Advance Journal of Food Science and Technology 10(9): 652-657, 2016
DOI: 10.19026/ajfst.10.2211
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: May 5, 2015 Accepted: June 22, 2015 Published: March 25, 2016

Research Article

A New Food Transportation Tracking Method Based on Optimal Loop Gain

[1, 2]Yangbin Liu, [1]Ying Xu, [1]Zhili He, [1, 2]Maoshu Zeng and [1]Hong Yuan
[1]Academy of Opto-Electronics, Chinese Academy of Sciences, Beijing 100094, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: In the traditional food transportation tracking loop, the loop gain is generally constant. In order to release the limitation, the adjustment on the optimal loop bandwidth can be applied to achieve high precision food transportation tracking. Aiming at shortening the lock-time of traditional algorithm, this study designed an optimal loop gain algorithm for food transportation tracking loop. By analyzing the loop transient response, the optimal loop gain is designed based on the least lock-time criteria. Since it is unable directly to obtain the numerical solution of the loop gain, a modeling method is developed based on piecewise cubic Hermite interpolation polynomial, in order to achieve the optimal loop gain design in loop under acceptable frequency error. Simulation results show that the proposed algorithm can speed up the loop lock-time. Compared with the constant-gain loop, when the frequency error is 30 Hz, the lock-time of the proposed optimal gain loop is improved at least 46.7%.

Keywords: Food transportation, hermite interpolation, the optimal loop

INTRODUCTION

In GNSS receiver, food transportation tracking loop, one of the key satellite navigation receiver techniques, is adopted to achieve stable food transportation tracking of received signal. In the conventional receiver food transportation tracking loops, to realize high-accuracy food transportation tracking, optimal bandwidth (Li and Yang, 2012; Bi *et al*., 2013) can be set according to dynamics and noise error (Razavi *et al*., 2008), with loop gain fixed. However, conventional food transportation tracking algorithm requires longer locking time, which may result in phase cycle slips, or even losing lock in some severe conditions. One efficient method is to expand loop bandwidth, cutting down loop locking time. Nevertheless, it will increase system thermal noise, which degrades food transportation tracking accuracy (Wu *et al*., 2011; Jie *et al*., 2010).

Ji *et al*. (2013) models and analyzes several food transportation tracking loop error sources and puts forward a design of adjusting methods for optimal loop bandwidth, which improve loop food transportation tracking accuracy and anti-interference with a longer locking time. Tang *et al*. (2007) proposes a method that outputs of frequency-discriminator and phase-discriminator are processed by means of ambiguity logics, which makes loop track navigation signal dynamics automatically, though no specific standards, can be determined by output domain determining strategy. Gao *et al*. (2011) suggests an optimum loop scheme of applying PID to include differentiation to diminish frequency errors, which improves loop dynamics and shortens locking time. Zhang *et al*. (2012) analyzes Phase-Lock Loop (PLL) adjustments, establishes a mathematic control model for gain adjustment according to frequency error information from frequency-discriminating output and realizes loop gain automation, shortening locking time, which, however, still remains future theoretical reasoning.

Through researches on PLL system functions, the paper shows that locking time of food transportation tracking loop can be changed by loop gain, thereby bringing up a food transportation tracking algorithm based on optimal gain. The design analyzes loop transient responses, then derives optimal gain algorithm and founds a fragmented there-ordered Hermite interpolation model.

MATERIALS AND METHODS

Gain-adjustable food transportation tracking loop: In satellite navigation receiver baseband signal process, food transportation tracking loop is usually designed as Costas loop, consisting of multiplier, coherent integrator, phase-discriminator, loop filter, Voltage-Controlled Oscillator (VCO) etc., wherein two-quadrant anti-tangent phase-discriminator. The proposed gain-adjustable food transportation tracking loop cascades a proportional gain module, which adjusts gain in terms of frequency error information from frequency-discriminating output. Figure 1 shows the loop system block diagram.

