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Time Syntonization and Frequency Stabilizing Using GPS Carrier Phase with Extension Controller

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Abstract: - This study discusses time syntonization and frequency stability calibration using GPS carrier phase measurements. Thus far most papers on this subject discussed using two GPS receiver measurements, and performing frequency stabilizing and vehicle positioning with the double differences. This paper proposes using a dual frequency GPS receiver and a novel extension controller neural network algorithm that can achieve the frequency stabilizing and coordinate positioning. The oscillation frequency of the rubidium atom clock is selected first as the satellite atom clock oscillation frequency as the criterion for adjusting the GPS receiver oscillator' s frequency. The receiver's oscillation frequency is synchronized with the reference atomic clock oscillation frequency using the designed extension controller and extension neural network. To finish the frequency stabilizing and time syntonization, the time can be calibrated and the position precision on the vehicle improved. The position precision can be improved from about 3.5 meters to about 1.5 meters using the extension controller. The time error is improved from about 4.85×10^{-7} seconds to about 2.85×10^{-8} seconds. Using the extension neural network to verify the position precision allows improvement from about 3.5 meters to about 1.3 meters. The time error is improved from about 4.85×10^{-7} seconds to about 2.8×10^{-8} seconds. The system was verified experimentally as satisfying the exactness, feasibility and robustness of the initial concept.

Key-Words: - GPS, Carrier Phase, Extension Controller, Extension Neural Network

1 Introduction

Wireless communication flourishes in high-speed communications, navigation, power systems, data acquisition instrumentation and in numerous other applications. Frequency usage and bandwidth requirements have increased. The extreme accuracy of navigation data is not influenced by time, place, or weather except for shielding the line of sight between the satellites and the navigator. There are global, all-weather, continuous, high accuracy three-dimensional navigation systems with encrypted security. GPS is a high- accuracy navigation system for all vehicles. However, GPS receiver errors reduce the precision of GPS positioning. Transmission errors due to ionospheric and tropospheric activity can cause delay. Because the satellites possess a high-accuracy atom clock and produce the L1 and L2 carrier phase signals, the navigators can access reasonably accurate navigation data through the GPS system in the world. The internal of each GPS receiver produces a pulse per second when the L1 and L2 carrier phase signals have been received. Thus, the time between the master station and slave station receivers can be adjusted simultaneously to improve the navigator positioning accuracy. [1][2][3]

Hence, a higher performance time and frequency techniques are expected if the GPS carrier phases are considered. The frequency stability of the GPS receiver is the most important factor for positioning. The cycle slip and multipath effects are not critical factors that influence the GPS solution. A new frequency synchronization method is proposed in this paper that uses the GPS carrier phase measurement is proposed in this paper. The idea is realized into a carrier phase frequency synchronization system. [4]

The goal of the system is to steer the receiver clock such that its frequency will follow the frequency of a given primary clock. The GPS receiver dual carrier phase measurement and the oscillation frequency of the master clock are used to achieve the frequency stabilizing and time synchronization. The clock error between satellites and receivers can be estimated through the GPS carrier phase observation. A master atom clock replaces the satellite atom clock, to estimate frequency error between the receiver and master atom clock. The extension control law and extension neural network are employed to implement the controllers in this system. The oscillation frequency of the GPS receiver is synchronized with the master atom clock frequency. The position precision can be improved by reducing the frequency error between the receiver and master atom clock. [5][6]

This paper is organized as follows:

1) Section 2 describes GPS carrier phase observation.
2) Section 3 derives the extension controller.
3) Section 4 depicts the extension neural network.
4) Section 5 discusses the experimental results.
5) Section 6 gives our conclusions.

2 GPS Carrier Phase Observation

The phase difference between the GPS satellite's carrier phase and the reference frequency of its GPS receiver oscillator can be expressed as follows: [7] [8]

$$\Phi_R^S = \phi^S(t) - \phi_R(T)$$

Φ_R^S: Carrier phase of the R-th receiver station to observe the S-th satellite.

$\phi^S(t)$: Carrier phase of the S-th satellite time transmission in t epoch.

