

Time synchronization of a Commercial Seismometer through IEEE-1588

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Abstract

Seismometers use a GPS signal for time synchronization and the seismic data are collected, time marked and stored. The precision of the time marks is a key parameter for the location and magnitude of an earthquake. Land seismometers are implemented with an internal GPS receiver where only an external antenna is needed for time synchronization. This paper presents the implementation of the time synchronization of a land seismometer through the IEEE-1588 protocol. Time synchronization tests have been carried out and results are presented.

Keywords: Seismometer, acquisition system, IEEE-1588, time synchronization, time error.

I. INTRODUCTION

The IEEE-1588 “Precision Clock Synchronization Protocol for Networked Measurement and Control Systems” [1] is a new standard widely used in industrial applications as robotics, sensor networks [2] and wireless applications [3]. The objective of this standard is to specify a protocol to synchronize independent clocks running on separate nodes of a distributed measurement and control system to a high degree of accuracy and precision. The clocks communicate with each other over a communication network. In its basic form, this protocol is intended to be administration free. The protocol generates a master slave relationship among the clocks in the system. Within a given subnet of a network, there will be a single master clock. All clocks ultimately derive their time from a clock known as the grandmaster clock.

The IEEE-1588 has not been used in seismic applications yet. In marine applications seismic sensors are deployed at cabled seafloor observatories [4] where GPS signal cannot be reached for time synchronization, IEEE-1588 can be used. Furthermore, in caves where there is no GPS coverage, seismic sensors can access time synchronization data through the Ethernet network by using IEEE-1588.

In this paper, the time synchronization of a land seismometer has been carried out using the IEEE-1588. The precision of the seismic data time marks allows the scientists to locate the earthquake epicenter coordinates as well as its magnitude.

II. SYSTEM IMPLEMENTATION

The seismic system used is a Trillium 120PA together with a Taurus acquisition system from Nanometrics Inc. Weighing only 7.2 kg and measuring only 21 cm in diameter, Trillium 120P/PA seismometers are three-component, very broadband, low-noise seismometers suitable for both portable and fixed applications. With an extended low frequency range useful out to beyond 1000 s, ability to resolve Peterson’s new low-noise model (NLNM) [5] down to a 100s period, low noise, and wide dynamic

range, these observatory-class seismometers are ideal for tele-seismic, regional, and local studies.

The Taurus Portable Seismograph is a compact, self-contained digitizer and data logger that combines exceptional performance with versatility and low power consumption. The Taurus can be used either as a stand-alone time-series data logger or as a component in a data acquisition network. Taurus incorporates a three-channel 24-bit Digitizer, GPS receiver and System Clock, removable data storage, and remote communication options. Taurus is configurable locally using the colour display screen and integrated browser or remotely using any web browser over a TCP/IP connection. The GPS antenna is connected to the Taurus digitizer where an internal GPS receiver takes care of the time synchronization. For our application, the Taurus internal GPS receiver is removed and the Taurus connector pin-out is modified in order to receive the timing data externally. In order to simulate the external GPS data, The LM3S9B96 microcontroller from Texas Instruments is used. The LM3S9B96 microcontroller internally implements the IEEE-1588 by hardware. It is in charge of sending time synchronization frames as well as PPS (Pulse Per Second) signal (trigger) to the Taurus. On the other hand the microcontroller board carries out a time synchronization with a grandmaster clock, in this case a PXI-6682 card from National Instruments. Luminary board and the grandmaster clock are connected through a LAN network. The GPS data and PPS trigger are sent from the microcontroller board to the Taurus digitizer via the serial port. Fig.1. shows a block diagram of the IEEE-1588 time synchronization system implemented.

