Strap-down seeker LOS angular rate estimation

Wang Wei, Lin Defu, Xu Ping

(School of Aerospace Engineering, Beijing Institute of Technology, Beijing 100081, China)

Abstract: With obvious advantages comparing to gimbaled seekers, strap-down seekers attract more and more attention from military of different countries. Since strap-down seeker can not measure the line-of-sight (LOS) angular rate directly, the problem of LOS angular rate extraction is solved firstly, which generally has two methods. One method is to get the LOS angular rate by solving the differential of LOS angle versus time, the other is to estimate the LOS angular rate by Kalman filter. The models of these two methods was built and simulations of them were made respectively. The simulation result shows that, the second method is better than the first one. The time delay of LOS angular rate estimated by Kalman filter is relatively shorter than that obtained through differential network. With the measurement noises at the same level, the output LOS angular rate noise of the second method is smaller than the first one.

Key words: line-of-sight (LOS) angular rate; strap-down seeker; Kalman filter

CLC number: TJ765 **Document code:** A **Article ID:** 1007-2276(2015)10-3066-04

捷联导引头弹目视线角速率估计

王 伟,林德福,徐 平

(北京理工大学 宇航学院,北京 100081)

摘 要: 捷联导引头相对于框架式导引头而言,拥有许多优势。捷联导引头技术越来越受到各国军方的重视。捷联导引头无法直接测量弹目视线角速率,实现捷联导引头的工程运用首先需要解决弹目视线角速率的提取问题。弹目视线角速率提取的方法主要有两类,第一类是利用微分网络对弹目视线角进行微分来获取弹目视线角速率,第二类是利用卡尔曼滤波器对弹目视线角进行估计。建立了基于这两类方法的模型,并进行了仿真,仿真结果表明:第二类方法比第一类更具有优势。由卡尔曼滤波器估计出的惯性系弹目视线角速率比运用微分网络得到的惯性弹目视线角速率具有更小的延迟;在相同的量测噪声水平下,第二种方案输出的惯性系弹目视线角速率信号噪声水平更低。

关键词: 弹目视线角速率; 捷联导引头; 卡尔曼滤波器

收稿日期: 2015-02-11; **修订日期:** 2015-06-27

基金项目: 国家自然科学基金(61172182)

作者简介: 王伟(1984-),男,博士生,主要从事飞行器总体设计、飞行器制导与控制方面的研究。Email: wangweiyh@bit.edu.cn

导师简介: 林德福(1971-),男,教授,主要从事飞行器总体设计方面的研究。Email: lindf@bit.edu.cn

0 Introduction

Strap–down seeker, with outstanding performance[1], has become the focus of many countries′ military. Fixed on missile body, strap–down seekers output the error angle between LOS and seeker light axis under the missile body coordinate system[2], rather than the LOS angular rate directly under the inertial coordinate system[3–4]. To put strap–down seekers into practice utilization, the problem of extracting LOS angular rate should first be solved. Nowadays, two methods are alternated: one method is to subtract the missile attitude angle from the error angle measured by the strap–down seeker and then pass the signal from a differential network, the other method is to estimate LOS angular rate using Kalman filter technology [5–8]. Analysis of these two methods is of significant importance for the practical utilization of strap–down seekers. The two methods are compared in the following sections.

1 Model building

Fig.1 is the model of the first method. The second order differential network $\frac{s}{(T_ds+1)^2}$ is to solve the differential of LOS angle. The first order inertial lag element $\frac{1}{Ts+1}$ is the lag of guidance system [9]. The second order element $\frac{1}{T_m^2s^2+2T_m\mu_ms+1}$ is the aerodynamics of missile control system [10]. This model has 6 states from X_1 to X_6, respectively representing the LOS angle q, the LOS angular rate $\dot{q}$, the LOS angular rate $\dot{q}_d$ induced by time delay, the differential of missile acceleration versus time $\dot{a}_m$, the missile acceleration a_m, and the missile velocity v_m. The two measurement values are Z_1 and Z_2. Where, Z_1 is the error angle output by the seeker, with measurement noise V_1. Z_2 is the attitude angle output by attitude gyro, with measurement noise V_2. w_2 is the system disturbance. It is supposed that both the measurement noise and system disturbance noise are zero mean white noises. t_F is the guidance time, t is flight time, k_s is the calibration factor of seeker, k_g is the calibration factor of attitude gyro, and v is the relative velocity of missile versus target[11–12].

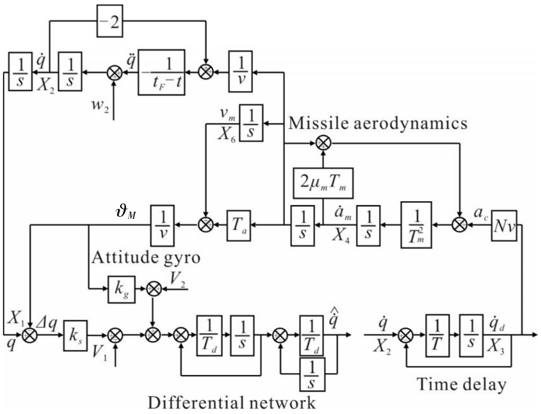

Fig.1 Model of the first method

Fig.2 is model of the second method. The symbols are the same with those in Fig.1.

