can reach 75 times/sec, but the interior buffering capacity is limted (max: 812 bytes). If we can not output the scans in time, the cache will be refreshed automatically, so that the part of the data

* Corresponding author.

would be lost. General serial interface, which is the serial interface RS232 of the computer, can not meet the needs of the transmitting speed (500k Baud), so it can not transmit the data completely and entirely. We insert the Quatech Card into PC with PCI slots so that the transmission baud rate can reach 500k. The rotating platform communicates with the computer by RS232.The structure of the portable 3D laser scanner is shown in figure 1.

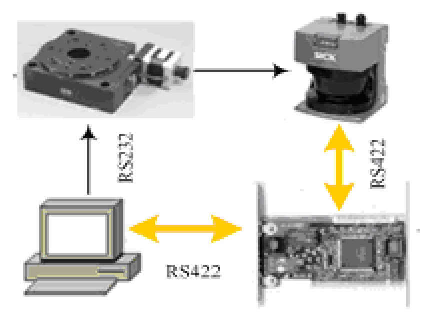


Figure 1. The structure of the portable 3D laser scanner

Figure 2 is the 3D laser scanner developed by us, its vertical scanline rotates around the z-axis continuously until up to 360^0, and the scan angle of the vertical scanline can be up to 180^0, and these scanlines form a closed spherical scan region.

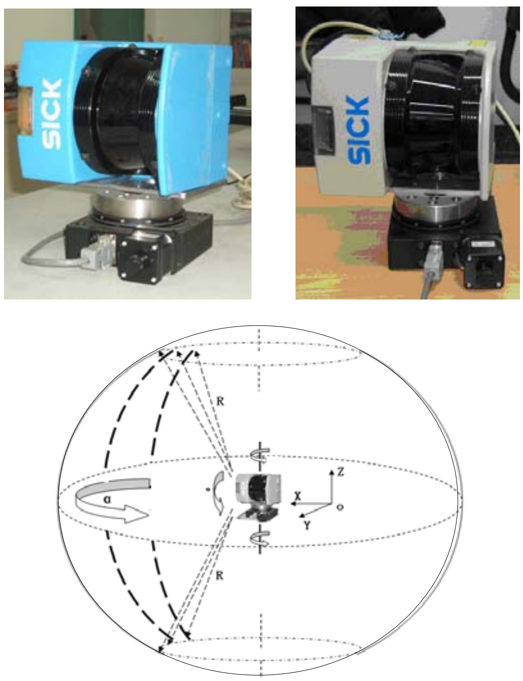


Figure 2. The Portable 3D laser scanner prototype system

Top: The Portable 3D laser scanner prototype;

Down: The closed spherical scan region.

2.2 Motion Compensation

While the rotating platform starting to rotate, before running at uniform velocity, there is a short-term accelerated process. Supposed the rotating platform starting is considered as constant accelerated rotation, its rotation angle is computed as follows.

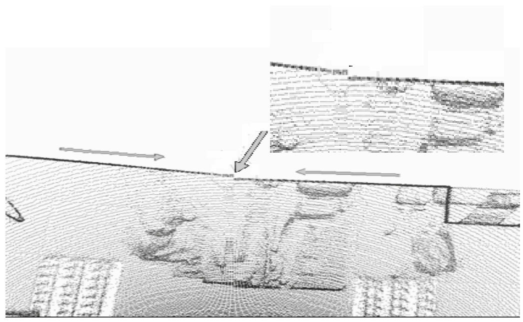
$$\omega = \partial t^2 \tag{1}$$

Here, ∂ is angle acceleration, ω is rotation angle, and t is time.

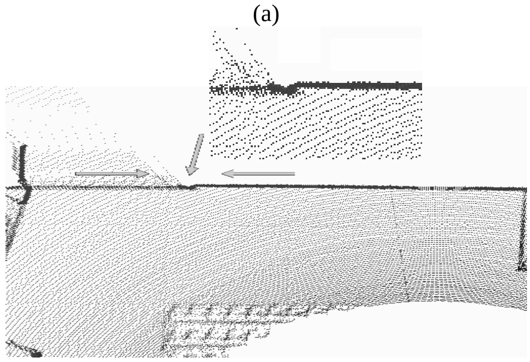
If the angular velocity is known as v and the accelerated time of the rotating platform is known as Δt, the rotation angle is described as follows.

$$\omega = \frac{v}{\Delta t} t^2 \tag{2}$$

If the interval between scanlines is Δt_v, and then $\Delta t = n \times \Delta t_v$. By testing, n=10, the results are the best. Figure 3 shows the results of motion compensation.