$\phi_R(T)$: The phase of R-th receiver produced at T epoch

If we consider the phase relationship between the GPS carrier phase frequency and the oscillator, the above equation can be rearranged using

$$\phi_R(T) = \phi^S(t) + f \cdot (T - t)$$

The propagation delay errors contain the ionosphere delay effect, the troposphere error and the uncertain error. It can be formulated as follows:

$$\Phi_R^S = \rho_R^S + c(dt^S - dT_R) + \lambda N_R^S - d_{ion}^S + d_{trop}^S + \varepsilon_R^S$$

ρ_R^S : The distance between the S-th satellite and the R-th receiver

dt^S : Clock bias of the S-th satellite

dT_R : The clock difference between the GPS time and the R-th receiver clock.

N_R^S: Initial carrier phase integer ambiguity

λ : The GPS L1 carrier phase wavelength

ε_R^S : Uncertain error amount

c : Speed of light

d_{ion}^S : Ionospheric delay

d_{trop}^S : Tropospheric delay

The wide lane method is used to dispel the ionospheric and tropospheric delay errors, and formulate a new relationship with the carrier phase. This is expressed as follows:

$$\begin{aligned}\Phi_W &= \Phi_{L1} - \Phi_{L2} \\ &= \frac{f_{L1} - f_{L2}}{c}\rho_R^S + (f_{L1} - f_{L2})\Delta\delta \\ &\quad + N_{L1} - N_{L2} - \frac{\alpha}{c}\left(\frac{1}{f_{L1}} - \frac{1}{f_{L2}}\right)\end{aligned}$$

$\Delta\delta$: Time difference between the satellite and receiver

α : Total ions number in the path

f_{L1} : The frequency of L1 carrier phase

f_{L1} : The frequency of L2 carrier phase

N_{L1}: The integer ambiguity of L1

N_{L2} : The integer ambiguity of L2

3 Extension Controller

Sometimes the engineering process is not able to setup a mathematical model that can accurately describe and control an integrated plant system. In other words, the traditional controller is not able to obtain the satisfactory results. Utilizing the extension controller to control a plant, can often obtain unexpected terrific results. The listed references used the PI controller, fuzzy controller and extension controller and the results were compared. The extension controller was verified to produce better performance than the traditional PI controller, and is similar to the fuzzy controller via the experimental results [9]. Using a GPS receiver to carry out frequency stability and time syntonization will influence the precision due to an unstable oscillation frequency in the GPS receiver, clock bias and integer ambiguity and so on. This paper proposes using the extension set and element model concept to design the extension controller, as shown in Figure 1. [10][11]

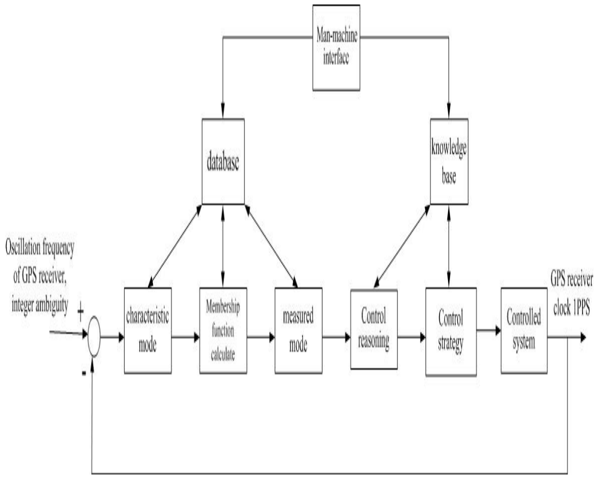

Figure 1. Extension Control System Functional Block Diagram

The basic extension controller concept is to transfer the signal point of view to deal with the control problem. Using a relational function of the control output signal as the control input correction let the control signal transfer to a reasonable range.

