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A NOVEL ROAD CENTERLINE RECOVERY ALGORITHM BASED ON THE NETWORK RTK GPS DATA

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Abstract. *Nowadays the requirement of performance for the Intelligent Transportation Systems (ITS) applications is increasing, especially for some safety critical applications, including lane control, collision avoidance and autonomous driving. The precise determination of road centerline underpins these applications. The Network Real-Time Kinematic (NRTK) Global Positioning System (GPS) positioning, which is able to provide centimetric positioning accuracy under an ideal observation condition, is possible for the road centerline determination. However, GPS signal obstruction can introduce gaps in the positioning trajectory. Sensor integration can certainly bridge these gaps but with a cost in terms of the complexity in data fusion and the actual cost in expenses. In this paper, a novel smooth spline based algorithm is developed to improve the accuracy and continuity of NRTK GPS solutions for the road centerline extraction and recovery. The simulation and field test results have shown that the proposed algorithm yields significant accuracy in the road centerline recovery compared to the other state-of-the-art algorithms, and remains an economically viable solution.*

Keywords: Network Real-Time Kinematic (NRTK), Road centerline detection, Smooth spline, Curve fitting

1. **Introduction.** The accurate road centerline is critical for the Intelligent Transportation System (ITS) applications such as lane level positioning and navigation. The extraction of the road centerline underpins these lane-level required applications. In recent years, some research has mentioned the road centerline extraction and recovering methods. Miao et al. [1] have proposed a Gaussian Mixture Model (GMM) and Subspace Constraint Mean Shift (SCMS) based centerline extraction model. Knoop et al. [2] have developed a Precise Point Position GPS (PPP-GPS) based positioning method to obtain the lane and road centerline information. Uduwaragoda et al. [3] have proposed a non-parametric Kernel Density Estimation (KDE) based lane information extraction method. Other research that indicated the methods for the road centerline recovery can be illustrated in [4-6]. By analyzing the existing literature, it is indicated that most of the research contains high computation cost, which hinders wide applications. Furthermore, some other research has used vision based methods, in which the quality of the collected data is highly affected by the weather conditions. In addition, the lack of reliable accuracy and integrity algorithm is also a problem of the current Global Navigation Satellite System (GNSS) based road centerline extractions.

In order to obtain the high accuracy positioning data with low cost and weather insensitivity, the Network Real-Time Kinematic (NRTK) GPS positioning, which is based on a network of reference stations to produce centimetric correction data, has been gradually introduced into the required applications with mobility, reliability and high accuracy [7,8]. However, GPS signal blockage can bring the gaps in the positioning solutions, which will affect the accuracy, continuity and availability of the road centerline determination. In this research, a novel smooth spline based algorithm for the road centerline extraction has been developed based on the high accuracy and low cost NRTK GPS data. The designed algorithm exhibits its superior performance in the road centerline recovery compared to the other state-of-the-art centerline recovery algorithms in simulation and has demonstrated its ability to bridge the gaps in the road centerline detection without expensive sensor integration in the field test. The rest of the paper is organized as follows. In Section 2, the novel algorithm design and its simulation for the road centerline extraction are introduced. Section 3 then presented the data collection scheme for the road centerline. Finally, the evaluation of the proposed algorithm based on the field test and conclusions are concluded in Sections 4 and 5.

2. **Algorithm Design and Simulation for the Road Centerline Extraction.** A novel smooth spline curve fitting method is designed to bridge the GPS data gaps for obtaining a continuous road centerline data. Smoothing spline fitting performs it advantage in fitting of the noisy data sets. Let (x_i, y_i); $x_1 < x_2 < \ldots < x_n$, $i \in Z$ be a sequence of observations. The relationship $y_i = s(x_i)$ is defined by the model. The smooth spline estimate s is defined to be minimizer over the class of twice differentiable functions and the spline is constructed for the specified smoothing parameter p and the specified weights w_i based on (1). The smoothing spline weights are assumed to be 1 for all data points.

$$p \sum_i w_i (y_i - s(x_i))^2 + (1-p) \int \left(\frac{ds^2}{dx^2} \right)^2 dx \tag{1}$$

Here, p is defined between 0 and 1. When $p = 0$, it produces a least squares straight line that fits to the data, whilst $p = 1$, it produces a cubic spline interpolant. p is often near $1/(1 + h/2)$ where h is the average spacing of the data points, and it is typically much smaller than the allowed range of the parameter, and choosing the proper p is crucial to the performance of the smooth spline fitting [9]. The proposed smooth spline fitting will be compared with the other two state-of-the-art interpolant fitting methods, including cubic spline interpolation and shape-preserving Piecewise Cubic Hermite Interpolation (PCHIP), to show the performance of fitting accuracy for the road centerline estimation.

