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Conceptualization of an Integrated Positioning & Time Synchronization System for GPS/INS Using VHDL/FPGA Tools for Marine Applications

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Abstract

*The synchronization of Global Positioning System (GPS) and Inertial Navigation System (INS) can overcome the defects of INS or GPS standalone systems. This scheme implemented conceptualize, a far more flexible, platform based time synchronization system using field programmable gate array (FPGA) technology. The biggest advantage of the FPGA-based system is that all the hardware and software components of the system are field re-programmable without any hardware changes. After successful software simulation and testing, the same can be implemented in real-time on a suitable FPGA hardware.This reprogrammable hardware configuration represents a system design methodology of lower risk. It has maximum flexibility with the integration of a wide range of GPS and INS sensor packages. A new solution for time synchronization using GPS receiver signals as reference is proposed. In order to improve the accuracy of time synchronization, we utilize IPPS (Pulse Per Second) signal from GPS receiver as a synchronization reference, and tag time stamp on the serial data package from IMU.***

***Keywords :** GPS/INS, Time synchronization, 1PPS, FPGA*

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I. INTRODUCTION

For precise location applications, the integration of GPS and INS (Global Positioning system/Inertial Navigation System) is an best optimal solution. The data fusion processor combines the measurement data's obtained from these two navigation equipments. The electromagnetic GPS signal which is blocked by buildings ,mountains cannot give the continuous information and reliable position all the time where as the INS which gives information regardless of the surroundings will deteriorate with time The short term accuracy and high availability of INS combines well with the long term accuracy of GPS to provide a more robust and reliable outcome than standalone systems [1]. The integration of GPS and INS system achieves a very reliable navigation determination such as position, velocity and attitude with an acceptable accuracy level.Time synchronization between GPS and INS measurement data is first and foremost an issue while implementing GPS/INS integrated systems. Several reasons are presented as below:

[1] The GPS receiver and IMU are two separate Subsystems [1].

[2] An absolute GPS time reference in the data is provided from a GPS receiver. However, any time information has not been included in the inertial measurement data from IMU. In other words there isn't a uniform time frame between the measurement data from these two separate subsystems.

[3] Measurement data from IMU are transmitted into FPGA through RS-232 serial interface. The key factor for the time synchronization is the unknown time delay due to the hardware interface delays and the use of non real time operating system .Of course, the different start-up time of the two systems also has a negative influence on time synchronization.

The alignment discrepancies are caused due to these factors which can degrade the data fusion performance and if these data's are utilized as the feedback to the INS, the results would be far from the true value. The time synchronization of the measurement data's from different sensors in GPS/INS integration is a major research topic where the researchers concentrate on the complex hard ware and peripheral circuits. The outcome may be good time synchronization but the high cost of the complex hardware is a question mark .This paper deals with the importance of time synchronization, its existing methods, the proposed method and its implementation details.

At first, the existing time synchronization solution is presented and compared in terms of the limitations and advantages in this paper. According to the above analysis, a new time synchronization solution is proposed. It utilizes the 1PPS signal from a GPS receiver as a reference signal of measurement data from IMU, which can get precise GPS time information. The great advantage of this solution is that this time synchronizer, implemented on FPGA device in VHDL is simple and feasible.

II. COMPARISON OF EXISTING SOLUTION

The time synchronizer circuit is mainly composed of complex hardware. The analog signal outputs from the IMU sensor has to be converted into digital signal for further processing. Therefore a 6-channel A to D (analog-to digital) converter is necessary to sample the outputs from 3 gyroscopes and 3 accelerometers. Most GPS receiver provides 1PPS signal along with the positioning data, velocity data and time information [1] through a dedicated pin. This electrical pps signal is synchronized with GPS Time on the leading edge of 1PPS signal [3]. The deviation between the 1PPS signal edge and GPS system time is normally better than 1us . So 1PPS signal can be used as a flag timing IMU measurement data.