First, obtain the classical domains in the control output plane:

$$R_G = \left(G, C_f, V_f\right) = \begin{bmatrix} G & C_{f1} & V_{f1} \\ & C_{f2} & V_{f2} \\ & \dots & \dots \\ & C_{fn} & V_{fn} \end{bmatrix}$$

$$= \begin{bmatrix} G & C_{f1} & < a_{01}, b_{01} > \\ & C_{f2} & < a_{02}, b_{02} > \\ & \dots & < \dots > \\ & C_{fn} & < a_{0n}, b_{0n} > \end{bmatrix}$$

G is the GPS receiver; G_f is the control characteristic of the GPS receiver. Where C_{f1}, C_{f2}, …, C_{fn} is to express *n* different characteristics such as the oscillation frequency of GPS receiver, integer ambiguity of G. And V_{f1}, V_{f2}, …, V_{fn} respectively is G about the range of C_{f1}, C_{f2}, …, C_{fn} value, namely classical domains.

then $V_{fi} = < a_{0n}, b_{0n} >$ （$i = 1, 2, \dots, n$）

The extensional domain in the control output plane is expressed as:

$$R_S = \left(G_o, C_{of}, V_{of}\right) = \begin{bmatrix} G_o & C_{of1} & V_{of1} \\ & C_{of2} & V_{of2} \\ & \dots & \dots \\ & C_{ofn} & V_{ofn} \end{bmatrix}$$

$$= \begin{bmatrix} G_o & C_{of1} & < a_{p1}, b_{p1} > \\ & C_{of2} & < a_{p2}, b_{p2} > \\ & \dots & < \dots > \\ & C_{ofn} & < a_{pn}, b_{pn} > \end{bmatrix}$$

G_o is the GPS receiver. G_{of} is the control characteristic of the GPS receiver. Where C_{of1}, C_{of2}, …, C_{ofn} is *n* different characteristics such as the GPS receiver oscillation frequency, integer ambiguity of G_o. And V_{of1}, V_{of2}, …, V_{ofn} respectively is G_o about the range of C_{of1}, C_{of2}, …, C_{ofn} value, namely extensional domains.

then $V_{ofi} = < a_{pn}, b_{pn} >$ （$i = 1, 2, \dots, n$）

According to the distance definition of the classical and extensional domains, determines a relational function computation.

$$\rho\left(v_i, V_{fi}\right) = \left| v_i - \frac{a_{0i} + b_{0i}}{2} \right| - \frac{b_{0i} - a_{0i}}{2}$$

$$\rho\left(v_i, V_{ofi}\right) = \left| v_i - \frac{a_{pi} + b_{pi}}{2} \right| - \frac{b_{pi} - a_{pi}}{2}$$

Calculate the relational function:

$$K\left(v_i\right) = \begin{cases} \dfrac{-\rho\left(v_i, V_{fi}\right)}{\left|V_{fi}\right|} & , v_i \in V_{fi} \\ \dfrac{\rho\left(v_i, V_{fi}\right)}{\rho\left(v_i, V_{ofi}\right) - \rho\left(v_i, V_{fi}\right)} & , v_i \notin V_{fi} \end{cases}$$

Judge the relational function to determine the control output.

$$\begin{cases} R_u(t) = R_u(t-1), \quad K(v_i) \geq 0 \\ R_u(t) = f(R_y, K(v_i)), \quad -1 \leq K(v_i) < 0 \\ R_u(t) = R_{u\max}, \quad K(v_i) \leq -1 \end{cases}$$

1. $K\left(v_i\right) \geq 0$, the output does not change and maintains the last output.

2. $-1 \leq K\left(v_i\right) < 0$, according to the element model algorithm, resolve the outputs element.

3. $K\left(v_i\right) < -1$, is the output element of the biggest control amount.

4 Extension Neural Network Algorithm

The extension neural network is a solution method that combines the extension theory with a neural network. The matter element model of the extension theory is combined with the neural network as the learning mechanism. By adjusting the receiver oscillation frequency, it is synchronized to the oscillation frequency of the master atomic clock.