Corresponding Author: Yangbin Liu, Academy of Opto-Electronics, Chinese Academy of Sciences, Beijing 100094, China

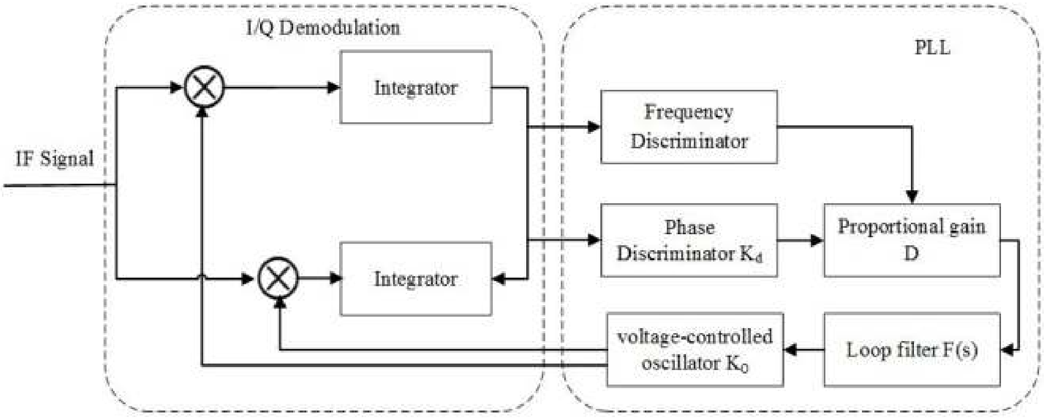


Fig. 1: Block diagram of adjustable gain food transportation tracking loop

Food transportation tracking loop system function: In Fig. 1, the PLL can be modeled as system function below:

$$H(s) = \frac{\theta_2(s)}{\theta_1(s)} = \frac{KF(s)D}{s + KF(s)D} \tag{1}$$

In it, θ_1 (s) and θ_2 (s) denote PLL input and feedback phase respectively, K is defined as $K = K_d K_0$, where K_d and K_0 denote phase-discriminator and VCO gain and D denotes loop proportional gain. Loop filter is one-ordered ideal integrating filter, the expression F (s) is showed below:

$$F(s) = \frac{\tau_2 s + 1}{\tau_1 s} \tag{2}$$

Substituting into Eq. (1), we get:

$$H(s) = \frac{2\xi w_n s D + w_n{}^2 D}{s^2 + 2\xi w_n s D + w_n{}^2 D} = \frac{2\xi' w_n' s + w_n'^2}{s^2 + 2\xi' w_n' s + w_n'^2} \tag{3}$$

In it, the characteristic frequency w'_n and damping coefficient ξ' is defined respectively as:

$$w' = \sqrt{\frac{KD}{\tau_1}} = \sqrt{D} w_n \quad \xi' = \frac{w_n \tau_2}{2} = \sqrt{D}\xi \tag{4}$$

w_n and ξ are characteristic frequency and damping coefficient without proportional gain D ($D = 1$).

Gain-adjustable food transportation tracking loop transient responses: In satellite navigation receiver baseband signal process, local, biased against intermediate frequency by Doppler frequency offset, is input to food transportation tracking loop once intermediate frequency is acquired and gone through frequency pulling. Therefore, in PLL transient responses analysis, frequency error of input signal $\theta_1(t)$ is set to Δw, whose S-domain expression is:

$$\theta_1(s) = \frac{\Delta w}{s^2} \tag{5}$$

The S-domain expression of output signal θ_2 (t) is:

$$\theta_2(s) = \theta_1(s) H(s) = \frac{\Delta w}{s^2} \cdot \frac{2\xi w_n s D + w_n{}^2 D}{s^2 + 2\xi w_n s D + w_n{}^2 D} \tag{6}$$

The Time-domain expression of output signal θ_2 (t), which is get through Laplace inverse transform, is showed as below.

When $\sqrt{D}\xi<1$:

$$\theta_2(t) = \Delta w t - \frac{\Delta w \sin(w_n \alpha t)}{w_n \alpha} e^{-D\xi w_n t} \tag{7}$$

When $\sqrt{D}\xi = 1$:

$$\theta_2(t) = \Delta w t - \Delta w t\, e^{-\sqrt{D} w_n t} \tag{8}$$

When $\sqrt{D}\xi>1$:

$$\theta_2(t) = \Delta w t - \frac{\Delta w \sinh(w_n \beta t)}{w_n \beta} e^{-D\xi w_n t} \tag{9}$$

where, $a = \sqrt{D - D^2\xi^2}$, $\beta = \sqrt{D^2\xi^2 - D}$.

Since the concerned input is frequency error, thus based the relationship between phase and angle frequency, angle frequency output w_{out} (t) is derived from phase output.