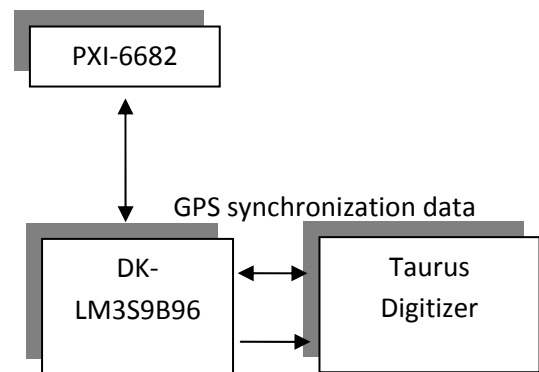


Fig. 1. IEEE-1588 time synchronization system

Software has been developed using the Code sourcery(Cprogramming)development environment and a Precision Time Protocol (PTP-V1) server. The timesynchronization flow chart is shown in Fig. 2. This software is charge of sending the necessary timing data to the Taurus.

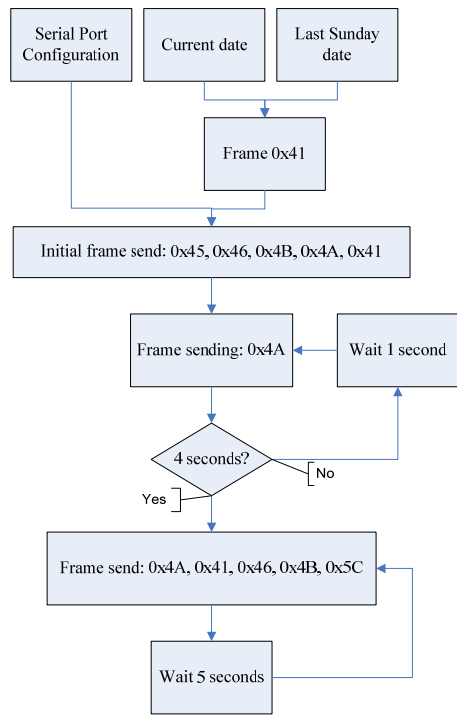


Fig. 2. Taurus time synchronization flow chart

III. TIME SYNCHRONIZATION TESTS AND RESULTS

To test the system operation, some tests have been carried out in order to calculate the IEEE-1588 time synchronization of the system implemented. In these tests we have used the synchronized PPS signal of the DK-LM3S9B96 as the input of the Taurus digitizer. A data acquisition is carried out with a 500Hz sampling rate and the stored data is studied to obtain the time synchronization error. As the synchronized PPS rising edges occur at 1s intervals, we can derive the error from the acquired data. As the sampling interval is low(2ms), it is not possible to sample the fast edges of the PPS. However, the acquired samples are interpolated and represented in a graph. Fig. 3. Shows the data acquired in this test.

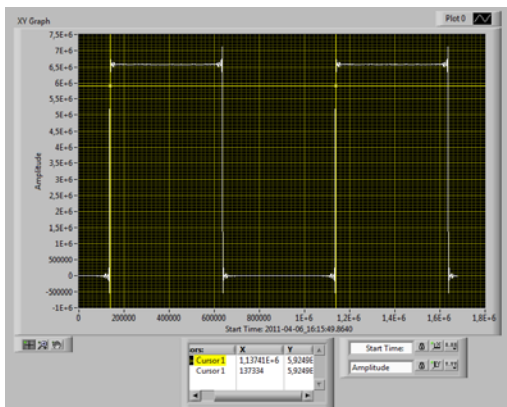


Fig. 3. Synchronized PPS signal acquired by Taurus.