Figure 2 shows the structure of the extension neural network. It is comprised of an input layer and output layer. The neuron of the input layer is made of the control plant characteristics. The output layer neuron is the control result. After adjusting the weighting factor, learning rate, and the extension distance, an ideal control result will be obtained. [12][13]

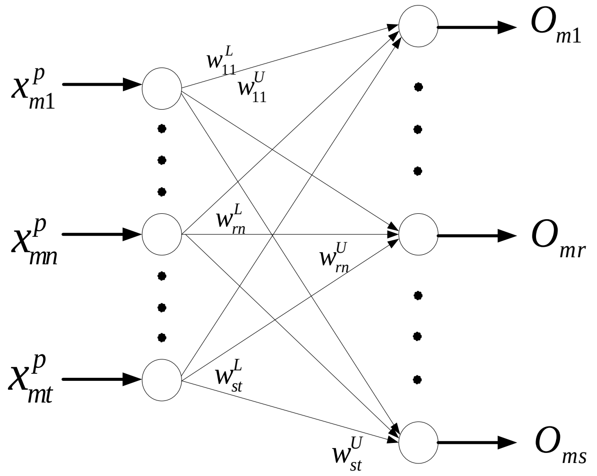

Figure 2. The structure of the extension neural network

The extension neural network algorithm procedure is as follows:

Step 1: Utilize extension matter element model to determine the weighting factor.

$$R_r = \left(N_r \quad c \quad V_r\right) = \begin{bmatrix} N_r & c_1 & V_{r1} \\ & c_2 & V_{r2} \\ & \vdots & \vdots \\ & c_t & V_{rt} \end{bmatrix}$$

N_r is the GPS receiver; c is the GPS receiver control characteristics of such as oscillation frequency, integer ambiguity, and so on. And $V_{rn} = \left\langle w^L_{rn}, w^U_{rn} \right\rangle$ expresses a region of the characteristics (weighting interval). The method for determining this region is obtained in the training set:

$$w^L_{rn} = \min\left\{x^r_{mn}\right\}$$

$$w_{rn}^{U} = \max\left\{x_{mn}^{r}\right\}$$

Step 2: Calculate the center of the weighting interval z_{rn}.

$$Z_r = \left\{z_{r1}, z_{r2}, \ldots, z_{rt}\right\}$$

$$z_{rn} = (w_{rn}^{L} + w_{rn}^{U})/2$$

Step 3: Calculate the extension distance.

$$ED_G = \sum_{n=I}^{t}\left[\frac{\left|x_{mn}^{P} - z_{rn}\right| - (w_{rn}^{U} - w_{rn}^{L})/2}{\left|(w_{rn}^{U} - w_{rn}^{L})/2\right|} + I\right]$$

Step 4: Define the extension distance of the atom clock oscillation frequency ED_S. Determine whether the extension distance of the controlled receiver ED_G is equal to ED_S or not. If $ED_S = ED_G$, then maintain the original output. If it is not the same then go to Step 5.

Step 5: Readjust the center of the weighting interval.

(1) $z_{pn}^{new} = z_{pn}^{old} + \eta(x_{mn}^{p(old)} - z_{pn}^{old})$

$$z_{pn}^{new} = z_{pn}^{old} - \eta(x_{mn}^{p(old)} - z_{pn}^{old})$$

(2) Adjust the weighting factor interval.

$$\begin{cases} w_{pn}^{L(new)} = w_{pn}^{L(old)} + \eta(x_{mn}^{p(old)} - z_{pn}^{old}) \\ w_{pn}^{U(new)} = w_{pn}^{U(old)} + \eta(x_{mn}^{p(old)} - z_{pn}^{old}) \end{cases}$$

$$\begin{cases} w_{pn}^{L(new)} = w_{pn}^{L(old)} - \eta(x_{mn}^{p(old)} - z_{pn}^{old}) \\ w_{pn}^{U(new)} = w_{pn}^{U(old)} - \eta(x_{mn}^{p(old)} - z_{pn}^{old}) \end{cases}$$

(3) Let $ED_S = ED_G$, O_{ms} is the result of the last output.

$$O_{ms} = z_{pn}^{new} + \eta(x_{mn}^{p(old)} - z_{pn}^{new})$$

5 Experimental Results

Accurate single point positioning is generally performed using a pair of dual-frequency GPS receivers. The ionospheric and tropospheric delay transmission errors can be dispelled via the GPS carrier phase observation and pair of GPS receivers to improve the position precision. However, if there is no oscillation frequency syntonization between the GPS receiver and satellite clock, the position precision will be reduced. Therefore, the extension controller and extension neural network are used to adjust the receiver oscillation frequency to synchronize the satellite oscillation frequency.

