Application of Street Tracking Algorithm to Improve Performance of a Low-Cost INS/GPS System

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Abstract—**This paper presents a novel algorithm named Street Tracking Algorithm (STA) for performance improving of a low-cost INS/GPS integrated System. Instead of the open-loop output position calculating method in the developed INS/GPS integrated systems, this STA calculates position based on three parameters of INS position output, IMU velocity increment within a time slot and the trajectory's digital map database. The position error of this STA reaches ± 2.5 meters within a considered period time slot of 28 seconds. This error is much improved up to 80 times when compare with the original INS/GPS integrated system.**

Index Terms—**inertial navigation system, global positioning system, kalman filter, street tracking algorithm.**

I. Introduction

Up to now, Global Positioning System is still one of the most popular used systems in the vehicle positioning and navigation applications because it can provide exactly positioning information to an unlimited number of vehicles mounted this device everywhere on the world. As a result, the number of applications utilizing GPS is more and more beyond most people's imagination and the applications consist of tracking of places where people, a fleet of trucks, cars, trains are and how fast they are moving. However, GPS only provides these types of information in the open-sky condition (see at least four satellites). But when GPS works in areas having many buildings, ancient trees; in bad weather condition or under overpasses, freeways, underground trench then GPS signal will be reflected, blockage or outage lead to positioning information is lost or no accuracy. So, GPS needs to combine with other systems, sensors, devices in order to provide continuous navigation information.

Contrary to GPS, Inertial Navigation System (INS) can be self-contained positioning and measures attitudes (pitch, roll and yaw) of vehicle thanks to accelerometers and gyroscopes. In other words, it can work in all environments. The primary advantage of utilizing an INS for the land vehicle navigation applications is that velocity and position of vehicle can be provided with abundant dynamic information and excellent short term performance. In addition, it has high update rates compare with update rates of GPS (1/64 sec with INS and 1 sec with GPS). However, in case we only use INS to navigate in a long term, drift errors are large because these errors accumulate with time. The cause of these errors is due to errors of gyroscope, accelerometer and errors of integration between them [1].

With above analysis, each positioning system has the advantages and disadvantages. Thus, a lot of students and scientists on the world have been interested in combining two systems into an INS/GPS integrated system to make use of advantages and limit disadvantages of them. The fact has demonstrated that studied results succeeded in actual applications and used widely in different areas. An INS/GPS integrated system can provide continuous update positioning information without being interrupted. However, low-cost INS/GPS integrated system still has large drift errors that need to be overcome; especially errors exist in a long term. With a view to limiting drift errors in the low-cost INS/GPS integrated system there is a series of methods as using the neuron-fuzzy model or the fuzzy logic expert system [2], [3].

In the previous study [4], we proposed a new algorithm named "Street Return Algorithm" (SRA) to embed into a low-cost INS/GPS integrated system. The experimental and simulated results proved that this algorithm is simple but efficient. In that experimental test, GPS signal was lost within 100 seconds. The maximum deviation of the INS/GPS system is about 40 meters without SRA and around one meter compare with transverse locations by using SRA. However, beside some constraints, this system still exists some limitations that could not be resolved yet such as incorrect locations along the lane. The vehicle can be monitored that it is still on the lane but in fact, it is somewhere in the road.

In this paper, we propose a new algorithm called "Street Tracking Algorithm" (STA) in order to embed in

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a low-cost INS/GPS integrated system that can overcome the disadvantage of our previous study. Its working principle is based on the velocity constraint of 2D navigation for land vehicles and digital map database. The paper is arranged as following sections: Section 2 presents the working principles of conventional INS/GPS integration system; the INS/GPS/SRA system has also reviewed in this section for the completeness. The proposed method is described in the Section 3. The simulation and results have been presented in the Section 4. Finally, some conclusions and future works are shown in Section 5.

II. Working Principle

A. *INS/GPS Integration*

To integrate INS and GPS, it can be used two architectures: Loosely-coupled INS/GPS integration architecture and Tightly-coupled INS/GPS integration architecture (see Fig. 1 and Fig. 2) [5].