A.Hardware-based Solution

As shown in Fig. 1, 1PPS signal from a GPS receiver is sent into multi -channel data acquisition circuit to produce a synchronized sampling impulse. Because of high update rate of IMU data and low rate of GPS receiver, 1PPS signal is also used to trigger synchronous sampling impulse, of which the frequency is generated by hardware frequency multiplier. Driven by synchronous sampling impulse, 6 samplers and A to D converters start working [2]. This hardware solution can achieve better than 1 us time synchronization accuracy [2]. Just considering the accuracy, the synchronization requirement could be satisfied with the hardware solution. But this solution is often implemented with high performance hardware, and its architecture is complex. Only the analog signal from IMU could be sampled and tagged with GPS Time and moreover it cannot support for an IMU that gives digital outputs. In summary, those shortcomings limit its application for other conditions.

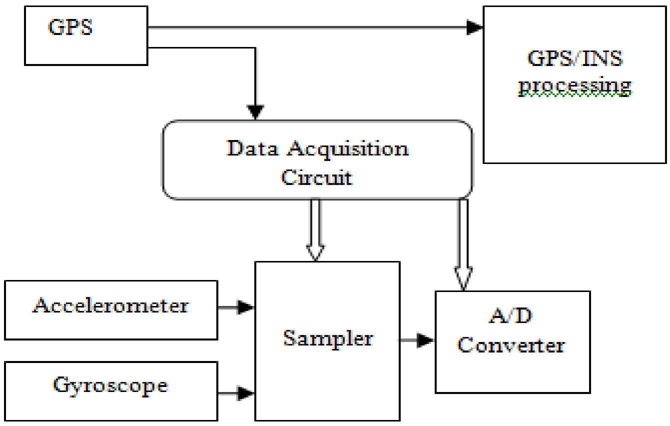

Fig.1 Hardware solution scheme

III. A NEW TIME SYNCHRONIZATION SOLUTION

In this section , a new time synchronization scheme based on FPGA is proposed. Compared to the existing time synchronizer, we would develop a better approach of time synchronization with low cost hardware, feasible system architecture and multi-purpose utility, not only for integration, but for other multi-sensors navigation systems. The information from a GPS receiver includes position and GPS Time . The GPS Time can be obtained from the GPS receiver outputs by FPGA coding in VHDL .The l PPS signal is synchronous with the receiver calculated GPS Time . In our time synchronizer, 1 PPS signal is the conjunct time flag for GPS Time and IMU data time, from which a time relationship between the outputs of GPS receiver and IMU data is set up. At first, the leading edge of 1PPS signal will trigger the counter to latch the value of time offset from GPS Time. The value is until the first byte of IMU data package. The time offset between the l PPS signal and the next closest IMU data package is given by the counter register in FPGA device. Combining the time offset and GPS Time together, we obtain an accurate time stamp for IMU data in the GPS Time frame, which is attached after every IMU data package.

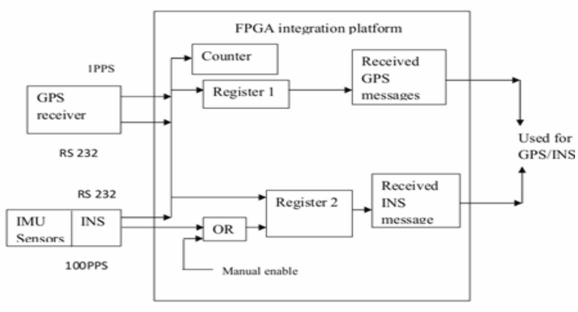

Fig.2 A new time synchronization scheme

At the same time, the information of velocity and GPS receiver is transmitted into navigation computer. The navigation computer compares the time information from the time stamped IMU data and the GPS receiver. At every data fusion epoch, the item close to epoch time from the synchronized IMU data is selected for further processing. If the time offset between GPS data at fusion epoch and the IMU data item is longer than a threshold set in advance, data interpolation is necessary. Note that the time stamp attached to IMU data package is the arrival time of the package, which includes additional time delays .The additional delays usual1y consist of IMU data processing delay and serial communication delay of IMU equipment. Usually, these delays are provided by IMU manufacturer as a constant parameter [1]. The stamped time of IMU data is calibrated with the constant parameter.