Figure 3 shows the structure of the experimental system. The oscillation frequency of the atomic clock is used to reduce the bias between the receiver and the atom clock frequency. The proposed approach can more accurately resolve the integer ambiguity, clock bias and wide lane carrier phase. Enhancing the accuracy of these parameters allows the vehicle position to be estimated more precisely.

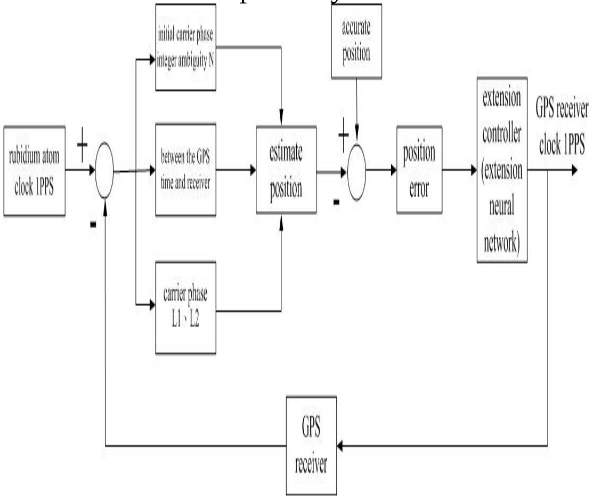

Figure 3. System Functional Block Diagram

Figure 4 shows the navigator's position error using GPS receiver observation. Using GPS ephemeredes and carrier phase measurements, the time errors between the GPS receiver and satellite can be estimated, as shown in Figure 5. Position precision is analyzed about 3.5 meters before using the extension controller. The time error is about 4.85×10^{-7} seconds.

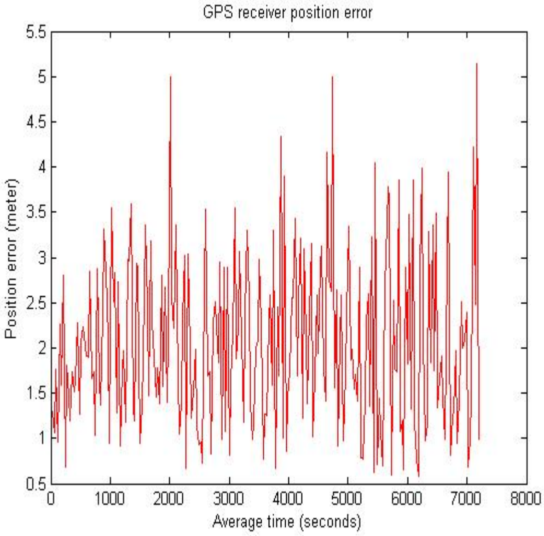

Figure 4. Receiver position error without using extension controller.

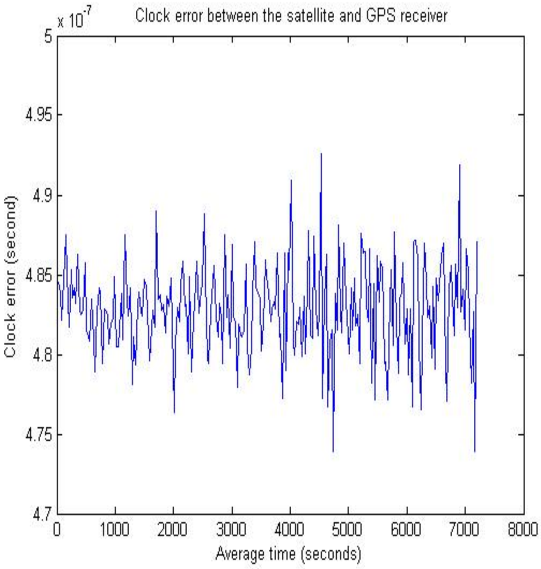

Figure 5. Time difference between GPS receiver and satellite without using extension controller.

