A Self-time-keeping Synchronization System Based on Timing Drift Fitting Algorithm

Yefeng Gao, Junwei Ren, Guangkun Guo, Ke Liu, Dong Hou*
School of Automation Engineering,
University of Electronic Science and Technology of China
Chengdu, China
*Email: houdong@uestc.edu.cn

***Abstract*—Time and frequency transfer is widely used in synchronization system, where the real-time transmission link is built between two synchronization sites. However, the real-time link is not allowed to use in some synchronization application. To solve this problem that transmission link is not always active, a self-time-keeping synchronization system is proposed in this paper. In our system, we design an algorithm to fit the time drift between GPS and a local rubidium clock over a period of time. Based on the fitting algorithm, we control the clock to achieve the time synchronization without GPS time signal. A 24-hour time synchronization experiment was carried out with the system, and the experimental result shows that the root-mean-square (RMS) time drift is lower than 5 ns in one day.**

***Keywords*—self-time-keeping; synchronization; time drift;**

I. Introduction

Time and frequency standard with high performance is one of the most important techniques of scientific research [1]. It also provides indispensable tool in various fields [2], for example navigation technologies, geodesic measurements, global communication networks, and high-speed data transmission channels. The performance of these application is based on high-precision time-frequency signals [3].

Using the remote high-performance time standards, time-synchronization is needed for local clock. With the development of science and technology, methods of short wave, long wave, microwave and TV have emerged to realize the transmission of standard time and frequency [4-11]. It is also common to use optical fiber, satellite communication and other means. Though it can get highly accurate time-synchronization with the methods, some problems can't be ignored. Almost all of methods used in time and frequency transfer depend on real-time transmission. Like the time-synchronization with short wave can't achieve without real-time remote time signal, when the electromagnetic waves for communication be disturbed, most methods for time-synchronization will fail. Fiber can avoid this problem, but laying fiber in advance can not be avoided which lead to big expenses. And the movement of device terminal is impossible. So, the methods of self-time-keeping is presented.

In this paper, we propose a method of self-time-keeping, and show its performance in an experiment.

II. Methods

Even though the accuracy of local atomic clock and decoding satellite signal is high, there is still a little frequency difference. The 1PPS signal is obtained by frequency division of the original 10MHz signal, and for the decrease of frequency, the time difference still exists, even increases. The frequency difference between signals is expressed as follows:

$$f_1 = f_2 + \Delta f \tag{1}$$

As we all know, phase is the integral of frequency in time. Therefore, the phase difference between two 1PPS signals has the following relationship:

$$\varphi_t = \int_0^t \Delta f \, dt + \varphi_0 \tag{2}$$

Among them, φ_t is the phase difference or time interval between two rising edges of signals at time t, φ_0 is the time interval at the initial time, and Δf is the frequency difference between the two signals. And Δf is affected by temperature, humidity, air pressure, vibration and other elements at the same time.

To verify the analysis above, we built an experimental setup which is demonstrated in Fig.1. With this setup, the time interval between the local free-running clock and satellite clock can be measured. The measurement of time interval in a day is shown in Fig.2. The time drift curve looks like as a line in large scale. However, the curve isn't a strict straight line and the