IV. TEST AND RESULT ANALYSIS

Generally information is transmitted to and from the GPS receiver via RS232 serial interface. The output from the receiver is in NMEA data format. NMEA consists of a number of sentences or character string. Due to latencies involved in serial communication NMEA sentence are not generally accurate enough to provide a timing reference so pps output can be fed in to microcontroller on the RS232 interface to provide hardware interrupt input for accurate timing. Here we are using Trimble GPS studio for monitoring the GPS receiver. Using this software we can monitor the satellite constellation, latitude, longitude, time, and speed and attitude information of the GPS receiver that is we can monitor PVAT solution from the GPS receiver. The GPS receiver here we are using is having a baud rate of 9600.

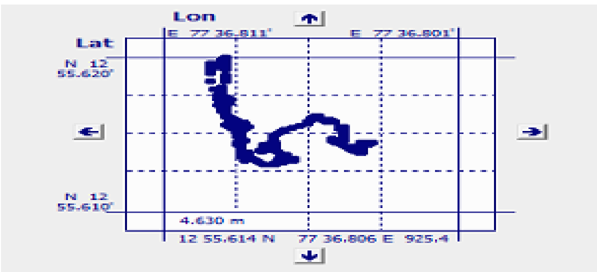

Fig 3 Position graph

Fig.3 shows the latitude vs longitude graph which gives the position of the GPS receiver.

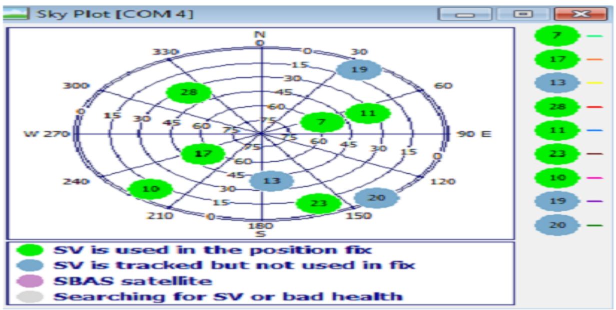

Fig 4: Sky plot of GPS receiver

There are nearly 24 or more active satellite orbiting in six different orbits for an fully operational GPS. Fig 4 shows the sky plot view of all the available satellites indicating whether it is active or passive. The angle of inclination is 55^{o} with respect to the equator between the orbits.

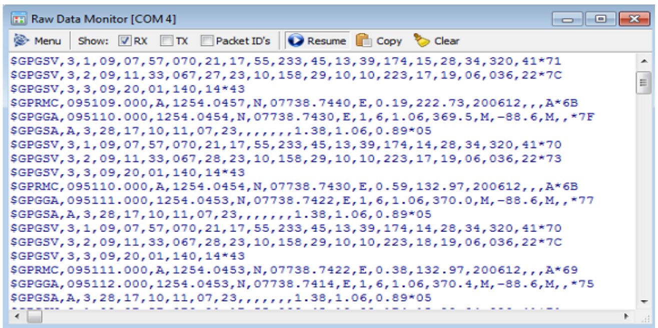

Fig 5: NMEA data from the GPS receiver

Fig 5.shows the NMEA date that are obtained from the GPS receiver. NMEA stands for National Marine Electronics Association. NMEA data include latitude, longitude, time and speed information. The NMEA message starts with '$' symbol, the first field indicate the NMEA code that include GPGSV, GPGSA, GPGGA, GPRMC etc.These code is having specific meaning like GPGSV indicates the GPS Satellite in View. GPGSA indicates GPS DOP and Active Satellites. GPGGA Global Positioning System Fix Data and GPRMC indicate Recommended Minimum Specific GPS/TRANSIT Data. Within the NMEA message the most useful one is the GPRMC message which will contains all the basic information required for the navigation system.