(a)



(b)

Figure 3. The results of motion compensation.
Top: before compensation; Down: after compensation

3. ERROR CORRECTION

If the sampling resolution vertical scanning is set at 0.25°, then every vertical scanline includes 401 points, it spends 45s for a yawing scan with 0.25° horizontal resolution. Supposed the center of the rotation axis and the center of the mirror wheel of the laser scanner are same, then,

$$x_{ij} = r_{ij}\cos\beta_j\cos\alpha_i$$
$$y_{ij} = r_{ij}\sin\beta_j\cos\alpha_i \quad (3)$$
$$z_{ij} = r_{ij}\sin\alpha_i$$

α_i is the step angle of the rotating mirror of the 2D laser, β_j is the step rotation angle, i and j are respectively the step number.

Actually, the portable 3D laser scanner has system errors: (1) Installation error l . There is a translational offset l between the center of the rotation axis and the center of the mirror wheel of the laser scanner. (2) Range error $\Delta\rho$, which results from the object's surface features, air humidity, time-gauges built-in to the equipment and the reflected energy, etc. (3) Scan angle error φ . When the rotating platform begins to move, it will spend some time to reach the constant speed, that results in that the of actual reference direction and the axis of coordinates can not be are not overlapping, then formula (3) should be modified as below:

$$\begin{cases} \hat{x}_{ij} = (\rho_{ij} + \Delta\rho)\cos\alpha_i\cos(\beta_j + \varphi) + l\cos(\beta_j + \varphi) \\ \hat{y}_{ij} = (\rho_{ij} + \Delta\rho)\cos\alpha_i\sin(\beta_j + \varphi) + l\sin(\beta_j + \varphi) \\ \hat{z}_{ij} = (\rho_{ij} + \Delta\rho)\sin\alpha_i \end{cases} \quad (4)$$

Here, ρ_{ij}, α_i, β_j are known; $\Delta\rho$, l and φ are unknown, so the parameters need further calibrated and corrected.

In order to calibrate the values of $\Delta\rho$, l and φ, we select the tablet calibration approach. We made 5 tablets, then put two of the tablets at the perpendicular direction of x-axis (+, -) of the actual reference coordinate system (tablet 1 and tablet 2), another two at the perpendicular direction of y-axis (+, -) of the actual reference coordinate system (tablet 3 and tablet 4), and the last one at the perpendicular direction of z-axis (+) (tablet 5). Then, the x-coordinate of the laser point on tablet 1 can be known accurately, X=L1. In a similar way, the x-coordinate of the laser point on tablet 2 is –L2; the y-coordinate of the laser point on tablet 3 is L3; the y-coordinate of the laser point on tablet 4 is –L4; the z-coordinate of the laser point on tablet 5 is L5. L1 to L5 are vertical distances between tablets and the origin of the actual reference coordinate. During calibration, we moved the tablets to change the values of Ln, so we acquired a set of equation, and then we performed a compensating computation utilizing additional parameters. After that, we used significance test to verify the parameters' significance, to solve correction parameters.

4. FAST MAPPING IMAGES ONTO POINT CLOUDS

In practice, the scanned data is not continuous, although contains continuous colour information. 2D images mapping on 3D points is satisfactory for some applications. The traditional methods are realized by rigidly attaching a camera onto the range scanner and thereby fixing the relative position and orientation of the two sensors with respect to each other [Früh C., 2003, Sequeira V., 2002, Zhao H.,2003]. Fixing the relative position between the 3D range and 2D image sensors sacrifices the flexibility of 2D image capture. In fact, because of occlusions and self occlusions, the methods above described are not suit to the large-scale scenes. We use a hand-held digital camera to take the images from different angles, in different times, in different focal length. It is a technical challenge integrating the images from freely moving cameras with 3D models or 3D point clouds. Some related works have done by [Stamos I., 2008, Zhao W., 2005.]. I.Stamos's methods assume the existence of at least two vanishing points in the scene and register individual 2D images onto a 3D model. W. Zhao's methods align a point cloud computed from the video onto the point cloud directly obtained from a 3D sensor. We use W. Zhao's methods to mapping images onto point clouds.

