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Data synchronization in IMU/GPS integrated measurement system of vehicle motion parameters

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Abstract: To realize the data synchronization between the inertial measurement unit (IMU) and the global positioning system (GPS), the synchronization technology in the IMU/GPS integrated measurement system of vehicle motion parameters is studied. According to the characteristics of the output signals of the IMU and the GPS, without the IMU synchronization signal, the synchronization circuit based on CPLD is designed and developed, which need not alter the configurations of the IMU and GPS. Experiments of measuring vehicle motion parameters, which rely on the synchronization circuit to realize IMU/GPS data synchronization, are made. The driving routes in experiments comprise a curve and a straight line. Experimental results show that the designed circuit can accurately measure the synchronization time difference and the IMU period, and can effectively solve the data synchronization in IMU/GPS integration. Furthermore, the IMU/GPS integrated measurement system based on the synchronization circuit can measure and calculate many vehicle motion parameters in high frequency mode.

Key words: vehicle movement; performance test; IMU/GPS; data synchronization

Many vehicle performance tests, such as dynamic performance, brake performance and steering stability, are accomplished by measuring and analyzing vehicle motion parameters. These motion parameters mainly consist of displacement, trajectory, velocity, acceleration and turn rate, etc. Due to the shortcomings of traditional measurement systems, some new measurement methods have been proposed in recent years. In Refs. [1 − 2], a low-cost integrated inertial measurement unit (IMU) was adopted in vehicle road tests and many motion parameters were then calculated based on the extended Kalman filter. But this method was only suitable for short-time measuring due to the inertial component's accumulative error. In Ref. [3], the real time kinematic (RTK) fifth wheel for vehicle road tests was developed based on the GPS carrier phase RTK technology. However, limited by GPS output frequency, the RTK fifth wheel could only provide data of 20 Hz.

To overcome the disadvantages of IMU and GPS and make full use of their integrated advantages, an integrated IMU/GPS measurement system of vehicle motion parameters (abbreviated by IMS) is developed, by which many vehicle motion parameters can be measured for a long time with high frequency and accuracy. It should be noted that as one of the key technologies in this measurement system, the time synchronization between the IMU signal and the GPS signal is very important. In this paper, the details about how to synchronize the data from GPS and IMU are discussed.

1 IMU/GPS Data Synchronization

For the IMU/GPS integrated measurement system, its working process can be summarized as follows: the signals of GPS and IMU are first captured according to proper time logic, and then are fused by some information fusion method; thus a vehicle's motion parameters can be obtained. But, only after the data synchronization problem is solved, can the integrated measurement system be taken full advantage of.

1.1 Three cases of IMU/GPS data synchronization

IMU/GPS data synchronization has been studied in some studies of the GPS/INS (inertial navigation system) integrated navigation system. Generally speaking, the GPS receiver can not only supply navigation information but also provide a 1 PPS timing signal which is consistent with UTS. To realize data synchronization, a GPS 1 PPS signal can be used as time synchronization benchmark, which is the most effective and general method at present. According to the nature of GPS/INS configurations, three synchronization cases have been identified as follows[4−6]: ① Synchroniza-

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tion at the IMU's data sampling circuit in an integrative instrument; ② Synchronization using GPS and IMU's timing signals; ③ Synchronization without IMU's timing signals.

For the synchronization in cases ② or ③, usually, the GPS 1 PPS signal is selected as the time benchmark, at which the IMU (INS) data are synchronized by polynomial fitting or interpolation in order to correspond to GPS positioning data.

1.2 Synchronization principle of IMU/GPS integrated measurement system

As discussed above, how to synchronize IMU/GPS is dependent on the actual configuration of IMU. In the IMU/GPS integrated measurement system, the NovAtel DL-4-RT2 GPS module is selected, which works on the carrier-phase differential mode, while XW-7100VG is chosen as IMU which belongs to case ③ described in section 1.1. XW-7100VG provides the carrier's 6-dimensional measuring information including three accelerations and three turn rates through RS232 serial communication. In this case, it seems to be the only way to make full use of serial output signal to realize synchronization.