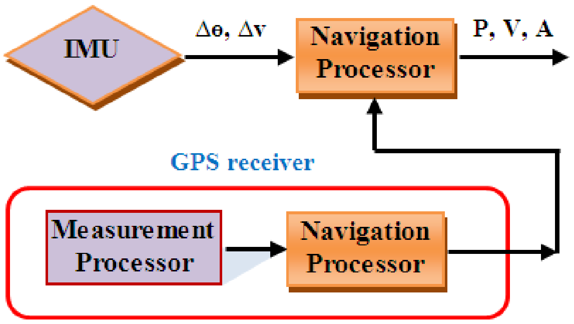

Figure 1. Loosely-coupled architecture.

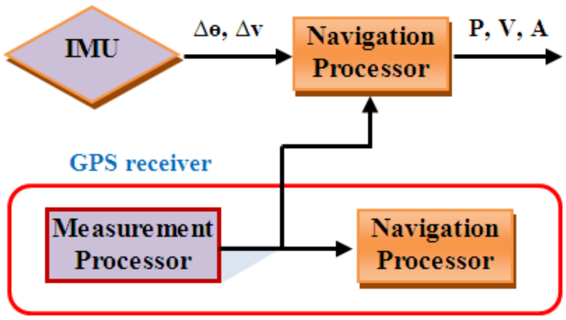

Figure 2. Tightly-coupled architecture.

where $\Delta\theta$, Δv are angular increment, velocity increment respectively. P, V, A are position, velocity, attitude of objects, respectively.

The fundamental of two architectures is quite the same, but there is a small difference in output of GPS receiver in which data is output from the navigation processor block in loosely-coupled architecture where as it is output from the measurement processor block in tightly-coupled architecture.

Each integration architecture can again use two error calibration methods: the feed forward (or open loop) method and the feedback (or closed loop) method (as shown in Fig. 3).

where position P_{INS}, velocity V_{INS}, and attitude A_{INS} are calculated by INS. Position P_{GPS} and velocity V_{GPS} are calculated by GPS.

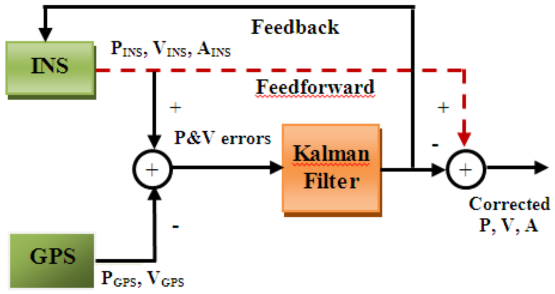

Figure 3. Error calibration methods.

Kalman Filter, shown in Fig. 3, is used as the navigation processor block. When GPS signal is available, performance of system will be better if utilizing feedback aiding. However, the integrated system will become more complex. Moreover, drift errors will be worse during GPS outage. In this case, feed forward aiding can be utilized to replace feedback aiding due to structure of system is simpler and performance is better. The disadvantage of feed forward aiding is large drift errors because these errors are accumulated with time. So, they need to be improved while GPS outage. Beside some methods listed in term "Introduction", there are still other methods.

B. *INS/GPS/SRA Integrated System*

In our previous study, we proposed the Street Return Algorithm (SRA) to limit transverse drift errors in a low-cost INS/GPS integrated system (see Fig. 4). In this figure, continuous line illustrates working mode of system during GPS signal is available and broken line is for the mode of GPS outage.

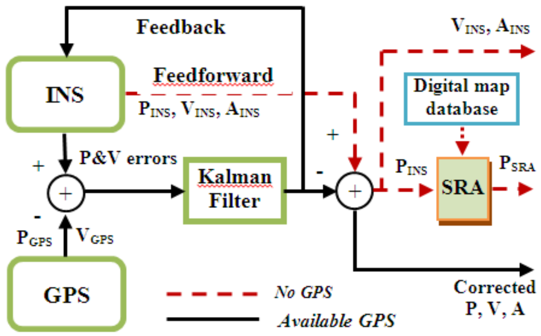

Figure 4. INS/GPS/SRA integrated system

The SRA only works when GPS signal is not available. Digital map database block implements two functions: determining joints based on digital map database and drawing serial line segments from those joints. Output of the second adder includes three parameters P_{INS}, V_{INS}, A_{INS}. SRA block receives data from digital map database block and P_{INS} of the second adder to correct positions calculated by INS. Output of SRA block is P_{SRA}. In this case, P_{SRA}, V_{INS}, A_{INS} play a role in replacing corrected P, V and A parameters when GPS is available.

