Appendix

In order to prove the feasibility of the lane-aided model in this paper, a set of robot test data is opened, which includes camera data, IMU data, odometer data, GNSS data, reference and lane map. The camera data used in this study were open-sourced which can be obtained on the website: https://github.com/dyh996/Lane_Dataset.git.

A. Platform

A low-cost GNSS/INS integrated navigation system, which consisted of a MEMS IMU ADIS16465 was used to evaluate the performance of the proposed lane-aided positioning algorithm. A tactical-grade GNSS/INS POS620 was employed as the reference truth.

B. Field Tests and Analysis

When the robot moves in open environment as shown in Fig. 1, the multi-information system can get continuous GNSS signals and keep centimeter-level positioning accuracy. Therefore, in order to evaluate the navigation performance improvement of the lane-aided positioning algorithm, the GNSS signals of the low-cost system is manually disconnected in 60 seconds for many times. We calculated the root mean square (RMS) values of the multiple max navigation errors in each field test. Especially, the RMS values of max navigation errors are used to evaluate the navigation accuracy of the multi-information fusion system.

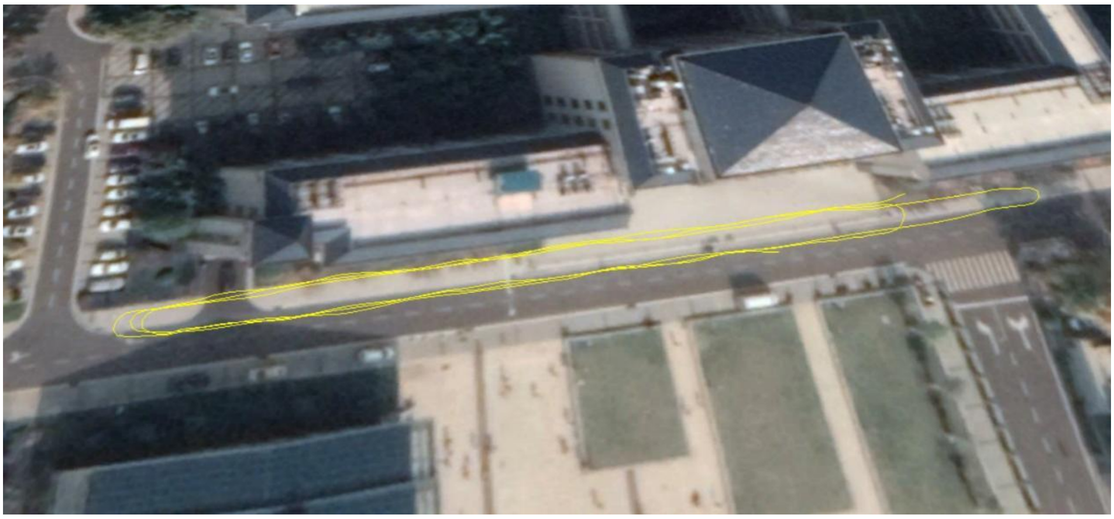

Fig.1 The trajectory of robot test

Taking one field test as an example, we recorded the max position errors in multiple GNSS outages for different algorithm mode in Fig. 2. The blue sections in Fig. 2 mean the whole 60-seconds outages, and the rest sections are GNSS available areas. In the first subgraph, only the INS works and the max position errors entirely rely on the quality of the IMU in GNSS outages. The second subgraph represents the positioning errors based on the odo-aided INS algorithm. In contrast, the results of the lane- and odo-aided INS positioning algorithm are also recorded in the third subgraph. NHC is used in all the modes.