Table 1 has shown that the four simulation tests are designed based on the high accuracy Global Positioning System/Inertial Navigation System (GPS/INS) reference data, which is recognized as true data, for the road centerline. In the tests design, different lengths and frequencies of the sample points are removed from the defined reference samples to test the performance of algorithms. In Test 1, the data is 20Hz with 600 samples. Among the samples, one point is removed randomly in the middle of the samples to simulate the data gap scenarios. In Test 2, the data is 20Hz with 600 samples. In this test, 20 consecutive points were removed in the middle part of the samples. Test 3 is based on the 20Hz data with 600 samples; in this test, 42 continuous points are removed. In Test 4,

Table 1. Test design in the simulation

Simulation Tests	Data Rate	Total No. of Data Points	Deleted Point(s)	Location(s) of the Deleted Points
Test 1	20Hz	600	1	200-400
Test 2	20Hz	600	20	200-400
Test 3	20Hz	600	42	300-500
Test 4	1Hz	231	24	50-180

Table 2. Statistical results for the designed tests in the simulation

Accuracy (cm)	Test 1		Test 2		Test 3		Test 4	
	Mean	Min	Mean	Min	Mean	Min	Mean	Min
Cubic Spline	0.6	2.4	2.7	10.0	5.7	23.9	13.356	41.924
PCHIP	0.5	2.4	4.2	14.7	24.0	58.6	20.013	61.476
Smooth Spline	0.5	2.5	1.8	7.2	3.9	15.9	13.080	40.059

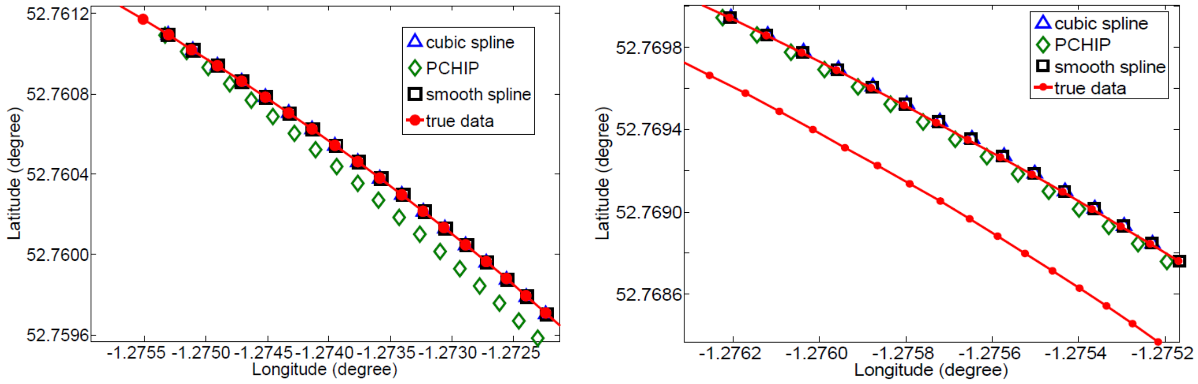

Figure 1. The comparison between the fitting results and true data in Test 3

the data is 1Hz with 231 samples, in which 24 points were removed. In addition, about 50 sample points on both sides of the trajectory are left to provide the sufficient points for data fitting. Total 1000 repeated tests are conducted for all the designed tests to calculate the mean and minimum accuracy based on the original reference points.