This algorithm can push the vehicle back to the street in the perpendicular direction very well. However, it cannot determine exactly the vehicle positions along the lane. It really needs a more powerful algorithm for this task.

III. INS/GPS/STA Prosposed Integration System

In order to overcome the disadvantages of SRA, we propose a new algorithm named the Street Tracking Algorithm (as shown in Fig. 5). In this figure, the STA block has three inputs and an output.

The first input is obtained from the IMU. In STA, the velocity constraint has been applied to the navigation system when the GPS signal is lost. It is obvious that the land vehicle does not slip and jump of the ground. Then, velocities in directions of axes X, Z in body frame (B) are zeros:

$$\begin{aligned} V_X^B(t) &= 0 \\ V_Z^B(t) &= 0 \end{aligned} \tag{1}$$

The information of accelerometers in IMU is then provided directly to the STA block in order to calculate the real distance of the vehicle from the moment the GPS signal is lost.

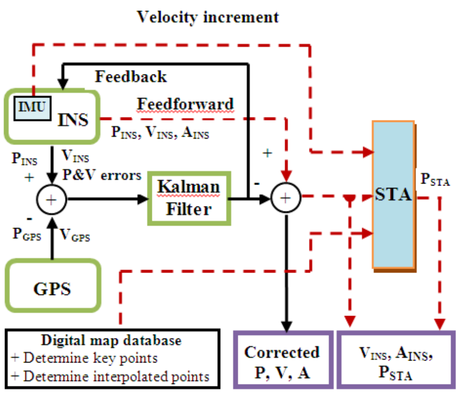

Figure 5. INS/GPS/STA integrated system

The second input is obtained from digital map database. It is assumed that the moving trajectory of land vehicle is certain roads. In this system, “digital map database” block implements two functions. The first function is to determine key points (including joints) based on map database and the second one is to find out some interpolated points from key points. It means that the number of points on the trajectory of land vehicle will be increased.

The third input of STA is the position information P_{INS}. It is obvious that when GPS signal is lost, this input would offer wrong locations of the vehicle that need to be corrected by STA. Note that the third input of STA is provided by output of the low-cost INS/GPS integration system. It consists of three parameters P_{INS}, V_{INS}, A_{INS} where V_{INS}, A_{INS} are used to represent corrected V, A and the remaining input P_{INS} is put into STA block to obtain the corrected position P_{STA}.

When GPS signal is lost, STA stores the last reliable location of the system denoted by d_0 (before the GPS signal is lost). The distance of vehicle at the time t_k is calculated by:

$$d = d_0 + d_b(t_k) \tag{2}$$

where $d_b(t_k)$ is the distance of the vehicle from the moment the GPS signal is lost to the epoch t_k. Note that this distance is computed by integrating the velocity provided directly from the IMU in the body frame.

The corrected position would be determined by comparison of d with d_{ref} which determined from the reference points from map database (the second input of STA). The vehicle will be pulled back to certain position determined in the database as following equation:

$$|d - d_{ref}| < \varepsilon \tag{3}$$

It can be seen that the performance would be improved if the number of the reference points is increased. However, it would be a tradeoff between the performance and the system complexity.

By using this algorithm, the vehicle can always track the real the road on the map in real-time scenario. By integrating the velocity in Y direction from the moment that GPS signal is lost; this algorithm can avoid the accumulated errors caused by MEMS based sensors. We neither need to transform this distance from body frame to navigation frame. It will also avoid the transformation errors caused by velocity constraints.

