Mobile 3D laser scanning technology application in the surveying of urban underground rail transit

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Abstract. Mobile 3D laser scanning technology is one hot kind of digital earth technology. 3D completion surveying is relative new concept in surveying and mapping. A kind of mobile 3D laser scanning system was developed for the urban underground rail 3D completion surveying. According to the characteristics of underground rail environment and the characters of the mobile laser scanning system, it designed a suitable test scheme to improving the accuracy of this kind of mobile laser scanning system when it worked under no GPS signal environment. Then it completed the application of this technology in the No.15 rail 3D completion surveying. Meanwhile a set of production process was made for the 3D completion surveying based on this kind of mobile 3D laser scanning technology. These products were also proved the efficiency of the new technology in the rail 3D completion surveying. Using mobile 3D laser scanning technology to complete underground rail completion surveying has been the first time in China until now. It can provide a reference for 3D measurement of rail completion surveying or the 3D completion surveying of other areas.

1 Introduction

The main task of traditional underground rail transit completion surveying is to survey the underground structures, and compare the measurement data with the original planning and designing data. Then the results would be provided to the relevant departments to carry out a comprehensive analysis [1]. However, with the requirements, the rail transportation management department also hopes to make the 3D completion surveying to support the rail transportation operation and management [2]. In recent years, the static ground 3D laser scanner has been used to the 3D completion surveying [3,4]. However, the efficiency of this kind of equipment is relatively low compared to the rail transit tight and heavy task. So it set up a kind of vehicle borne 3D laser scanning system, which consists of one 360 degree 3D laser scanner, one GPS, one IMU, one distance measuring instrument and some cameras. All the sensors are fixed on the slide rail car with the technology of the time and space synchronization. And it finished 1.5km rail 3D surveying data collection and modelled this data.

2 The vehicle borne laser scanning system and its principle

The main sensors of this vehicle borne system are one 360 degree laser scanner, one high accuracy IMU, one GPS and a wheel distance measuring instrument. (Figure 1), the parameters of these sensors are shown in Table 1.

