The improvement of the active support control system force transducer performance, based on Kalman filtering

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Keywords: Kalman filtering, active support control, noise processing

Abstract. In the active support control system, the sampling accuracy of force sensor directly affect the force control precision of the system, the surface of the primary mirror, and then affect the imaging quality of the optical system. Based on the Kalman filtering, this document introduces the force sensor signal filtering model of the active support system, verifies the validity of Kalman filtering to filtering the random noise signal via the Kalman filtering processing and analysis of the sampling of the active support system, realizes the high accuracy force of the system, which better the shape of the primary mirror.

Introduction

The active support system, show in Fig. 2, control the mirror surface shape through the force actuator, show in Fig. 3, distribute on the back of the mirror, to calibrate shape error because of the manufacture error, elastic deformation and surface shape error caused by the temperature gradient. It is of significance to reduce the telescope quality, shorten the manufacturing cycle and lower the cost. It is also the key technology in the development of the large scale telescope. The sampling accuracy of force sensor have a direct impact on the force applied to mirror control precision, thus affecting the primary mirror shape[1].

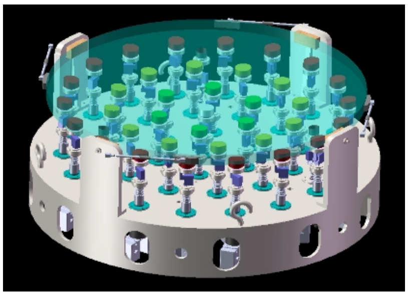

Fig. 1 Active support system

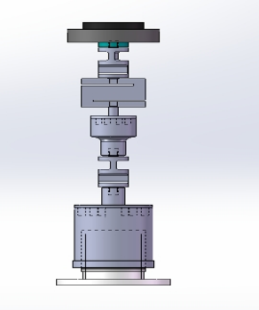

Fig. 2 Force actuator

Because of the random noise of the sensor amplifier, circuit board, and the external in the practical application process, huge deviation and disturbance exists in the feedback of the control system. Due to the low sampling precision of the force sensor, the power couple back to the mirror has great bias, which will have a great effect on the whole mirror shape. To solve the problem, we usually reduce the proportion of the noise in the measured value via large span and high accuracy A/D chip. However, the core of the system is the TMS320F2812(F2812) and its ADC module. So if do as the above, it will produce many hardware dissipation, and the range of the AD will directly impact the sampling precision of the force transducer.

This document utilize the Kalman filtering to wipe out the noise, using the DSP's ADC module, make good use of the DSP's resource, spare the cost of the hardware and diminish PCB's proportion, that increase the reliability of the PCB's signal. Appling the Kalman filtering to the system can filter the random noise greatly, getting stable, reliable signals.

Kalman Filtering

In 1960, the famous paper, describing recursion algorithm of the problem of the linear filtering of discreet system, was issued by Kalman. As the great advance of the digital computer, the Kalman filtering is widely used in the engineering, especially in the area of location navigation, signal processing and automatic control. The algorithm is based on the state-space representation, using the former estimation and the present observation, and show as the evaluation of the state. As an optimal state evaluation, Kalman obtain the recursion arithmetic. On account of the real-time observation data, polluted by the random noise, the arithmetic obtains the optimal estimation of the linear, unbiased and minimum error's variance of the system's status[2].

Mathematical model of the force transducer. Assume the state variable of the system's time k is X(k), then the system's state and observe equation show as follows[3]:

$$X(k) = AX(k-1) + W(k). \quad (1)$$

$$Z(k) = HX(k-1) + V(k). \quad (2)$$

A represents the gain among the state variables, W(k) is the process inspire noise, Z(k) represents the observed value of time k, H is the conversion matrix between the state variable and output, V(k) represents the observed noise; and suppose that W(k) and V(k) are separate, zero mean white noise, and their variance are Q and R respectively.

Owing to the object of filtering is the force transducer sampling signal, the true value of the signal keeping invariant is the state variable of the system, the process inspire noise is inexistence, so its mathematical model show as follows according the above:

$$X(k) = X(k-1). \quad (3)$$

$$Z(k) = X(k-1) + V(k). \quad (4)$$

Its state variable is invariable, that mean it's a true value. The system's signal model is depicted in the Fig. 3[4]. The true value with the noise comprises the observed value i.e. sampling value. The main goal of filtering is to find the true value among the sampling value.

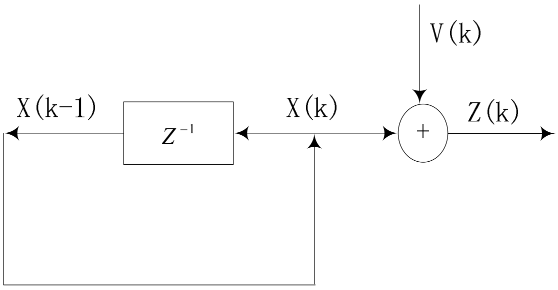

Fig. 3 Signal model

Establish of the Kalman Filter Model. After established the object's mathematical model, we should set up the Kalman filter model. There are two parts of the Kalman filtering: estimation and correction. The main task of the estimation process is to evaluate the current state according to the time update equation and calculate the value of present state variable and error covariance, to construct a prior estimate value. The correction process is responsible for the negative feedback, i.e. build the present state's revise via the prior estimation value and the current observe value.