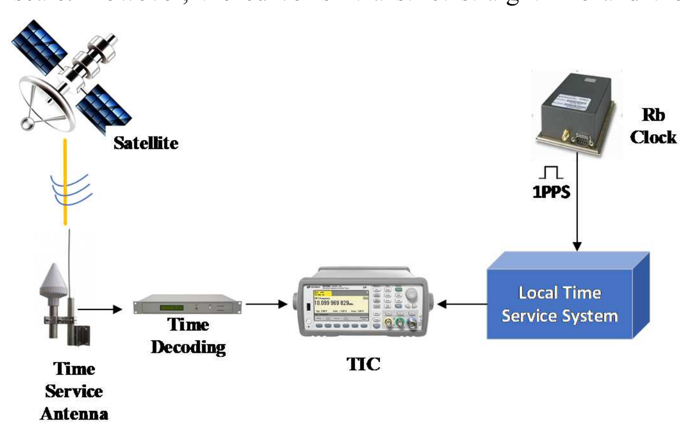

Fig. 1. The measurement setup between the local time and satellite time

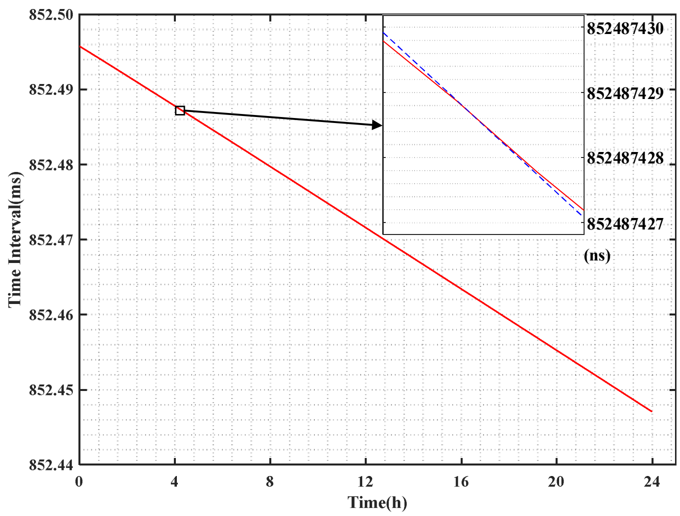

Fig. 2. Time interval measurement result

slope rate changes significantly many times. (The dash line is a straight line connecting two points in the data.) So, the theory is basically consistent with the experiment.

Therefore, as long as the time interval variation law between the two signals which can lead to the inferred value of Δf is found, and then the time interval between the two signals at the initial time φ_0 is obtained, the predictive value of subsequent phase difference can be calculated. Then the local atomic clock 1PPS signal is compensated for delay according to the predictive value to the output with high synchronization level. The common method of curve fitting is least square method, which is often used in scientific research and engineering technology to process experimental data and determine the relationship between variables [12].

If there is a set of experimental data(x_i, y_i) $i = 1, 2, 3, \cdots, n$, and let its fitting function be following:

$$h_\theta(x_1, x_2, \cdots, x_n) = \theta_0 + \theta_1 x_1 + \cdots + \theta_n x_n \quad (3)$$

And it also can be expressed on matrix expression as follows:

$$h_\theta(\boldsymbol{X}) = \boldsymbol{X\theta} \quad (4)$$

$\boldsymbol{X}$ is an m × n matrix, $\boldsymbol{\theta}$ is an n × 1 vector, m represents the number of samples, and n represents the characteristic number of samples.

And its loss function can be expressed by:

$$J(\boldsymbol{\theta}) = \frac{1}{2}(\boldsymbol{X\theta} - \boldsymbol{Y})^T(\boldsymbol{X\theta} - \boldsymbol{Y}) \quad (5)$$

$\boldsymbol{Y}$ is the output vector of the sample, and the dimension is n × 1. According to the principle of the least square method, $J(\boldsymbol{\theta})$ need to be minimum. So, we need to derive the loss function from $\boldsymbol{\theta}$ and let it be zero. The result is following:

$$\frac{\partial}{\partial \boldsymbol{\theta}} J(\boldsymbol{\theta}) = \boldsymbol{X}^T(\boldsymbol{X\theta} - \boldsymbol{Y}) = 0 \quad (6)$$

And after sorting the above equations, we can get:

$$\boldsymbol{\theta} = (\boldsymbol{X}^T\boldsymbol{X})^{-1}\boldsymbol{X}^T\boldsymbol{Y} \quad (7)$$

Solving simultaneous equations, we can get the value of coefficient matrix $\boldsymbol{\theta}$ and the fitting function.

If there only need a simple linear regression, we can use the function following:

$$\boldsymbol{\theta} = \frac{\sum(x_i - \overline{x})\sum(y_i - \overline{y})}{\sum(x_i - \overline{x})^2} \quad (8)$$

If Δf is a constant, we can get a line fitting by least square method easily. But Δf is affected by many elements related to time, which may cause the changes of slope rate in Fig.2 and the traditional least square method for linear fitting is not reliable.