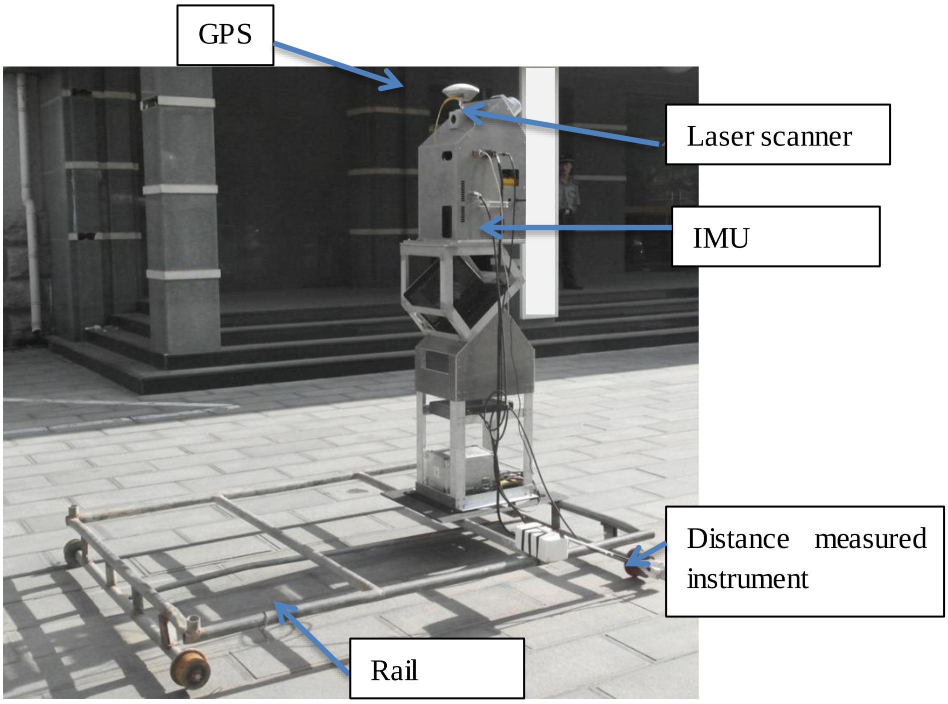

Figure 1 rail vehicle borne laser scanning system

Table 1 The parameters of these main sensors

Sensors	Style	Main technic parameters
Laser scanner	RA-360 III	Range resolution: 5mm Range scope: 0.6m-300m Range precision: 2cm(100m) Divergence angle: 0.3 mrad(0.017°) Angle accuracy: 0.1 mrad(0.0057°) Angle scope: 0-360° Acquisition frequency: 200kHZ
IMU	POS50	Heading angle accuracy: 0.03(°)/hr(RMS) Roll angle accuracy: 0.03(°)/hr(RMS) Pitch angle accuracy: 0.05(°)/hr(RMS) Acquisition frequency: 200Hz
GPS	Trimble5700	Acquisition frequency: 20Hz Post processing differential positioning accuracy:

		5mm+1ppm CEP Time resolution: 20ns
Distance measuring instrument	sick	Frequency: 10000Hz， Resolution: ≤5mm

All these sensors are fixed on the rail car rigidly, with the time and space synchronization technology to all devices. After a comprehensive calibration obtained sensors relative spatial relationship [5]. It acquires space 3D information with the vehicle moving forward. GPS, IMU and wheel encoder together constitute the system positioning and attitude determination system. With the inertial Explorer processing software, the three navigation data are computed combined to get the center vector corresponding to the attitude and position data [6]. It can get the absolute coordinates by these three position sensors.

3 The system precision analysis

The precision of vehicle borne 3D laser scanning technology is affected by the range and angle accuracy of the laser scanner, the positioning accuracy of the vehicle, and other factors. The range and angle accuracy of the laser scanner have been removed by the system calibration, which can't been optimized during working [7,8]. So the system accuracy depends on the positioning accuracy of the carrier during navigation. However there is no GPS signal during underground mobile measurement, And the location accuracy got by IMU itself will be getting worse with the extension of the time, so it add a distance measuring instrument to correct the navigation accuracy [9], which provides a direction of the distance information for IMU to help integrated navigation. But this kind of integrated navigation technology will be out of operation when the GPS signal missing in a long time, it also needed other means to improve the navigation precision, in order to meet the rail traffic completion surveying requirements.

Based on the principle of the control surveying, it added some control points along the rail to improve the accuracy of the rail transition completion surveying based on the vehicle borne 3D laser scanning system. The distribution of the points should be even in some extend and must be surveyed by higher level methods. Then the control points can be used to correct the whole laser scanning data.

4 Experiment analyses

4.1 Experiment profile

This experimentation area is the Beijing subway Line 15, Guan Zhuang station to An Li road station, which is a typical underground rail transit new line. Before the laser scanning data collection, some planning control points were set up along the line, which were designed by high reflection film (shown in Figure 2). After some test, it found this kind of control points were easily to be recognized in the scanning data (also named point cloud). In this experiment these control points were put up on the wall of the rail left and right alternately by 25m interval. Some of these points are for control, the others are for the accuracy detection.