In this test an error of about $76\mu\text{s}$ is observed. In order to find the delay in the acquisition, the first PPS generation time is compared to the first PPS acquired. The PPS generation time obtained from the PXI-6682 with a time resolution of a few nanoseconds. PXI-6682 indicates us that PPS generation start time is 2011-04-08_08:45:43.000000000. When this time is compared with our data retrieval, we observe that our first PPS rising edge finishes (90%) is just on 2011-04-08_08:45:43.000 (Fig. 4)

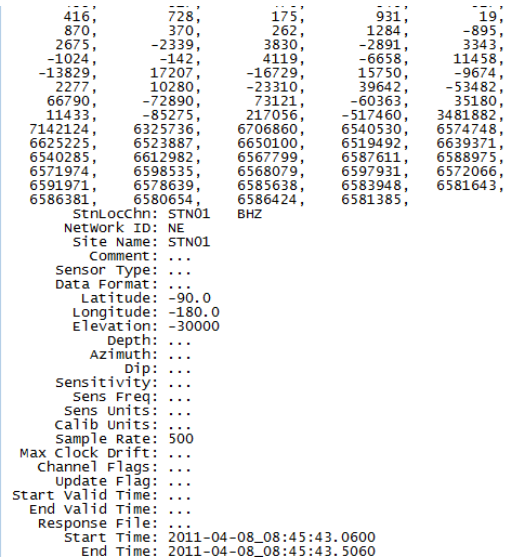


Fig. 4. Data acquired by the Taurus digitizer

However, as the sampling interval is 2ms and the data acquired is interpolated, we can only assure that the error is below 2ms. In order to increase the time measurement resolution the PPS signal generated by the DK-LM3S9B96 is used to trigger a burst from a signal generator. The signal generated is used as the Taurus input signal. The linear signal triggered by the PPS crosses 0V at every rising edge. This behavior can be seen in Fig. 5.

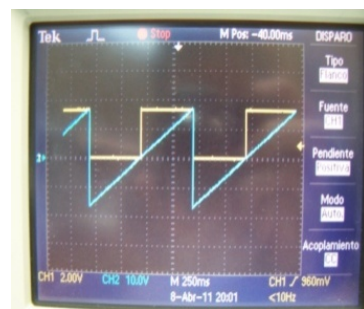


Fig. 5. Linear signal generated by a signal generator triggered by the PPS signal.

In yellow we can see the PPS trigger signal and in blue Burst signal generated by the signal generator. By decreasing the slope of the input signal at instants where the trigger signal (PPS) is generated, we can measure the time difference between zero crossings and ensure an improved error measurement. The generated signal is acquired by Taurus (Fig. 6.).

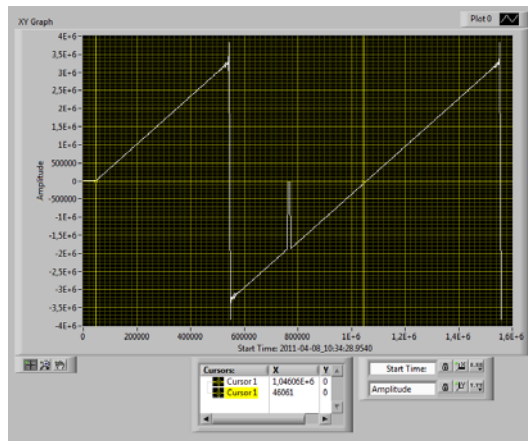


Fig. 6. Linear signal acquired by the Taurus digitizer.

We can observe an error in the second ascendant slope but it is caused by a software error when it reconstructs the signal based on ASCII data retrieval format. Fig. 6. shows that the start time of the first pulse is on 2011-04-08_10:34:29,000061 and but it should be on 2011-04-08_10:34:29,000000000 so we have an error of $61\mu\text{s}$.

IV. CONCLUSIONS

A time synchronization of a commercial seismometer is carried out by using the IEEE-1588 standard. This implementation is highly useful in applications where the GPS signal is not accessible. The IEEE-1588 can achieve synchronization errors below $1\mu\text{s}$. The tests carried out show the synchronization error is about $61\mu\text{s}$. This delay takes into account the acquisition and data processing software delay of the Taurus. In previous research, the delay between the grandmaster clock PPS and the PPS generated by DK-LM3S9B96 was measured to be about 50ns [6]. This means that the external IEEE-1588 GPS can provide synchronization trigger error of 50ns.

ACKNOWLEDGEMENTS

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