As a preliminary test device a low cost accelerometer, gyroscope and Ardunio UNO(ATMEG 328P) microcontroller were used. The details of the products are

[1] ADXL 335-Accelerometer.
[2] LPR5150AL-Gyroscope
[3] Ardunio UNO (ATMEG 328P) microcontroller

Fig 6, 7 and 8 shows the test results obtained using the former devices. We have used Matlab for the simulation .Fig 6 depicts the state of rest of accelerometer with acceleration as zero and figure 7 shows the when the body is moving.

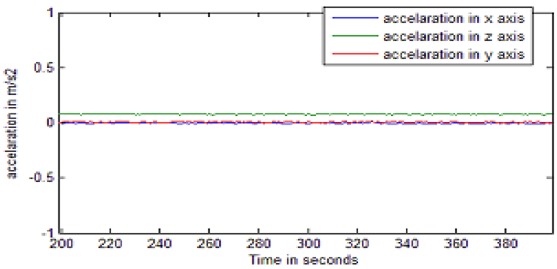

Fig 6:Acceleration when accelerometer at rest

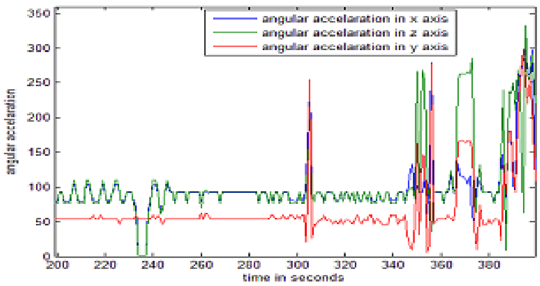

Fig:7 Acceleration measured by Accelerometer

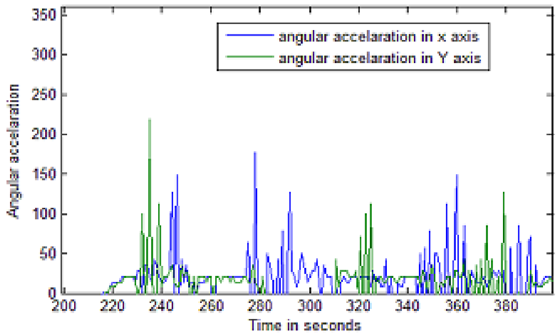

Fig:8 Angular acceleration measured by Gyroscope

Figure shows the simulated integration platform. The platform is simulated using Xilinx13.2. GPS counter, INS counter will show the counter value associated with GPS receiver, INS sensor respectively. Buffer 1 will store the GPS data and Buffer 2 the INS data. Transmit 1 and transmit 2 are the indication of GPS and INS data reception. If the value of transmit 1 is 1 then it shows the reception of GPS data if it is 0 then the reception is stopped. Similarly for the INS transmit 2 is 1 INS data is receiving if it is 1 then it shows reception is stopped. Following figures shows the datas of gps, ins and the synchronized datas respectively.