(1) Recover multi-view relations from an image sequence by structure and motion.
(2) Compute dense depth map using multi-view stereo.
(3) Determine the camera poses by aligning 3D point clouds from the camera and the 3D sensor using ICP (Iterative Closest Point). Figure 4 is a result of texture mapping.

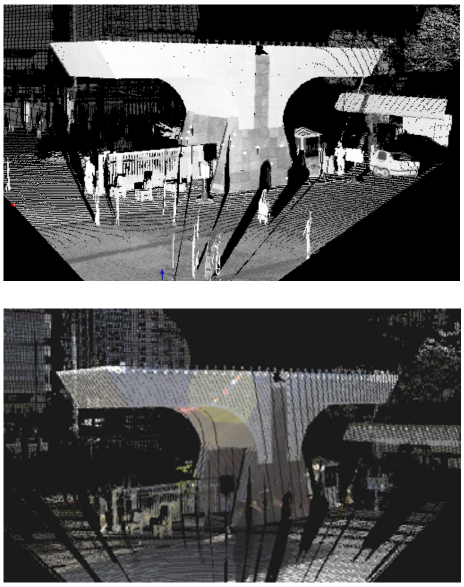


Figure 4 3D image of the gate of the university
Top: 3D reflectance image; Down: 3D colour image.

5. ANALYSIS OF EXPERIMENTAL RESULTS

Generally, the quality and accuracy of the recorded 3D points of laser scanners are main parameters, which affect on the application fields of the laser scanners. Technical data for our laser scanner is shown as follows.

Measurement range	0.5m to 80m
Accuracy	6mm
Measurement rate	up to 8000/sec
Laser wavelength	near infrared
Vertical (line) scanning range	0^0 to180^0
Horizontal (frame) scanning range	0^0 to360^0
Weight	6kg

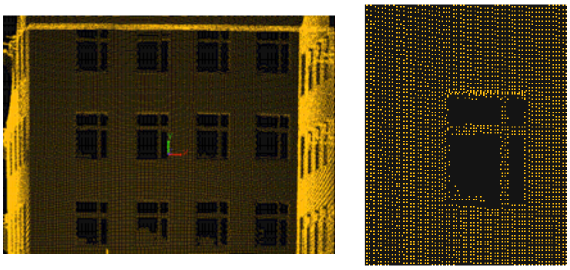
We did a lot of experiments to test the portable 3D laser scanner including data quality, optimal measurement range, influence of surface reflectivity, environmental conditions.

(1) Test of data quality

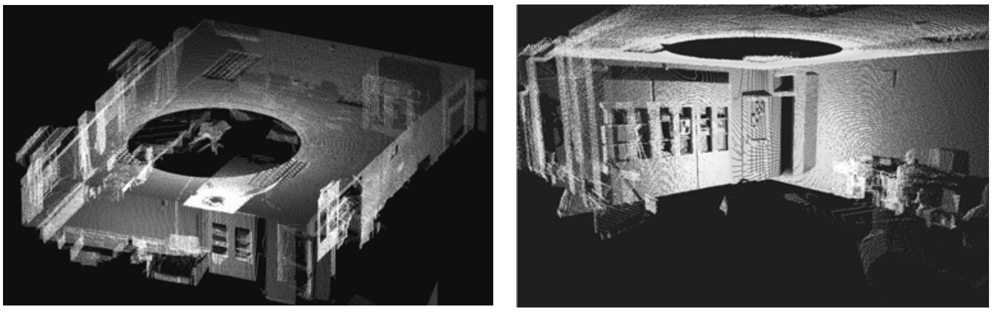
We scanned the wall of a building using the portable 3D laser scanner (figure 5(a)). Seen from the enlarged part, the laser sampling points are distributed in order, and there are few jump points on the wall plane. It shows the data quality is very good. Figure 5(b) is the 3D point cloud of our researching room. We can see the door, the windows, the cabinets, the desks, the chairs, the clock on the wall, and the lamps on the floor clearly. The edges of objects are also seen clearly.

(2) Test of optimal measurement range

The max measurement range is 80m, but the optimal measurement range is from 0.2m to 40m. While we captured 3D data of outdoor scenes, we found out that the objects within about 40m from the laser scanner to objects are described as detailed as shape information, for example, figure 6. It is suitable for acquiring 3D data of long galleries and tunnels. We collected 3D data of the prayer-wheel gallery of Jokhang Temple using the 3D laser scanner to (figure 7).