Utilizing the extension theory to design the extension controller, the relational function is defined via adjusting the GPS receiver oscillation frequency to synchronize with the atomic clock oscillation frequency. Position precision can be improved from 3.5 meters to 1.5 meters after using the extension controller, as shown in Figure 6. The time error is improved from 4.85×10^{-7} seconds to 2.85×10^{-8} seconds after using the extension controller. It is obvious that the accuracy is improved by about 17 times, as shown in Figure 7.

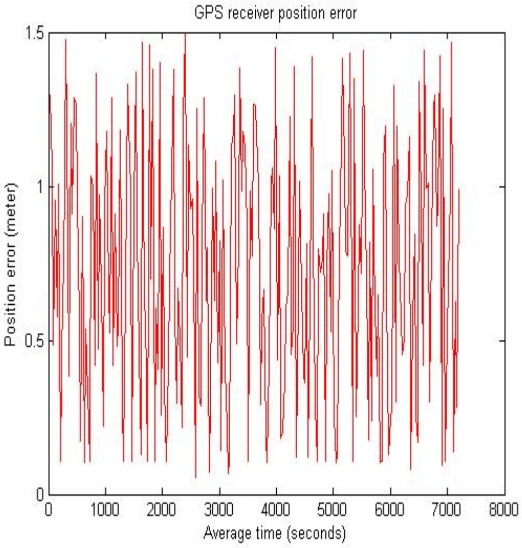

Figure 6. The position error using extension controller.

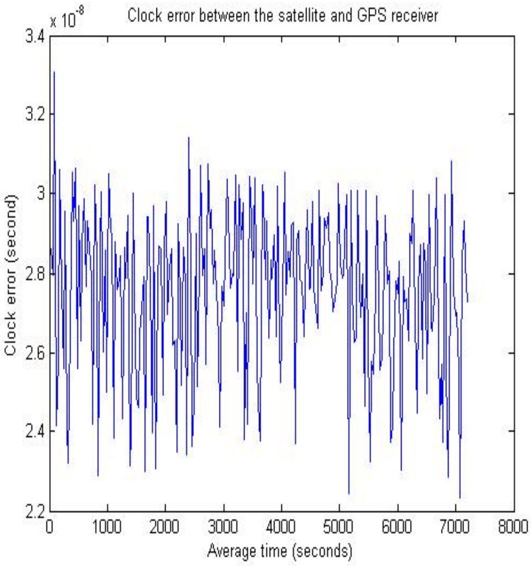

Figure 7. Time difference between GPS receiver and satellite using extension controller.

The neural network extension distance idea is used in cooperation with adjusting the weighting factor of the neural network to synchronize the receiver oscillation frequency with the oscillation frequency of the reference atomic clock. Position precision can be improved from 3.5 meters to 1.4 meters after using the extension neural network, as shown in Figure 8. The time error is improved from 4.85×10^{-7} seconds to 3×10^{-8} seconds after using the extension neural network. The accuracy is improved by about 16 times, as shown in Figure 9.

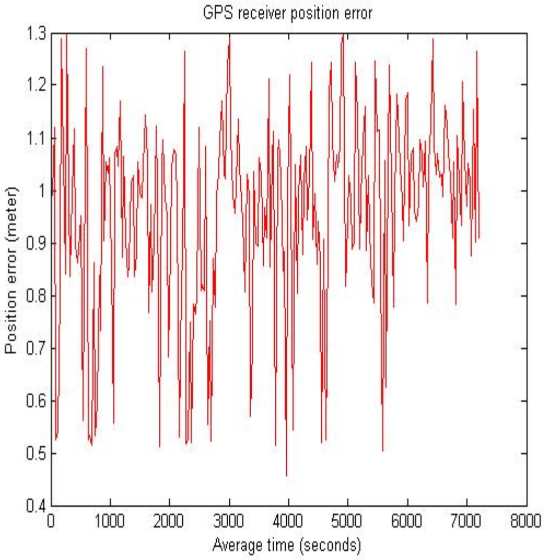

Figure 8. The position error using extension neural network.