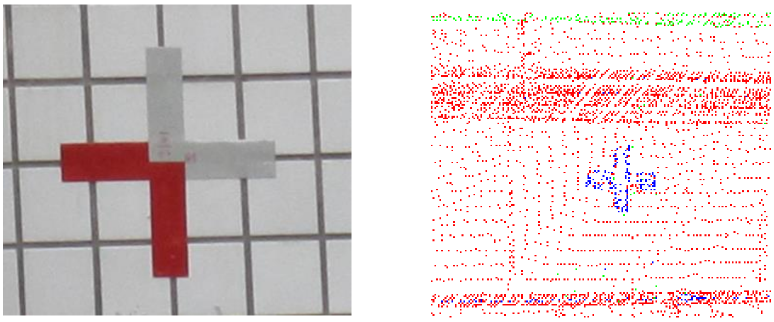

Figure 2 Control point design picture （left）、the point cloud capture of the control point（right）

The position of this 3D laser scanning system is differential positioning, so it needed a reference station on the road surface in the surveying area, which is relatively open. This experiment reference was set up on the Guan Zhuang Station. At the beginning of this experiment, it needed initial the system in about 15 minutes on the ground, and then it opened the laser scanner and moved this system from ground to underground rail vehicle to obtain 3D point cloud of this section rail. At the end of the experiment, it also needed another initial period. This experiment need finished as soon as possible to minish the GPS lock time and improve the position accuracy.

4.2 The technic framework

It designed a technic framework for this experiment (shown in figure 3). First it would capture the laser data and the position data. Then it computed the position data and tested the result. After the real coordinate point cloud would be computed. The core step was the point cloud correction. It needed correct the plane firstly then correct the elevation. Each step need to be test before go ahead. Aim to some rough data it needed to add more control points to get the right data which can meet the requirements.

The result was the point cloud which was culled noise.

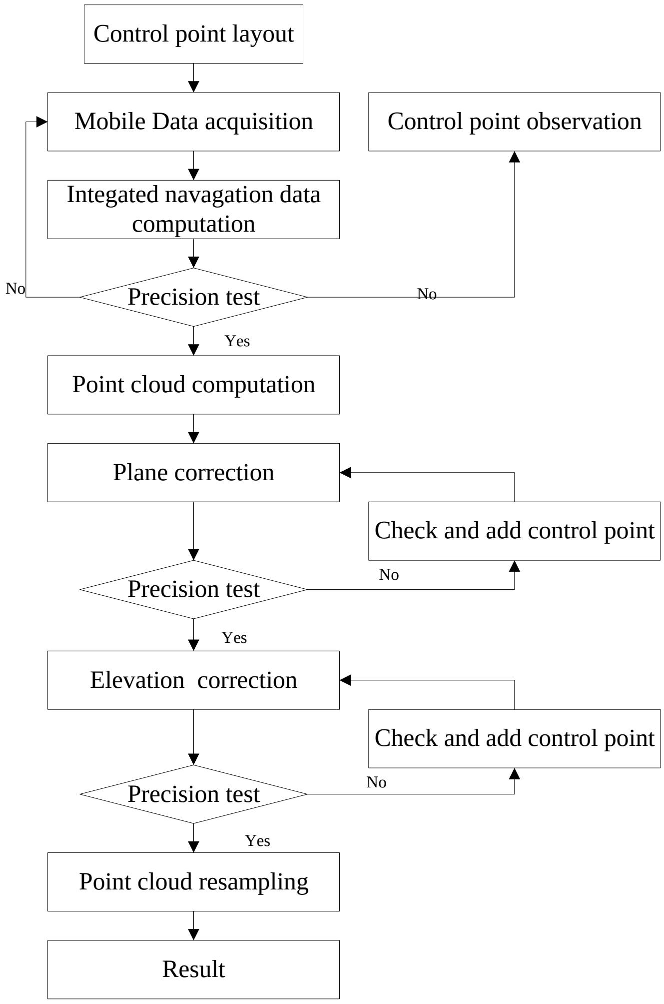

Figure 3 A technic framework

The final point cloud was shown in figure 4.

Figure 4 The point cloud for the underground rail

4.3 Point cloud correction

The correction principle is the bilinear interpolation. The software is programmed by us named as SWDY.

I）Plane correction

The detailed steps of this section were shown blow.

a. Control point projection（shown in figure 5）.