Therefore, we carry out the least square method for linear fitting in time according to the possible conditions. The diagram of fitting in four sections is shown in Fig.3.

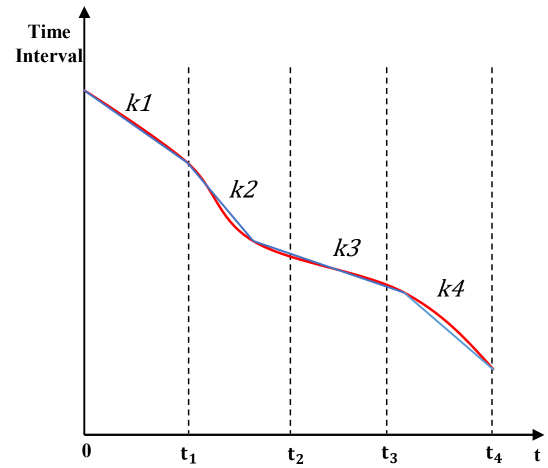

Fig.3. Fitting in four sections

φ_0, φ_1, φ_2 and φ_3 are the time interval for 0, t_1, t_2 and t_3, k_1, k_2, k_3 and k_4 are the slopes of the straight line of the four fitting segments, which are fitted by least square method at the right time. As a result, the equations of fitting curve are followed.

$$0 \sim t_1: \ \varphi_t = \varphi_0 + k_1 t \quad (9)$$

$$t_1 \sim t_2: \ \varphi_t = \varphi_1 + k_2 t \quad (10)$$

$$t_2 \sim t_3: \ \varphi_t = \varphi_2 + k_3 t \quad (11)$$

$$t_3 \sim t_4: \ \varphi_t = \varphi_3 + k_4 t \quad (12)$$

After that, the fitted curve will take one day as a cycle, and these change trends will be reused to accumulate for time drift compensation.

III. Experiment and Result

For the high accuracy and simple operation of time drift compensation, we choose FPGA with an on-chip 500MHz

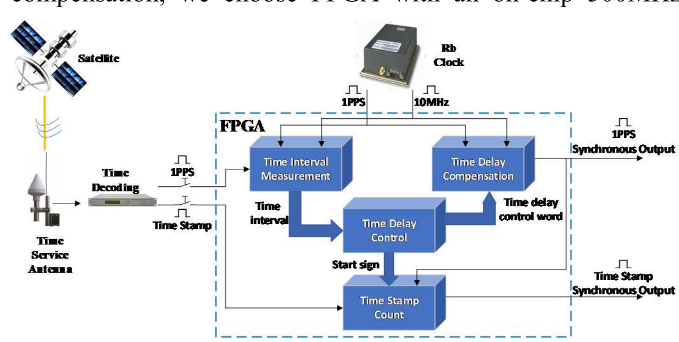

Fig.4. Bock diagram of autonomous punctuality system based on time delay control

clock based on a phase-locked loop to realize the adjustment accuracy of 2ns.

The bock diagram of autonomous punctuality system based on time delay control is demonstrated in Fig.4.

The 1PPS signal decoded by the satellite signal and the 1PPS signal generated by the local atomic clock are input to the FPGA at the same time, the time interval measurement starts, and the data of time interval is transmitted to the module of time delay control. The measurement time length can be set before measurement. Because the method is mainly aimed at maintaining the highly accuracy in a short time, the measurement time is generally one day by default.

After the time of data transmission arrived setting time, the FPGA fits the received data and get the time delay control words corresponding.

After data fitted by FPGA, the data will be transmitted to the module of drift compensation. The FPGA will perform the last time interval measurement and keep the value, which is the initial value of the time interval between the two signals in the register. At the same time, the module of time stamp count needs record the value of time stamp.

And then, the signal input of satellite timing is no longer necessary. The time delay control word and initial time interval are used to correct the output continuously, which carry out synchronization. And FPGA also updates and output the time stamp with the counter inside at the rising edge of 1PPS signal generated by synchronization.