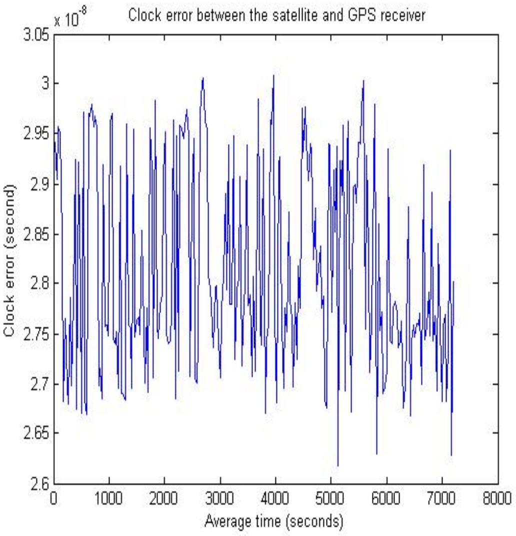

Figure 9. Time difference between GPS receiver and satellite by using extension neural network.

6 Conclusions

This paper proposed using GPS carrier phase measurements to perform frequency stability and time calibration. Originally, position precision was not high and time error was great. Using an extension controller and extension neural network to adjust GPS receiver oscillation frequency will enhance the position precision and frequency stability.

The advantage of the extension controller is that it produces an extension element model for any required control system. The extension controller algorithm estimates the relational function among the oscillation frequency stability, time syntonization and integer ambiguity, then combines the default value of the relational function. The control targets are controlled one at a time, until satisfactory system control is obtained. The experiment results show that the time error is improved from 4.85×10^{-7} seconds to 2.85×10^{-8} seconds using the extension controller. The advantage of the proposed approach is the combined neural network learning mechanism and extension theory element model. The factor that most influences positioning accuracy is the oscillation frequency stability of the GPS receiver, the time syntonization, and integer ambiguity. The relational extension distance and weighting factor adjustment are merged to adjust non-ideal value into an ideal interval fast and efficiently. The entire system performs frequency stability and time syntonization to obtain the optimum control result. The time error is improved to about 3×10^{-8} seconds after using the extension neural network. Then the position precision is greatly promoted.

In the future, we can use the cesium atom clock with higher precision as the foundation for adjusting the receiver oscillation frequency. At the same time, the cesium clock frequency can dispel the multipath effects and estimate the cycle slip error to better improve vehicle position precision. Through wired or wireless transmissions, the proposed method gives all remote stations accurate analysis data. And then the frequency of remote GPS receivers can be syntonized using the extension neural network algorithm. Figure 10 shows an overview of the entire system to achieve frequency stability and time syntonization.

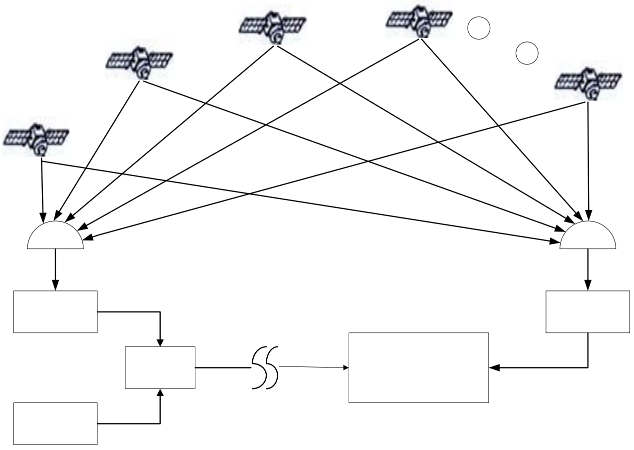

Figure 10. Systematic block diagram of the frequency control process using carrier phase.

Acknowledgements

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