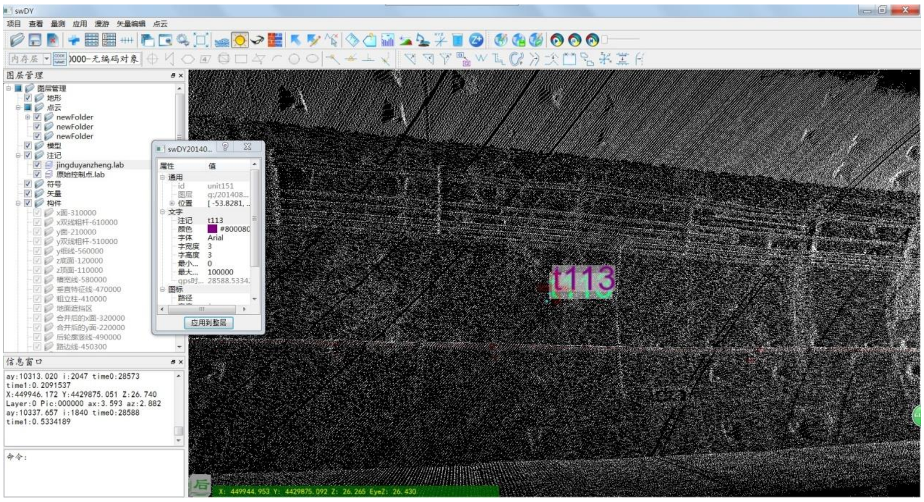

Figure 5 SWDY point cloud software

b. Mapped each point at the corresponding area which was the real position of each control point. Map one by one with the planning 50m interval.

c. Checked the plane accuracy of the correct point cloud, and added necessary control point at the area which accuracy was out of requirements.

d. Corrected the whole point cloud.

e. Checked the plane accuracy of the whole correct point cloud.

II）Elevation correction

After the plane correction, the elevation correction would be done. The detail steps were following.

a. The elevation control point projection.

b. Projected the point cloud, map each control point at the real area of each control point on the point cloud with 50m interval.

c. Check the elevation accuracy of the correct point cloud，and adds necessary control point at the area which accuracy was out of requirements.

d. Correct the whole point cloud.

e. Check the elevation accuracy of the correct point cloud.

4.4 Accuracy analysis

I）Plane accuracy

There were 39 plane points to test the plane accuracy with about 50m interval. The adjustment model is formula (1):

$$m = \pm\sqrt{\frac{vv}{2n}} \tag{1}$$

The plane error of mean squares was m=±0.039m.

2）Elevation accuracy

There were also 39 elevation points to test the elevation accuracy with about 50m interval. The adjustment model is:

$$m_h = \pm\sqrt{\frac{vv}{2n}} \tag{2}$$

The elevation error of mean squares was m_h=±0.026m.

The accuracy of the correct and uncorrected point cloud was shown in table 2 and table 3.