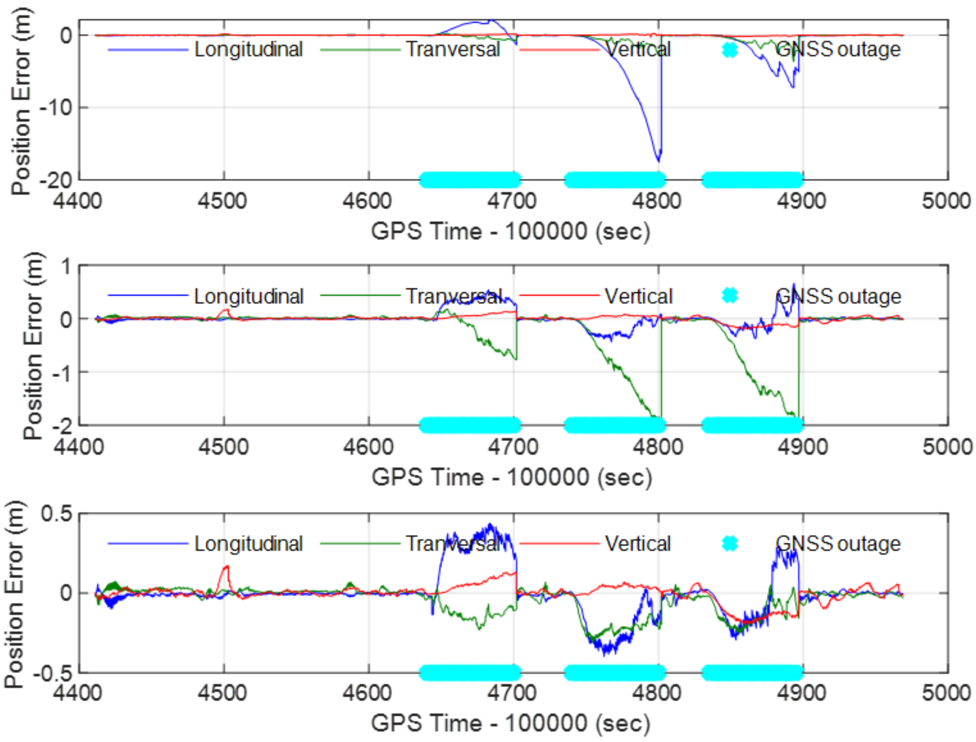

Fig.2 Position drift error in 60s GNSS outages for different integration modes.

As shown in Fig. 2, the max position errors of pure INS algorithm is controlled within 20 m, and it can reduced to within 2.0m by adding the odo-aided navigation mode. However, the transversal position errors of the odo-aided INS algorithm in multiple GNSS outages cannot reach the decimeter level of position accuracy. The lane- and odo- aided INS algorithm shown in the third subgraph significantly reduce the transversal position errors within 0.5 m.

It is can be drawn from the single filed test that the proposed multi-information fusion scheme in this paper can achieve reliable decimeter-level positioning accuracy in multiple GNSS outages by integrating the odo- and the lane- aided positioning module with GNSS/INS algorithm. The following will conduct statistical analysis of navigation performance in difference modes through multiple field tests

TABLE 1

STATISTICAL RESULTS (RMS) OF MAXIMUM POSITION DRIFT ERROR OF GNSS OUTAGES IN THREE MODES

MODE Number	Position Errors (m)			Velocity Errors (m/s)			Attitude Errors(deg)		
	Long.	Tran.	Vert.	Long.	Tran.	Vert.	Roll	Pitch	Yaw
1	10.893	2.600	0.227	0.585	0.166	0.039	0.126	0.243	0.556
2	0.555	1.624	0.144	0.130	0.151	0.038	0.125	0.188	0.539
3	0.384	0.265	0.141	0.128	0.116	0.038	0.125	0.187	0.608

Table 1 lists the statistical results of maximum navigation drift error of GNSS outages in the three modes, including position error, velocity error and attitude error.

In the mode of pure INS, it is clear that the RMS values of the position errors in longitudinal, transversal and vertical directions are about 10.89m, 2.60m and 0.23m respectively; the RMS values of the attitude errors in roll, pitch and yaw are about 0.161°, 0.322° and 0.637° respectively. The reduction of transversal and vertical errors are attributed to NHC. However, the conditions for the establishment of NHC in robot are not as good as the vehicle, resulting in a large heading angle error.

In the mode of odo-aided INS algorithm. The RMS values of the position errors in longitudinal, transversal and vertical directions are about 0.56m, 1.62m and 0.14m respectively; the RMS values of the attitude errors in roll, pitch and yaw are about 0.125°, 0.188° and 0.539° respectively. Compared with results in pure INS algorithm, the RMS values of the longitudinal position errors decreases from approximately 10m to less than 1.0m due to the odometer measurements. However, the decimeter level of the transversal position accuracy is not achieved even using the odo-aided INS algorithm. Therefore, the transversal position errors of the odo-aided navigation algorithm need to be further reduced.

In the mode of lane-aided navigation algorithm. The RMS value of the transversal position errors in 60-seconds GNSS outages is about 0.3m, which is five times smaller than 1.6m in odo-aided positioning system. It can be drawn that significant improvement is achieved with lane-aided positioning algorithm and the best performance is obtained by using multi-information fusion scheme. The lane-aided navigation algorithm mainly provides absolute correction of the transversal position and has no strong relationship with the attitude, so the attitude accuracy is basically unchanged.

The navigation errors in 60s GNSS outages in different integration modes have been analyzed through multiple field tests. The statistical results shows that the odometer and NHC can ensure the longitudinal position accuracy and the attitude accuracy, and the lane information from camera and HD map can further improve the transversal position accuracy. The proposed multi-information fusion can reach the decimeter level of the positioning accuracy.