Table 2 has shown the statistical analysis of 3D accuracy for the designed tests. It is obvious that although the increasing number of the deleted points will decrease the fitting accuracy, the smooth spline based algorithm still outperforms the other algorithms. Especially in Test 3, the obvious advantage of smooth spline fitting for horizontal coordinates is shown in Figure 1. The mean accuracy and minimum accuracy of the smooth spline based fitting is 3.9cm and 15.93cm, which exhibit much better accuracy than the other two approaches. In addition, the lower data rate will decrease the accuracy of the fitting results. For 1Hz data fitting in Test 4, as the fitting errors will increase based on the increased data separations compared to the 20Hz data, the smooth spline still performs the best estimation accuracy among the other two approaches. In Section 3 and Section 4, the real data will be collected and the smooth spline based algorithm will be validated in the field test.

3. **Equipment and Data Collection.** The trajectory data of kinematic test was collected in Nottingham region starting from the Japanese water garden close to A52 as shown in 'route covered' in Figure 2 on the left side. A Leica 1200 receiver with a Leica AX1202 antenna was used to collect the raw measurement and conduct real-time RTK GPS positioning through receiving NRTK corrections from Leica SmartNet services. The high grade GPS/INS combined data from an expensive Inertial Navigation System (INS) sensor, which was collected at the same time, is used as a reference data. Two runs of road centerline data collection were carried out on the same route with 20Hz output rate in the morning and afternoon separately. The objective of the data collection is to validate the performance of the designed algorithm in the real road centerline fitting by comparison with a highgrade integrated GPS/INS system as a reference.

There are many data gaps in the collected RTK GPS data. The main reason for the occurrence of these missing points is that when the van was passing through the bridge or there was a passing high lorry, the satellite signal was obstructed by the bridge or

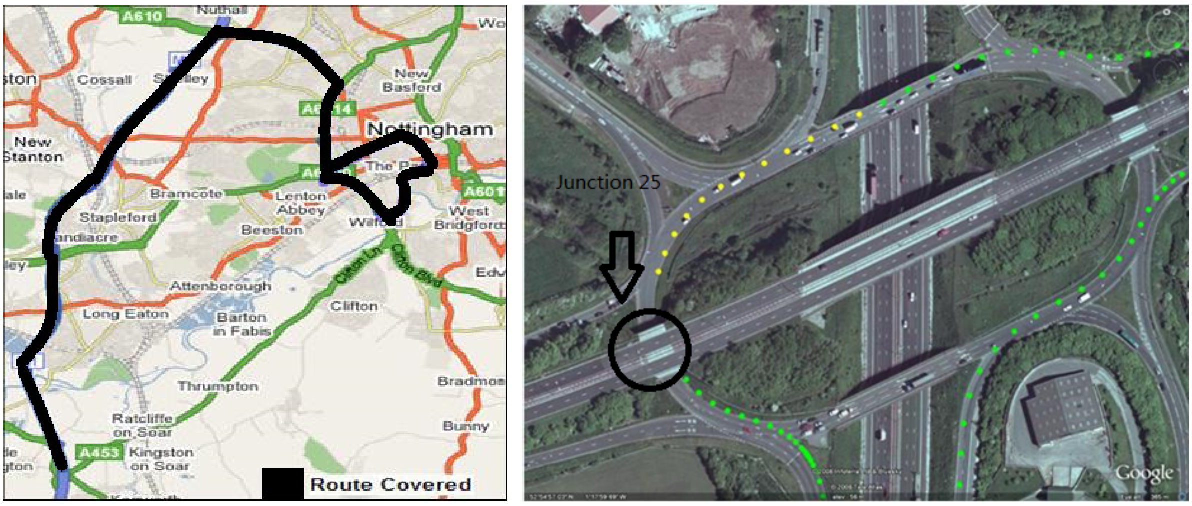

Figure 2. Test route for data collection figure (left) and data interruption caused by the signal obstruction when passing a flyover bridge (right)