(a) Plane test



(b) Edge test

Figure 5. Test of quality data

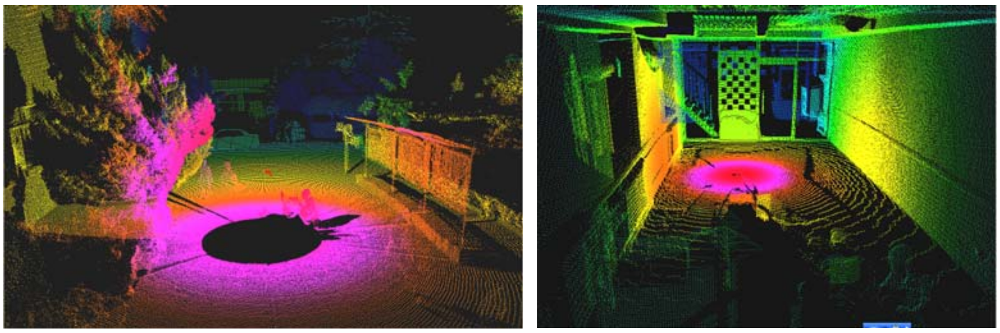


Figure 6. Test of optimal measurement range

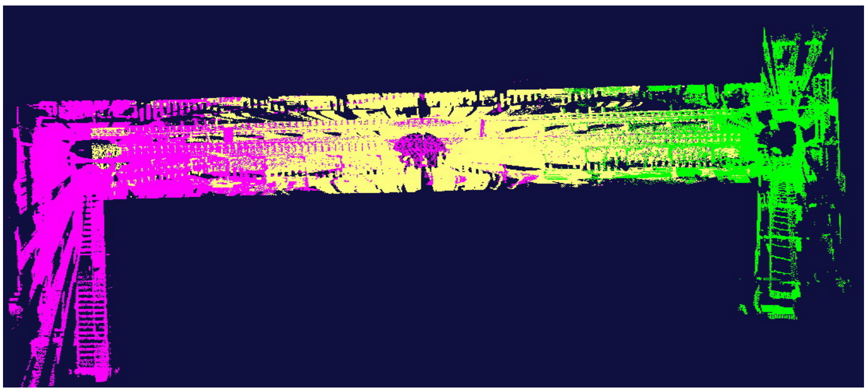
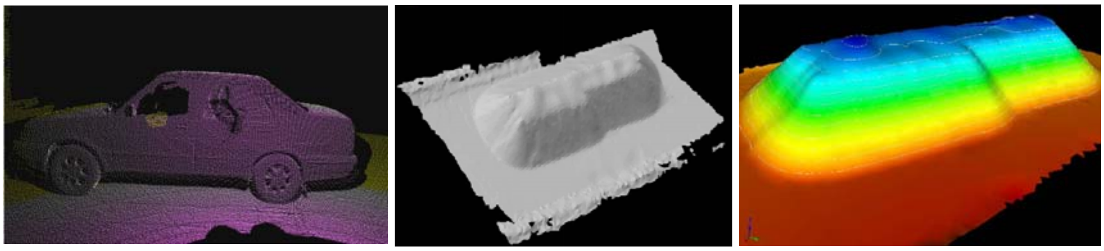
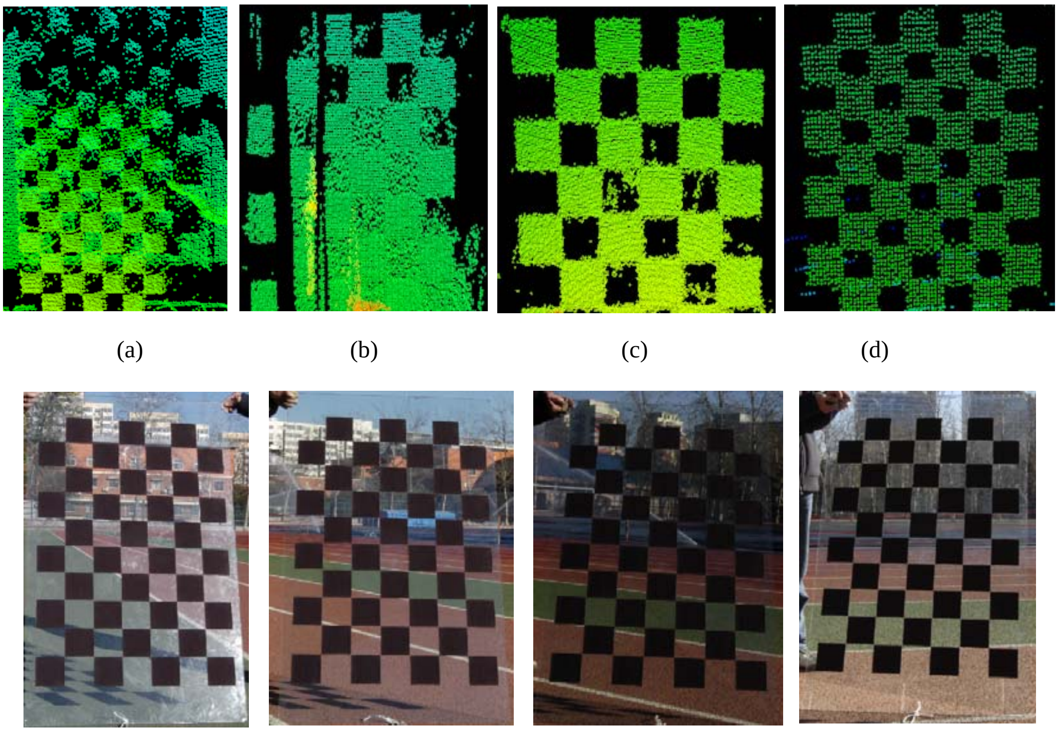