When $\sqrt{D}\xi<1$:

$$w_{out}(t) = \Delta w - \Delta w\, e^{-D\xi w_n t}\left[\cos(w_n \alpha t) - \frac{D\xi \sin(w_n \alpha t)}{\alpha}\right] \tag{10}$$

When $\sqrt{D}\xi = 1$:

$$w_{out}(t) = \Delta w - \Delta w e^{-\sqrt{D} w_n t}\left[1 - \sqrt{D} w_n t\right] \tag{11}$$

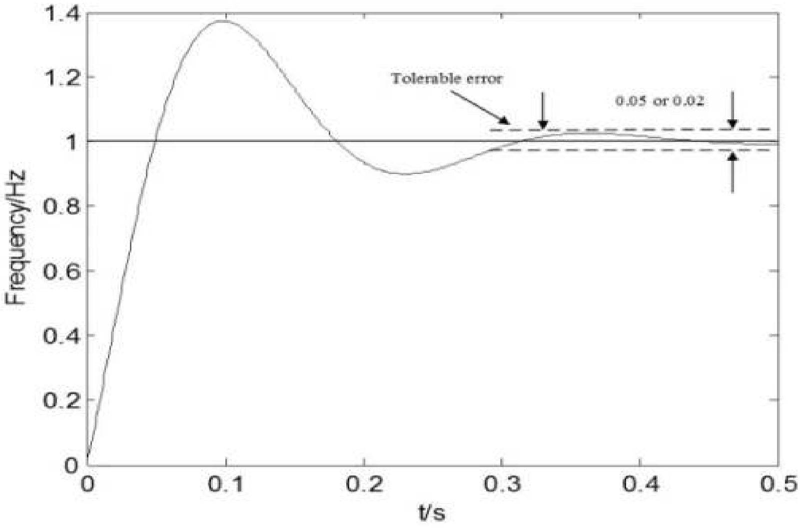


Fig. 2: Typical transient response curve of the 2nd-order system

When $\sqrt{D}\xi>1$:

$$w_{out}(t)=\Delta w-\Delta w e^{-D\xi w_n t}\left[\cosh(w_n\beta t)-\frac{D\xi\sinh(w_n\beta t)}{\beta}\right] \tag{12}$$

The key goal of designing gain-adjustability is to shorten loop locking time. Figure 2 shows the typical transient response curve of the two-ordered system.

From Fig. 2, adjusting time t_s refers to the shortest time to reach and retain within ±5% or ±2% of the final value, which reflects the synthetic index of response speed and damping intensity.

Food transportation tracking loop adjusting time t_s is solved via error transient response. Learned from Eq. (10) to (12), angle frequency error output response $w_e(t)$ is deduced.

When $\sqrt{D}\xi<1$:

$$w_e(t)=\Delta w e^{-D\xi w_n t}\left[\cos(w_n\alpha t)-\frac{D\xi\sin(w_n\alpha t)}{\alpha}\right] \tag{13}$$

When $\sqrt{D}\xi = 1$:

$$w_e(t)=\Delta w e^{-\sqrt{D}w_n t}\left(1-\sqrt{D}w_n t\right) \tag{14}$$

When $\sqrt{D}\xi>1$:

$$w_e(t)=\Delta w e^{-D\xi w_n t}\left[\cosh(w_n\beta t)-\frac{D\xi\sinh(w_n\beta t)}{\beta}\right] \tag{15}$$

Learned from w_e (t) expression, its steady-state value is 0. When analyzing adjusting time, loop locking time is decided by 5% error band. Thus, adjusting time t_s is the minimum value satisfying permanent establishment of 5% error band, namely:

Table 1: Parameter settings of the optimal gain food transportation tracking loop

Parameters	Setting
Sampling frequency	5.714 MHz
IF signal	1.405 MHz
Loop gain	1
Noise bandwidth	25 Hz
Damping	0.707
CNR	45 dB/Hz