Table 3. Statistics of the collected data sets

Test Run	Total Points	Total Missing Points	Outage Percentage	Available Percentage
Loop1	42945	2945	7%	93%
Loop2	42945	2774	6%	94%
Test Run	The longest Gap No. of Missing Points		The Shortest Gap No. of Missing Points	
Loop1	154		14	
Loop2	161		12	
Test Run	The Longest Gap in Length (km)		The Shortest Gap in Length (km)	
Loop1	0.11		0.01	
Loop2	0.13		0.01	
Test Run	SPS Solution	DGPS Solution	NRTK Solution	NRTK Percentage
Loop1	649	17112	22239	56%
Loop2	19	22499	16483	42%

the lorry and several seconds might need for the satellite signal or NRTK correction to reacquisition. If there were no sufficient satellites to fix integer ambiguities, the position solution would be downgraded to DGPS positions. Table 3 summarizes the statistics of testing data and their position quality. In addition, the collected 3D coordinates were shown in Figure 2 on the right side. The darker dots represent the NRTK GPS solutions and the lighter dots represent the DGPS positioning solutions. It is apparent that when the van passed underneath a flyover of the Junction 25, the signal was blocked and the position was interrupted completed for several epochs. When the van came out of the bridge, it took several seconds to re-acquire the signal to attain DGPS positions and then recovered to full NRTK positions.

Since abrupt turning in these cases will not be possible based on the collected real data, it is possible to apply the designed algorithm to bridging the gaps for recoverying the road centerline surveyed by the test van.

4. **Real Road Centerline Fitting.** From the simulation results, it is obvious that the designed smooth spline based fitting algorithm outperforms the other fitting algorithms

in the road centerline fitting. In the real road test, the fitting results of the proposed algorithm are compared with the reference road centerline produced by an integrated INS/GPS system. From Figure 3, it is shown that the smooth spline based fitting results can bridge the gaps caused by NRTK GPS outage and perform high accuracy in centerline estimation compared to the reference data from the GPS/INS solutions. The right side of Figure 3 is the zoomed in version for an epoch without GPS data on the left side and it is indicated that the proposed smooth spline based algorithm fitted positioning results are very close to the reference.

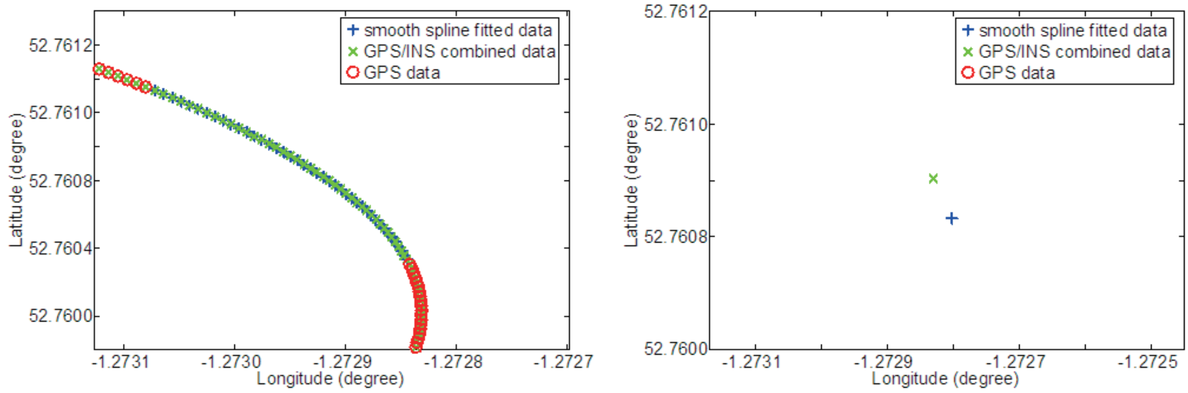

Figure 3. The comparison between the NRTK GPS data and smooth spline fitted data with respect to different references

From the comparison of the smooth spline based algorithm with the reference, it is indicated that the proposed algorithm can provide a mean and minimum horizontal estimation accuracy of 2.56cm and 5.28cm respectively, which can meet the requirement for the road centerline determination. Meanwhile, with this novel algorithm, the cost for the road centerline would only be a small amount of Leica RTK GPS service fee, which is much cheaper than the high grade GPS/INS sensor. Thus, the novel designed solution could provide a simple and cost-effective solution for the road centerline recovery and extraction.

5. **Conclusions.** In this paper, a novel smooth spline based road centerline recovery algorithm is proposed with the merit of simple computation and low cost. According to the simulation analysis, the smooth spline based algorithm, which outperforms the other fitting methods, is able to provide the highest estimation accuracy to bridge the GPS outage for determination of the centerlines on highway. The proposed algorithm is further validated in the field test to show its ability for the real road centerline extraction.

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