The time relationship between GPS 1 PPS signal time and XW-7100 IMU sampling time is shown in Fig. 1. In the same time coordinate, each thin vertical line at time t_i ($i=0, 1, \dots, k, \dots$) corresponds to data update time of XW-7100 IMU while the thick vertical line corresponds to the rising edge of the GPS 1 PPS signal; i.e., the GPS data update time. Since the GPS's working status is independent of that of XW-7100, the IMU data update does not occur at each GPS 1 PPS in most cases. Here, it is supposed that the intervals between the GPS 1 PPS and its two neighboring IMU update times; i.e., t_{k-1} and t_k, are t_b and t_a, respectively. IMU output frequency may vary due to such factors as the temperature change, etc., which can lead to the uncertain variation of t_b or t_a. Obviously, once t_b or t_a is obtained by means of either software or hardware, synchronized IMU data can be ascertained at each GPS 1 PPS through interpolation. For high dynamic applications, high order interpolation can be used. For example, the $(2n+1)$-th order Lagrange interpolation equation is as follows:

$$X_{syn}(t_{GPS}) = \sum_{i=k-n-1}^{k+n} X_{IMU}(t_i) \prod_{\substack{j=k-n-1 \\ j\neq i}}^{k+n} \frac{t_{GPS}-t_j}{t_i-t_j} \quad (1)$$

where t_{GPS} is the GPS measurement time (i.e., GPS 1 PPS), $X_{IMU}(t_i)$ is the IMU data at t_i, and $X_{syn}(t_{GPS})$ is the synchronized IMU data after interpolation. For the low dynamic vehicle, it is sufficient to adopt the first order linear interpolation. Let n be equal to 0, then Eq. (1) is simplified as

$$X_{syn}(t_{GPS}) = \frac{t_{GPS}-t_{k-1}}{t_k-t_{k-1}} X_{IMU}(t_k) + \frac{t_k-t_{GPS}}{t_k-t_{k-1}} X_{IMU}(t_{k-1}) \quad (2)$$

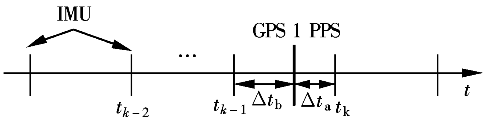

Fig. 1 Time relationship between GPS 1 PPS time and IMU sampling time

Since the loose and indirect-feedback fusion mode[7,8] is utilized in the integrated measurement system, to form the system's measurement equation of the Kalman filter fusion process, it is necessary to synchronize the position and velocity data calculated from IMU at each GPS 1PPS. Namely, X_{IMU} in Eq. (1) or Eq. (2) denotes the position or velocity calculated from IMU.

In view of time consumption including sampling, A/D converting and data processing, etc., XW-7100 transfers the measuring data later in interval T_c than its update time t_i ($i=0, 1, \dots, k, \dots$). Moreover, T_c is a known constant which has been ascertained and given by manufacturers. Consequently, if the interval $\Delta t'_b$ between the GPS 1 PPS and the transferring start point of XW-7100 serial signal just prior to GPS 1 PPS can be measured, then t_b can be computed.

Compared with software timing, measuring $\Delta t'_b$ by a proper hardware method not only can achieve higher reliability and accuracy but also does not occupy the CPU's processing time. Therefore, a particular hardware synchronization circuit is designed to measure $\Delta t'_b$ in the integrated measurement system.

2 Realizing Synchronization Based on CPLD

2.1 Design of data synchronization circuit

In order to realize data synchronization accurately, the synchronization circuit should possess two fundamental functions: First, it can measure $\Delta t'_b$ by hardware timing; secondly, it can measure the interval of consecutive IMU serial data signals.

According to the requirements mentioned above, the synchronization circuit is mainly composed of a piece of complex programmable logic device (CPLD) and a piece of large scale integrated counter 8253. The programmed CPLD realizes all of the logic circuits and decoders. Fig. 2 shows the circuit block diagram.