Figure 7. The part of the prayer-wheel gallery of Jokhang Temple



(a) (b) (c)

Figure 8. Test of influence of surface reflectivity



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 9. Test of environmental conditions

(3) Test of influence of surface reflectivity

While we captured 3D data of our researching room, we found that the data of black chairs is entire. So we used the portable 3D laser scanner to scan a black car, the 3D point cloud data of the black car is very good (Figure 8(a)). The portable 3D laser scanner can measure black objects, and it is easy applied to measure terrains coal piles. We used it to acquire the 3D data of the coal piles in Tianjin Huanghua, built 3D model of the coal piles, gave the profile maps of the coal piles, and compute the volumes of the coal piles, just like figure 8(b)-8(c).

(4) Test of environmental conditions

Lasers operate in a very limited frequency band. Therefore filters can be applied in the receiving unit allowing only this frequency to reach the receiver resp. the camera. If the radiation of the illumination source (sunlight, lamps) is strong as compared to the signal, enough of this ambient radiation will pass the filter and influence the accuracy or prevent any measurements at all[Boehler, w., 2003]. We employed a glass plate with the black and white chessboards to test the influence of environmental conditions. To prevent from the interference of environment, we put the glass plate on the playground. We found that dust is present lead to the edge blur (figure 10(a)). We also found that the angle between the laser beam and the light lines of sun is to effect on the scanned data, while the angle is closer to 0^0, the scanned data is very bad (figure 10(b)), while the angle is more than 90^0, there is a little negative influence on the scanned data (figure 10(c)), and the angle less than 90^0 is the most ideal (figure 10(d)). Figure 10(e)-(h) are the corresponding photos described above.

6. CONCLUSIONS

We developed a 360^0 continuous scanning, portable 3D laser scanner, which can be applied to many fields, such as city planning, industrial survey, virtual reality, and digital preservation of cultural heritage. The comparison of its all Technical data with those of foreign 3D laser scanner is shown in Table 1. It shows technical data of our 3D laser scanner (AX200) reaches these of foreign products of this kind. In addition, it has the advantages of small volume and low weight about only 6 kg, so it is easy to take, and it only costs about one fifth of the price of the foreign commercial 3D laser scanner.

Because it can measure black objects, it can used in autonomous tunnel mapping. In the future, we will develop an autonomous tunnel mapping system based on our 3Dlaser scanner.

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Type	Callidus	Cyrax2500	I-SiTE	GS 100	ILRIS-3D	LMS-Z420	AX100
Laser class	1	2	1	2	1	1	**2**
wavelength (nm)	905	532	904	532	1540	904	**532**
Measurement range (m)	80	100	450	100	800	200	**80**
Accuracy (mm)	5(30m)	6(50m)	8(300m)	6(100m)	7(100m)	10(100m)	**6(32m)**
Measurement rate (pts)	3300	1000	6000	1000	2000	9000	**7256**
Vertical scanning range (deg)	360	40	340	360	40	360	**360**
Vertical scanning range (deg)	180	40	80	60	40	80	**180**

Table 1 Comparison with foreign products in the technical parameter