The time drift of synchronous output shown in Fig.5, which has an rms drift of 5 ns and a peak-to-peak time drift of 25 ns in a day. It was caused by the difference between the time delay control word and the real slope. As the value of difference changed, the slope of synchronous output will increase or decrease. When the value of difference for positive or negative reverses, the upward or downward trend of the difference between synchronous output and real-time signal input of satellite timing will also be opposite.

The variation is the concentrated embodiment of the influence of Gaussian noise and external temperature, humidity and others on the clock, which are the deeper reasons. What's more, we can see that the time deviation of input can be more

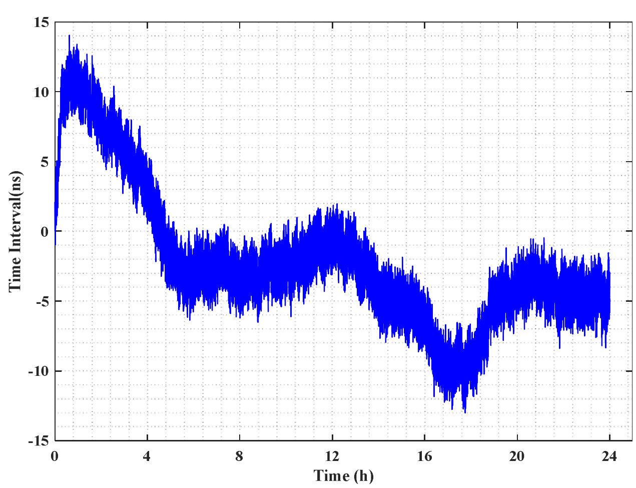

Fig.5. Time interval of synchronous output in one day

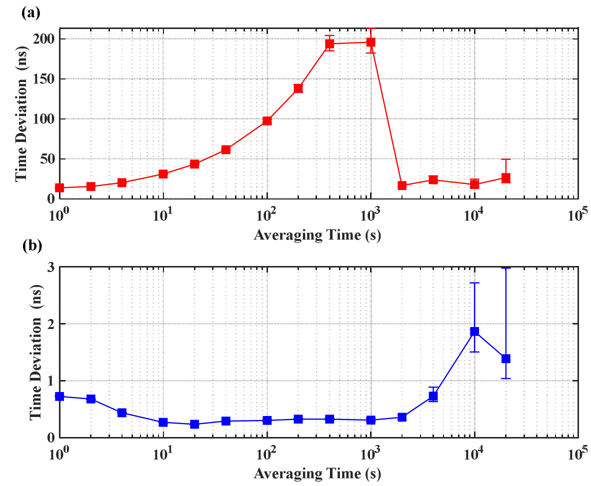

Fig.6.a, Time deviation of the input local atomic clock are more than 10ns all the time. b, Time deviation of the synchronous output are less than 3ns all the time.

than 200 ns as shown in Fig. 6(a), and the time deviation of synchronous output is less than 0.8 ns at 1-s and less than 3 ns all the time after compensation, which is shown in Fig.6(b).

IV. CONCLUSIONS AND FUTURE WORK

By breaking the limitations of real-time transmission link in synchronization, we propose the method of self-time-keeping. In a one-day experiment, the maximum of time difference is lower than 15ns, and the measured RMS fluctuation of the time deference is about 5 ns a day.

Although the RMS timing drift of the self-time-keeping synchronization system has reached ten-nanoseconds-level, it can be further improved. The experiment was carried out under the assumption that the meteorological conditions of the two days were completely consistent. But we all know it can't be achieved. Temperature is the most important factor in all the factors, which can affect the synchronous output. We decide add the module of temperature measurement in next step. And the time delay control words will be measured at the corresponding temperature before experiment, which can be called at the corresponding temperature at work.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (No. 61871084), by the Applied Basic Research Programs of Sichuan Province (No. 2019YJ0200), and by the Equipment Advance Research Field Foundation (No. 80902010601), China.

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