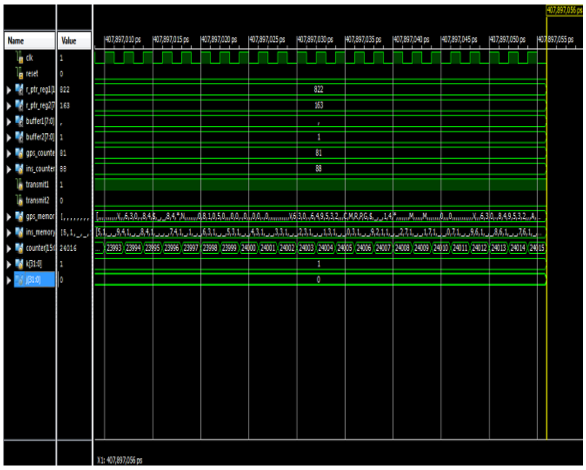

Fig 9:Simulation of Time Synchronization Block

Fig 10: Reception of GPS,INS Data

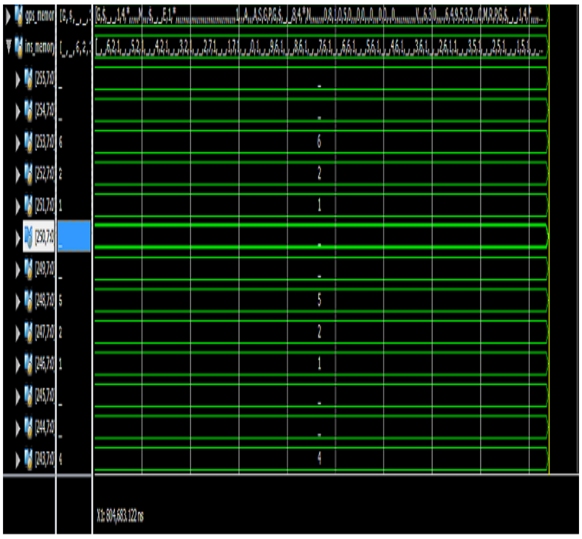

Fig 11: Stored INS Data

Fig 10 shows the synchronized data that is if the GPS or the INS counter value become modulus of eight the other will stop the reception of corresponding data until the other counter value also become modulus of eight. When the INS counter value become 160 that is modulus of eight then it stops the reception until GPS counter value also become modulus of eight by which the corresponding time delay can be calculated . This Synchronized data can be used for further processing that is for the integration of GPS with INS.

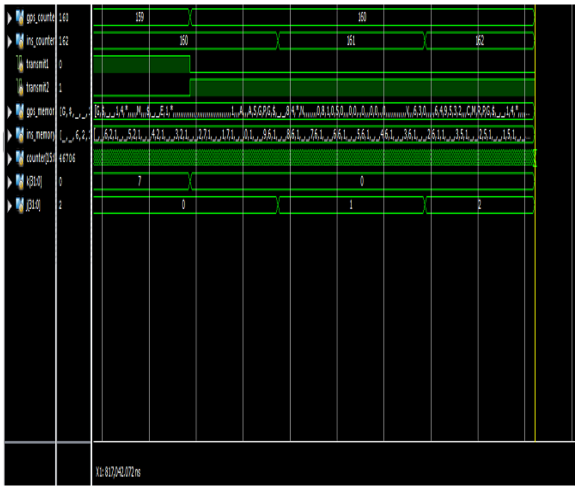

Fig 12: Synchronized Data Reception

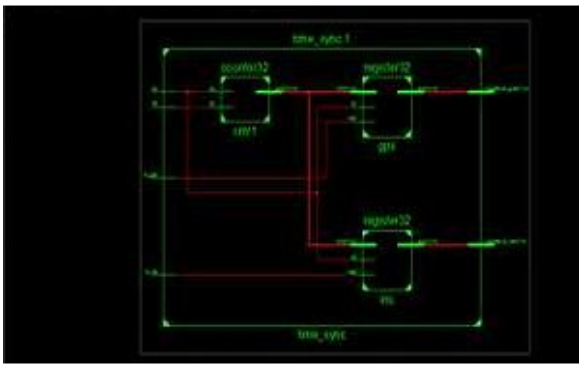

Fig 13: RTL Diagram

V. CONCLUSION

Time synchronizing is important for implementing the GPS/INS integrated systems. As different types of sensors are used, different time synchronization strategies can be implemented [1]. Limitations and advantages coexist in the primary time synchronization solutions. It can achieve high synchronization accuracy in certain situations where the solutions need to run at high cost of hardware resources which include either external control circuit or navigation computers.Aiming at their flaws, a new time synchronization mechanism is proposed in this paper. The new time synchronizer can process digital output of inertial sensors with low cost hardware.Although the time synchronizer device in this is designed for the integration of GPS and INS, the principles developed here are equally applicable for the cases in which additional navigation sensors are involved.

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