Table 2 The accuracy of the uncorrected point cloud

ID	Coordinate of the point cloud for each teest point/m			High precision coordinate for each test point/m			Difference value /m		
	x	y	z	x	y	z	dx	dy	dz
k1	450820.863	4429665.474	9.289	450815.330	4429676.415	18.157	5.533	-10.941	-8.868
k2	450784.417	4429670.743	9.645	450778.865	4429681.748	18.307	5.552	-11.005	-8.662
k3	450753.897	4429680.675	8.641	450748.387	4429691.816	17.216	5.510	-11.141	-8.575
k4	450708.795	4429684.214	9.896	450703.440	4429695.139	18.570	5.355	-10.925	-8.674
k5	450662.131	4429696.363	9.853	450657.103	4429707.251	18.653	5.028	-10.888	-8.800
k6	450615.771	4429711.979	9.841	450611.198	4429722.941	18.838	4.573	-10.962	-8.997
k7	450549.091	4429738.812	9.716	450545.315	4429749.953	19.070	3.776	-11.141	-9.354
k8	450503.595	4429757.874	9.590	450500.334	4429769.121	19.257	3.261	-11.247	-9.667
k9	450457.285	4429777.331	9.400	450454.414	4429788.612	19.400	2.871	-11.281	-10.000
k10	450411.241	4429796.436	9.186	450408.724	4429807.907	19.553	2.517	-11.471	-10.367
k11	450391.484	4429809.837	8.051	450388.483	4429819.865	17.223	3.001	-10.028	-9.172
k12	450367.333	4429813.657	9.163	450365.095	4429825.402	19.844	2.238	-11.745	-10.681
k13	450323.067	4429828.739	9.820	450320.990	4429840.764	20.622	2.077	-12.025	-10.802
k14	450278.926	4429841.146	10.499	450276.860	4429853.337	21.431	2.066	-12.191	-10.932
k15	450259.061	4429851.228	9.784	450257.122	4429863.563	20.809	1.939	-12.335	-11.025
k16	450212.676	4429860.306	10.522	450210.584	4429872.660	21.580	2.092	-12.354	-11.058
k17	450188.104	4429858.719	11.724	450185.948	4429870.962	22.903	2.156	-12.243	-11.179
k18	450165.241	4429866.626	11.212	450163.289	4429878.977	25.074	1.952	-12.351	-13.862
k19	450142.611	4429863.514	12.565	450140.307	4429875.761	23.727	2.304	-12.247	-11.162
k20	450095.636	4429865.792	13.504	450093.120	4429877.915	24.563	2.516	-12.123	-11.059
k21	450048.922	4429865.973	14.659	450046.161	4429877.818	25.557	2.761	-11.845	-10.898
k22	449999.201	4429864.831	15.787	449996.243	4429876.461	26.337	2.958	-11.630	-10.550
k23	449926.547	4429868.170	16.311	449923.415	4429879.707	26.337	3.132	-11.537	-10.026

k24	449905.570	4429863.257	15.479	449902.477	4429874.561	25.122	3.093	-11.304	-9.643
k25	449862.476	4429862.292	15.866	449859.297	4429873.469	24.982	3.179	-11.177	-9.116
k26	449779.359	4429859.690	17.321	449776.131	4429870.826	24.893	3.228	-11.136	-7.572
k27	449757.617	4429863.218	18.557	449754.365	4429874.420	25.705	3.252	-11.202	-7.148
k28	449736.731	4429857.756	19.549	449733.451	4429868.690	26.463	3.280	-10.934	-6.914
k29	449579.518	4429848.067	21.226	449578.664	4429863.998	26.135	0.854	-15.931	-4.909
k30	449546.673	4429846.533	21.370	449539.136	4429862.532	26.091	7.537	-15.999	-4.721
k31	449505.237	4429845.483	20.680	449496.519	4429860.412	26.032	8.718	-14.929	-5.352
k32	449480.256	4429844.559	20.375	449476.059	4429864.290	25.135	4.197	-19.731	-4.760
k33	449454.078	4429843.427	19.532	449453.676	4429857.797	25.963	0.402	-14.370	-6.431
k34	449389.851	4429829.565	14.560	449380.964	4429856.355	23.206	8.887	-26.790	-8.646
						REMS		±13.623	±9.343