For the absence of synchronization pulse in IMU, a new synchronization pulse is made by CPLD,

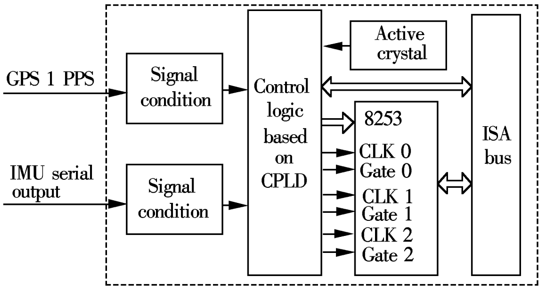

Fig. 2 Synchronization circuit block diagram

which is called "the IMU status signal". The delay time of the IMU, i. e., T_c is known; therefore the acquisition time can be gained by knowing the rise time of the IMU status signal. Similarly, to make the software inquire the coming time of the 1 PPS conveniently, make it wider, and name it " the GPS status signal". All of the three counters of the 8253 work on a mode 2-rate generator.

2.2 Time sequence analysis

The working time sequence diagram of the synchronization circuit is given in Fig. 3. Normally, counters 0 and 1 count every period of the IMU alternately, and at any moment the CPU can read the result of the stopped counter. When the GPS 1 PPS comes, both counters 0 and 1 stop counting, while counter 2 begins to work immediately, till either counter 0 or 1 works again.

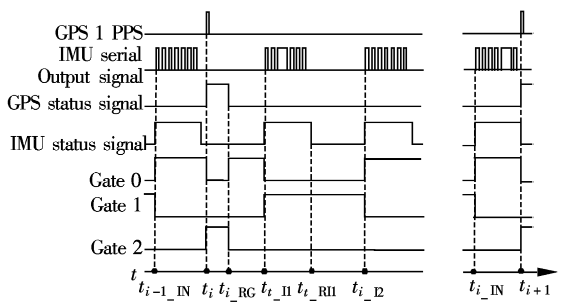

Fig. 3 Time sequence diagram of the synchronization circuit

In Fig. 3, when the IMU begins to communicate at t_{i-1_IN}, CPLD sets the IMU status signal to high, and counter 1 stops. The synchronization time difference of t'_b is obtained by

$$\Delta t'_{b\_i-1} = t_i - t_{i-1\_\mathrm{IN}} = f_0 V_{i-1\_\mathrm{end}} \qquad (3)$$

where f_0 is the clock frequency of three counters of 8253, and V_{i-1_end} is the result of counter 0 at t_i.

The CPU is busy in other cases when the GPS 1 PPS comes. When the CPU is idle at t_{i_RG} and finds the change in the GPS status signal, it gains the result of counter 0, and then resets the GPS status signal to let counter 0 begin to work again. Between t_i and t_{i_RG}, counter 2 counts until counter 0 begins to work.

3 Experimental Results

The experiments of measuring vehicle motion parameters based on the developed IMS are made, which rely on the synchronization circuit to realize IMU/GPS data synchronization. The driving routes in experiments comprise a curve and a straight line, which are also typical in vehicle road tests. After the experiments, the synchronized IMU/GPS data collected during the experiment course are post-processed according to the indirect feedback-correction Kalman filter with loose mode; i. e., position and velocity mode. In this way, the output frequency of the IMS is consistent with that of the IMU, which can reach 120 Hz.

4 Conclusion

The data synchronization problem in the IMU/GPS integrated measurement system of vehicle motion parameters is studied in this paper. On the premise of not altering the configurations of the IMU and the GPS, according to the characteristics of the output signals of the IMU and the GPS, the synchronization circuit based on CPLD is successfully developed. In the experiments of the IMU/GPS integrated measurement, the circuit exhibits good performances in accuracy and reliability, which can effectively solve the data synchronization problem of the IMU and the GPS.

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汽车运动参数 IMU/GPS 组合测试中的数据同步技术

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摘要:为解决 IMU 和 GPS 的数据同步问题,对汽车运动参数 IMU/GPS 组合测试中的数据同步技术进行了研究. 根据 GPS 和 IMU 信号的特点,在 IMU 不提供同步脉冲信号并且不改变它们各自结构的前提下,设计并研制了基于 CPLD 的同步电路. 进行了测量汽车运动参数的试验,行驶路径包括直线和弧线,利用同步电路实现了 IMU/GPS 数据的同步. 试验结果表明:该电路能够准确测量同步时差,有效地解决了 IMU 和 GPS 数据的时间同步问题;基于该同步电路的 IMU/GPS 组合测试系统实现了对多种汽车运动参数的高频测量与解算.

关键词:汽车运动;性能试验;IMU/GPS;数据同步
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