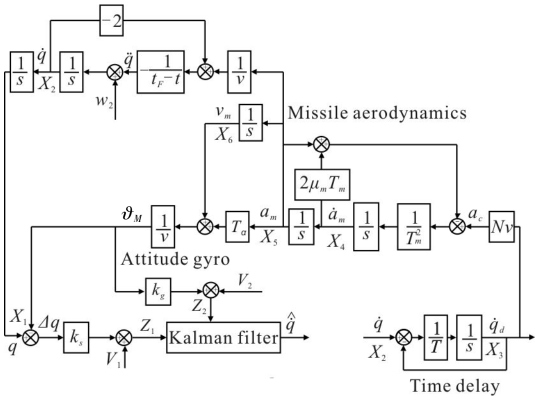

Fig.2 Model of the second method

The system state–space equation of Fig. 2 is:

$$\begin{cases}\dot{X}_1=X_2\\ \dot{X}_2=-\frac{1}{(t_F-t)}(-2X_2+\frac{X_5}{v})+w_2\\ \dot{X}_3=\frac{1}{T}(X_2-X_3)\\ \dot{X}_4=\frac{1}{T_m^2}(NvX_3-2\mu_mT_mX_4-X_5)\\ \dot{X}_5=X_4\\ \dot{X}_6=X_5\end{cases} \tag{1}$$

The measurement equation is:

$$\begin{cases}Z_1=k_s(X_1-\frac{1}{v}X_6-\frac{T_\alpha}{v}X_5)+V_1\\ Z_2=k_g(\frac{1}{v}X_6+\frac{T_\alpha}{v}X_5)+V_2\end{cases} \tag{2}$$

The preceding equations can be written in matrix mode as:

$$\dot{X}(t)=A(t)X(t)+F(t)W(t)\,;Z(t)=H(t)X(t)+V_n(t) \quad (3)$$

Where,

$$A(t)=\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & \frac{2}{t_F-t} & 0 & 0 & -\frac{1}{(t_F-t)v} & 0 \\ 0 & \frac{1}{T} & -\frac{1}{T} & 0 & 0 & 0 \\ 0 & 0 & \frac{N_v}{T_m^2} & -\frac{2\mu_m}{T_m} & -\frac{1}{T_m^2} & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad (4)$$

$$F(t)=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix},$$

$$H(t)=\begin{bmatrix} k_s & 0 & 0 & 0 & -\frac{k_sT_\alpha}{v} & -\frac{k_s}{v} \\ 0 & 0 & 0 & 0 & \frac{k_gT_\alpha}{v} & \frac{kg}{v} \end{bmatrix},$$

$$X(t)=\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \\ X_6 \end{bmatrix},W(t)=\begin{bmatrix} 0 \\ w_2 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix},Z(t)=\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix},V_n(t)=\begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

The model disturbance noise $W(t)$ and measurement noise $V_n(t)$ are zero mean white noises.

$$E\{W(t)\}=\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix},\mathrm{Cov}\{W(t),W(\tau)\}=Q(t)\delta(t-\tau)\,;$$

$$E\{V_n(t)\}=\begin{bmatrix} 0 \\ 0 \end{bmatrix},\mathrm{Cov}\{V_n(t),V_n(\tau)\}=R(t)\delta(t-\tau)$$

2 Simulation analysis

Suppose that the inertial LOS angular rate at the initial time is 0.034 9 rad/s. Set T=0.02, N=3, v=220, μ_m=0.1, T_m=0.08, T_a=1.6, k_s=1.0, k_g=1.0, T_d=0.1. Ignore the system disturbance noise.

The measurement noise power density spectrum matrix is $R(t)=\begin{bmatrix} 1.218\times10^{-8} & 0 \\ 0 & 1.218\times10^{-8} \end{bmatrix}$, the initial state is $X(0)=[0\quad 0.034\,9\quad 0\quad 0\quad 0\quad 0]^{\mathrm{T}}$, the initial value of Kalman filter is $\hat{X}(0|0)=[0\quad 0\quad 0\quad 0\quad 0\quad 0]^{\mathrm{T}}$;

$$P(0|0)=\begin{bmatrix} 0.007\,46 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.001\,218 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.001\,218 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 10 \end{bmatrix}$$

Solve the Kalman filter[13] equation under the preceding condition according to the system state equation and measurement equation. Then start the simulation with Fig.1 and the simulation result is illustrated in Fig.3. As shown in this figure, the time delay of LOS angular rate estimated by Kalman filter is relatively shorter than that obtained through differential network. With the measurement noises at the same level, the output LOS angular rate noise of the second method is smaller than the first one. As for the transient performance, the second method exhibits larger overshoot.