IV. Simulated Results

In this section, the data was obtained by experiment using a vehicle equipped by IMU BP3010 and GPS HI-COM as shown in Fig. 6 [6]. The vehicle completed a trajectory in about 25 minutes. The referenced trajectory is obtained by the GPS in a good condition (i.e. GPS signal is always available). Of course that we can improve the correctness of this referenced trajectory by using some kinds of facilities such as DGPS, high cost INS/GPS integration system, etc.

Figure 6. The INS/GPS system in outdoor experimentation

In this scenario, the GPS would be lost from 728th to 756th seconds. The Fig. 7 shows the position comparison between the reference and the conventional INS/GPS without STA. The solid curve is the reference trajectory and the dotted curve is the INS/GPS one without STA. The Fig. 8 is the closer look of the trajectory that the GPS signal was assumed to be lost. The results show that the position error is more than 200 m.

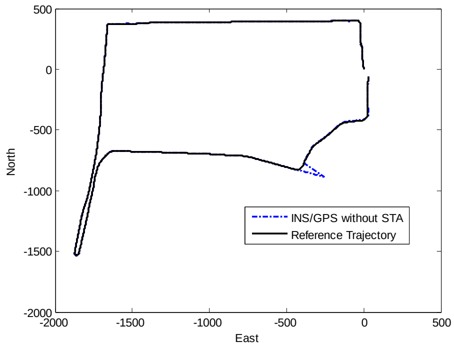

Figure 7. Comparisons of the reference trajectory with the INS/GPS without STA

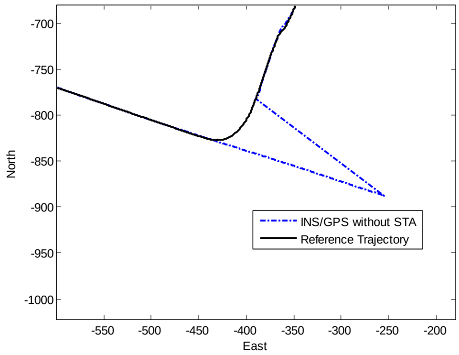

Figure 8. A closer look of the comparison of the reference trajectory with the INS/GPS without STA

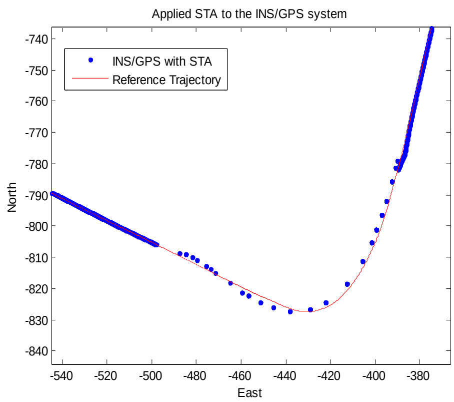

Figure 9. Comparisons of the reference trajectory with the INS/GPS with STA

Fig. 9 shows the position comparison between the reference and the conventional INS/GPS with STA. The error of this STA proposed INS/GPS system reaches ± 2.5 m. It shows that the STA's position error is much improved up to 80 times when compare with the original INS/GPS system error of ± 200 m. However, this STA requires more complexly computation due to number of integration calculations. Therefore, the number of key points cannot be too large. This number is depended on the used processor performance and required time resolution.

V. Conclusion

In this paper, we have proposed a Street Tracking Algorithm in order to track a vehicle on the road when the GPS signal losing. This algorithm calculates position based on parameters of INS position output, IMU velocity increment within a time slot with referencing to the trajectory's digital map database. The performance of the proposed system has been examined with experimented data. The position error of the novel systems is about ± 2.5 meters within 28 seconds. It is much improved when comparing with the original ING/GPS system error of ± 200 meters. This STA considers both longitudinal and transverse position errors when comparing with the developed SRA system which can only improve the trajectory transverse error parameter. However, the accuracy of the SRA on the transverse error can reach ± 1 meter within 100 seconds time period, where STA one is ± 2.5 meters within only 28 seconds. In the future work, the output of STA would be feed backed to INS/GPS block to improve the information of attitude and velocity.

This STA system can be applied in city vehicle navigation, railway transportation navigation, and so on.

Acknowledgment

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