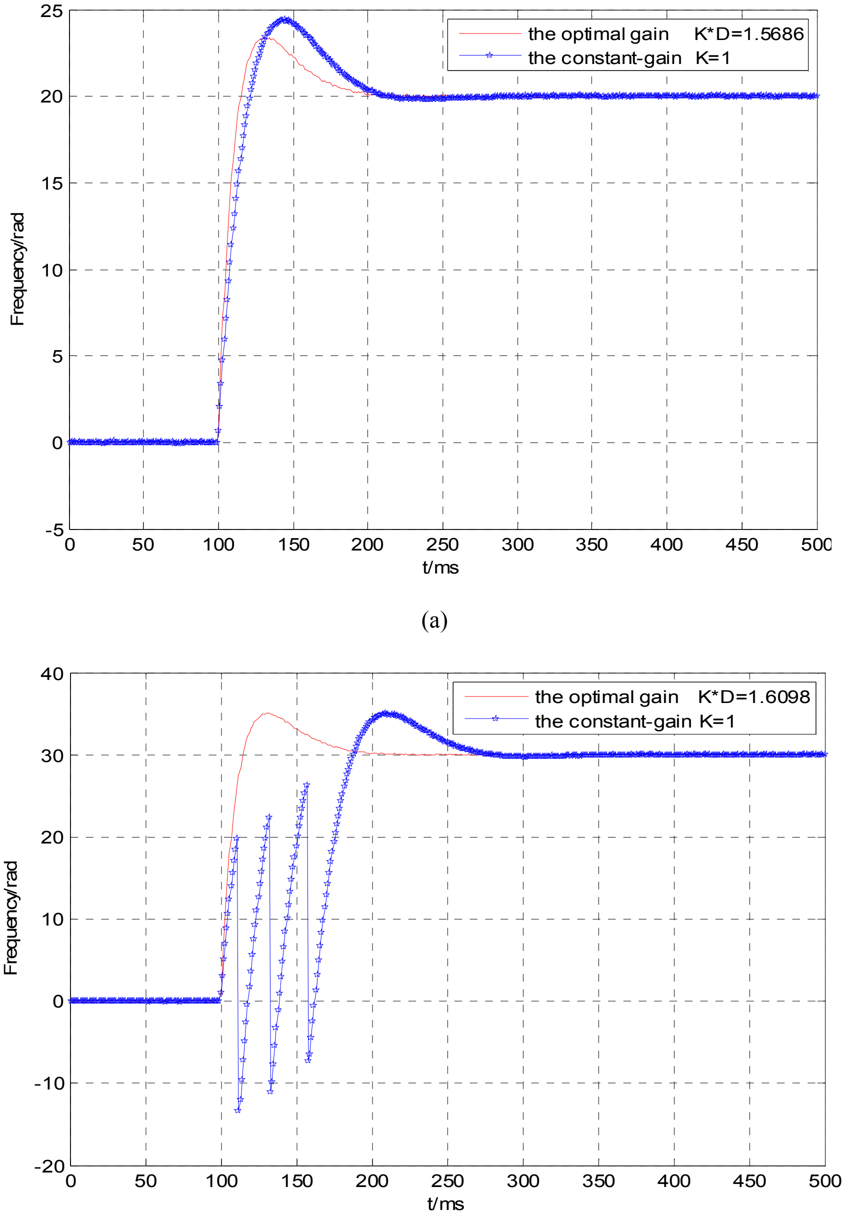
$$|w_e(t_s)| \le 5\% \tag{16}$$

Substituting Eq. (13) to (15) into Eq. (16), the analysis expression of proportional gain D regarding adjusting time t_s is still unable to attain. In the next chapter, the research will focus on the effects of proportional gain on adjusting time and solve the optimal gain.

RESULTS AND DISCUSSION

Simulation and analysis: Use MATLAB-based software receiver as the test platform and test signal is generated by the GPS signal simulator which chooses L1 band of the 7th Star. Food transportation tracking loop parameters setted as shown in Table 1. The following analysis will compare the traditional constant-gain loop with the designed optimal gain loop on lock-time and accuracy problems. Comparative analysis on lock-time applies 5% error as the evaluation standards. Food transportation tracking precision is measured by angular frequency output variance after loop locked.

Figure 3 is a comparison chart between the constant-gain and optimal gain food transportation tracking loop which are plotted in the MATLAB software receiver platform. Figure 3a and b, respectively, frequency error information is 20 and 30 Hz.