Table 3 The accuracy of the corrected point cloud

ID	Coordinate of the point cloud for each test point/m			High precision coordinate for each test point/m			Difference value /m		
	x	y	z	x	y	z	dx	dy	dz
t1	449817.692	4429872.170	24.904	449817.686	4429872.251	24.941	0.006	-0.081	-0.037
t2	449880.687	4429877.544	26.091	449880.691	4429877.738	26.092	-0.004	-0.194	-0.001
t3	449796.974	4429875.011	25.924	449796.998	4429875.225	25.903	-0.024	-0.214	0.021
t4	449712.447	4429873.752	25.799	449712.370	4429873.384	25.562	0.077	0.368	0.237
t5	450792.757	4429684.836	17.049	450792.754	4429685.013	17.001	0.003	-0.177	0.048
t6	450770.932	4429688.175	17.135	450770.966	4429688.289	17.098	-0.034	-0.114	0.037
t7	450739.322	4429688.148	18.380	450739.288	4429688.031	18.445	0.034	0.117	-0.065
t8	450724.880	4429695.888	17.324	450724.891	4429696.011	17.234	-0.011	-0.123	0.090
t9	450681.258	4429705.781	17.485	450681.266	4429705.902	17.379	-0.008	-0.121	0.106
t10	450635.333	4429719.663	17.624	450635.428	4429719.790	17.517	-0.095	-0.127	0.107
t11	450589.739	4429736.914	17.850	450589.846	4429737.008	17.739	-0.107	-0.094	0.111
t12	450524.262	4429764.478	18.098	450524.308	4429764.618	18.010	-0.046	-0.140	0.088
t13	450477.980	4429784.120	18.228	450478.038	4429784.274	18.122	-0.058	-0.154	0.106
t14	450433.458	4429803.091	18.388	450433.499	4429803.201	18.281	-0.041	-0.110	0.107
t15	450345.098	4429838.124	19.282	450345.146	4429838.297	19.157	-0.048	-0.173	0.125
t16	450299.980	4429852.399	20.086	450300.053	4429852.584	19.914	-0.073	-0.185	0.172
t17	450233.420	4429863.307	21.966	450233.374	4429863.147	22.019	0.046	0.160	-0.053
t18	450117.107	4429882.367	23.253	450117.168	4429882.505	23.229	-0.061	-0.138	0.024
t19	450069.377	4429883.235	24.068	450069.448	4429883.409	24.026	-0.071	-0.174	0.042
t20	449970.592	4429880.922	25.431	449970.594	4429880.935	25.427	-0.002	-0.013	0.004
t21	449946.172	4429875.051	26.740	449946.178	4429874.922	26.691	-0.006	0.129	0.049
						REMS		±0.039	± 0.026

It got that, the plane accuracy of point cloud, which got only by combinative navigation, would be ±13.623m and the elevation one would be ±9.343m. This result would never meet the need of the completion surveying. While some control points were used to correct the point cloud, the results were improved greatly. And the point accuracy of the corrected point cloud was 0.039m, and the elevation one was 0.026m, which can meet the accuracy requirements of rail traffic completion surveying.

5 Conclusion

It developed a set of underground vehicle borne rail traffic laser scanning system and used it to finished one section rail transit completion surveying. One set of completion surveying technic rout based on this kind of vehicle borne scanning system was summarized. When there were no enough GPS signals in underground rail transit area, some control points can improve the point cloud accuracy greatly. This experiment area was one typical trail transit, and there were no spatial terrain which would influence the result. Another conclusion was the control point interval should be about 50m which could improve the point cloud accuracy well.

In order to verify the efficiency of the mobile measurement technology, the traditional surveying method was also used to complete this section rail transit. The practice showed that the vehicle borne time was 16 days. In the same environment, the traditional surveying method need about 20 days, the vehicle borne scanning technology compared with the traditional surveying method has obvious advantages. With a high precision integrated navigation technology advance in the future, the cost of this new technology would decline. The point cloud result can also be used to build the 3D scene model, to improve the data support for subsequent trail transit operations and management. So the vehicle borne scanning technology would have more advantages in the area of the underground rail transit construction completion surveying. It was the first experiment of the vehicle born laser scanning technology in China in the area of the underground rail transit, which can provide a reference for the other areas completion surveying and even 3D surveying.

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Acknowledgments

Authors wishing to acknowledge assistance or encouragement from colleagues of the Beijing Key Laboratory of Urban Spatial Information Engineering.