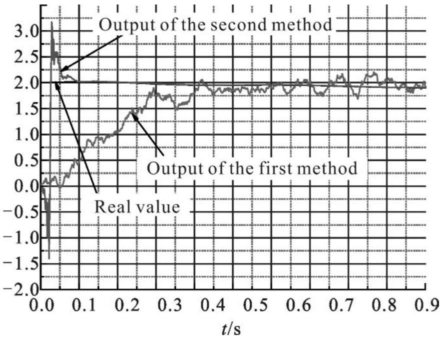

Fig.3 LOS angular rate comparison of the two methods

3 Conclusion

Based on strap-down seeker proportional navigation model, two LOS angular rate extraction methods are analyzed and the two models are founded respectively. The simulation result shows that the Kalman filter method is better than the traditional differential network method. The research conclusion is of significant practical value for the utilization of strap−down seekers.

References:

[1] Captain Thomas, Callen R. Guidance law design for tactical weapons with strapdown seekers[R]. AIAA−79−1732.

[2] Qian Xingfang, Lin Ruixiong, Zhao Yanan. Missile Flight Mechanics [M]. Beijing: Beijing Institute of Technology Press, 2000: 28−77. (in Chinese)
钱杏芳, 林瑞雄, 赵亚男. 导弹飞行力学 [M]. 北京: 北京理工大学出版社, 2000: 28−77.

[3] Zhou Ruiqing, Liu Xinhua, Shi Shouxia, et al. Strap−down seeker stability and track technology [M]. Beijing: National Defence Industry Press, 2010: 8. (in Chinese)
周瑞青, 刘新华, 史守峡, 等. 捷联导引头稳定与跟踪技术[M]. 北京: 国防工业出版社, 2010: 8.

[4] Yao Yu, Zhang Guojiang. Discussion on strapdown imaging guidance systerm[J]. ***Infrared and Laser Engineering***, 2006, 35(1): 1−6. (in Chinese)
姚郁, 章国江. 捷联成像制导系统的若干问题探讨 [J]. 红外与激光工程, 2006, 35(1): 1−6.

[5] Zhang Yue, Chu Hairong. Strapdown optical seeker characteristics and multi−dimension optimal guidance law [J]. ***Infrared and Laser Engineering***, 2013, 42 (11): 2967−2973. (in Chinese)
张跃, 储海荣. 捷联式光学导引头特性和多维度最优制导律 [J]. 红外与激光工程, 2013, 42(11): 2967−2973.

[6] Zhang Xin, Du Zhiyuan, Qiao Yanfeng, et al. Study on linear field of strapdown semi−active laser seeker [J]. ***Chinese Optics***, 2015, 8(3): 415−421. (in Chinese)
张鑫,杜智远,乔彦峰,等.全捷联激光半主动导引头线性视场研究[J]. 中国光学, 2015, 8(3): 415−421.

[7] Zhang Yue, Chu Hairong. Technical characteristics of strapdown image seeker guidance [J]. ***Optics and Precision Engineering***, 2014, 22(10): 2825−2831. (in Chinese)
张跃,储海荣. 全捷联图像导引头制导的技术特点[J]. 光学精密工程, 2014, 22(10): 2825−2831.

[8] Zhang Yue, Liu Bo, Yin Shengli. Strapdown optical seeker: stabilization,tracking principle and system simulation [J]. ***Optics and Precision Engineering***, 2008, 16 (10): 1942−1948. (in Chinese)
张跃,刘波,闾胜利. 捷联式光学导引头的稳定、跟踪原理与系统仿真[J]. 光学 精密工程, 2008, 16(10): 1942−1948.

[9] Yan Dong, Zhang Hongcheng. Strap−down seeker guidance system guidance law and adaptive filter design [J]. ***Journal of Astronautics***, 1996, 17(1): 8−14. (in Chinese)
颜东, 张洪铖. 捷联导引头制导系统导引律及自适应滤波方案设计[J]. 宇航学报, 1996, 17(1): 8−14.

[10] Jacques Waldmann. Line−of−sight rate estimation and linearizing control of an imaging seeker in a tactical missile guided by rroportional navigation [J]. ***IEEE Transactions on Control Systems Technology***, 2002, 10(4): 556−567.

[11] Sun Tingting, Chu Hairong, Jia Hongguang, et al. Line−of−sight angular rate decoupling and estimation of strapdown optical seeker[J]. ***Infrared and Laser Engineering***, 2014, 43 (5): 1587−1593. (in Chinese)
孙婷婷, 储海荣, 贾宏光, 等. 捷联式光学视线角速率解耦与估计[J]. 红外与激光工程, 2014, 43(5): 1587−1593.

[12] Lin Minxu, Wang Yongyang, Dai Ming, et al. Application of linear acceleromerer to Kalman filter for piezoelectric gyro [J]. ***Chinese Optics***, 2011, 4(6): 600−605. (in Chinese)
林旻序,汪永阳,戴明,等. 线性加速度计在压电陀螺卡尔曼滤波技术中的应用[J]. 中国光学, 2014, 4(6): 600−605.

[13] Wang Zhixian. Optimum State Estimation and System Identification [M]. Xi′an: Northwestern Polytechnical University Press, 2004: 6. (in Chinese)
王志贤. 最优状态估计与系统辨识[M]. 西安: 西北工业大学出版社, 2004: 6.