(a)

(b)

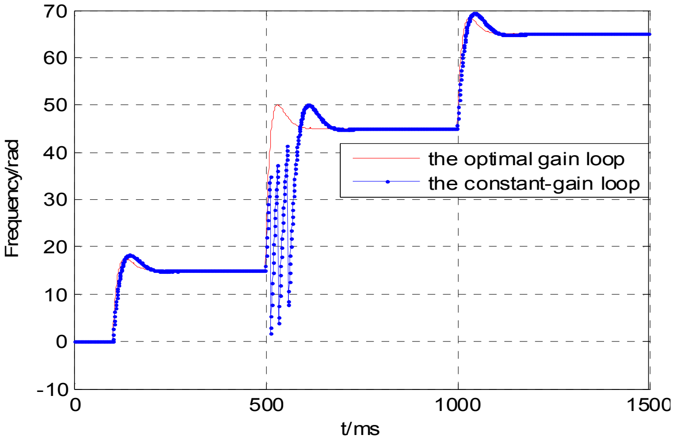
Fig. 3: Comparison chart of food transportation tracking loop performance

Table 2: Comparative analysis of food transportation tracking loop performance

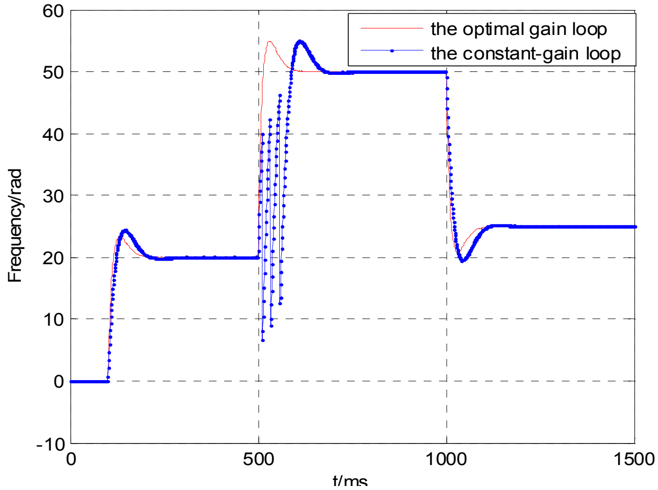
Evaluation indicators	Lock-time (msec)		Food transportation tracking accuracy (rad^2)	
Doppler shift (Hz)	20	30	20	30
The constant-gain loop	184	257	6.9×10^{-4}	6.7×10^{-4}
The optimal gain loop	120	137	6.5×10^{-4}	6.6×10^{-4}

Drawn from Table 2, compared with the constant-gain loop, when Doppler frequency shift is 20 and 30 Hz, the lock-time of the proposed optimal gain loop is respectively improved as 34.5 and 46.7%, which is substantially reduced. While Fig. 3b shows, when the frequency error is larger, the optimal gain loop can avoid the phase cycle slips. Due to the loop noise, food transportation tracking accuracy is to the same order of magnitude. So the designed optimal gain loop ensures food transportation tracking accuracy.

Signal food transportation tracking under low dynamic environment in actual satellite navigation, Doppler frequency shift will produce when velocity changes. Suppose Doppler frequency shifts respectively



(a)



(b)

Fig. 4: Simulation results figure

produced in food transportation tracking loop are 100, 500 and 1000 msec, respectively comparatively analyze the lock performance between the constant-gain and the optimal gain food transportation tracking loop. Figure 4 are the simulation results when Doppler frequency shift changes as 15, 30, 20 and 20, 30, -25 Hz, separately.

Shown from Fig. 4, the designed optimal gain food transportation tracking loop can well adapt to frequent low dynamic food transportation tracking environment. Compared with the constant-gain loop, the optimal gain food transportation tracking loop has obvious advantages in lock-time and can overcome phase cycle slips, which improves loop stability and ensures accuracy of the food transportation tracking loop.

Therefore, the designed optimal gain food transportation tracking loop not only shortens the loop lock-time, but also ensures the accuracy of the food transportation tracking loop, which has great promotional value in real-world applications.

CONCLUSION

The loop gain is generally constant in the traditional food transportation tracking loop of satellite navigation receivers, resulting in the relatively limited loop dynamics. So it’s unable to meet the needs of fast-lock loop. Thus this study designs an optimal loop gain algorithm for food transportation tracking loop. By testing in software receiver platform, the optimal loop gain design in loop can achieve fast-lock in food transportation tracking. At the same time it takes into account the loop food transportation tracking accuracy and the stability of signal is improved as well.

ACKNOWLEDGMENT

Fund project: This study is supported by Youth Foundation, National Natural Science Foundation of China (61102130), “Innovation Project of Academy of Opto-Electronics”, Chinese Academy of Sciences (Y12414A01Y).

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