On the basis of the details described above, we can get the system's Kalman filtering model:

$$X(k|k-1) = X(k-1|k-1). \tag{5}$$

$$P(k|k-1) = P(k-1|k-1). \tag{6}$$

X(k|k-1) is the result through the forecast of the previous state; X(k-1|k-1) is the optimal result of the previous state; P(k|k-1) is the covariance of X(k|k-1); so as the P(k-1|k-1) and X(k-1|k-1).

$$X(k|k) = X(k|k-1) + Kg(k)(Z(k) - X(k|k-1)). \tag{7}$$

$$Kg(k) = P(k|k-1)/(P(k|k-1) + R). \tag{8}$$

$$P(k|k) = (1 - Kg(k))P(k|k-1). \tag{9}$$

X(k|k) is the optimal value, and also the value we want to get; Kg(k) is the Kalman gain. When turns to the next moment, P(k|k) is the P(k-1|k-1) of expression (6), then the algorithm can compute by itself.

The Kalman filtering use the previous moment's estimate and the present moment's observe value to update the evaluation of the state variable via the signal and random noise's state-space representation. It has a great effect on filtering the random noise.

The Achievement of the Kalman Filtering

Origin of Signal. The major signal of filter is the force transducer's sign. The signal sampling system is shown in Fig. 4. The system adopt pneumatic actuator to emerge the power, while the transducer, interface SM-500N, transform the power into electrical signal, and convert to the signal of range of -10V～+10V via special amplifier. Owing to the DSP's ADC module that own the span of 0～3V, we should transform the signal of -10V～+10V to the range of 0～3V via signal conditioning module before sampling. According to the engineering experience, the DSP's ADC module exist gain and drift error in the practical application process, which lead to the three digit loss of the actual sampling precision of the DSP's ADC module, the true and the sampling value's relative error exceed 15% even[5]. So considering the veracity of the sampling value, we adopt measure of the rectification of two exact input signals, and adopt the normal input as the ADC module's referenced voltage.

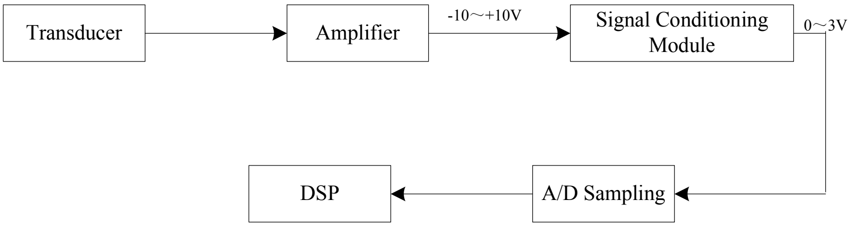

Fig. 4 Signal sampling system of force transducer

Application of Kalman Filtering. The experiment equipment is fixed upper and link to the cylinder below. When the cylinder is on the fly, the pressure of 23.55N exists on the upper of actuator, electrical signal is -0.471N corresponding. After transition of the signal convert module, the voltage is up to 1.57065V, while the sampling frequency of A/D is 10 kHz, show in Fig. 5. The sample value ranges from 1.5452V to 1.6211 without any filter dispose while the cylinder stays in static state, the deviation area is -0.0254～0.0505V,and with 0.0759V total offset. That, if as the feedback of the active support control system, the actuator would produce the force of -8.467～16.833N, while there is no pressure produce in theory. The power generated by the actuator directly effect to the primary mirror, that would lead to great error of the surface shape, so it is necessary to smooth the signal.

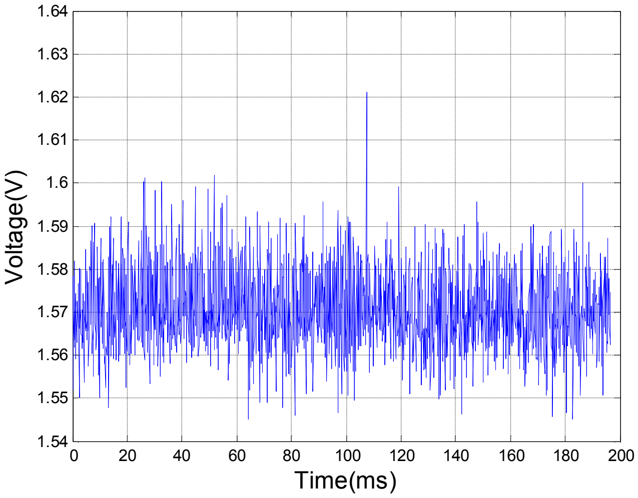

Fig. 5 Original sampling signal

Deal with Kalman filtering, the original signal voltage stays in the span of 1.5704～1.5709V, after 800 sets data when remain stable, while hold -0.00025～+0.00025V offset theoretically, the original signal after Kalman filtering is shown in Fig. 6 and its residual error depicted in Fig. 7.

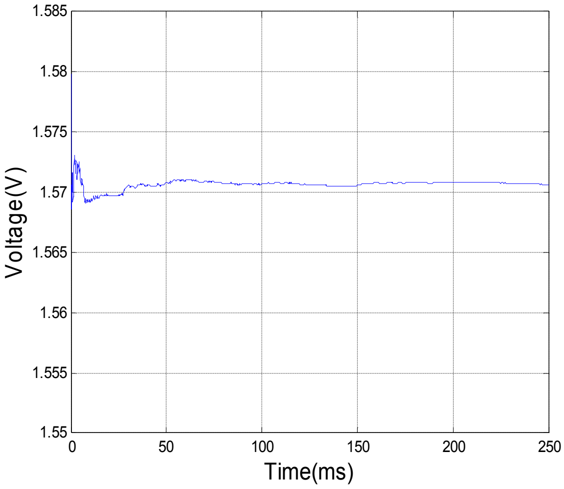

Fig. 6 Original signal after Kanlman filtering

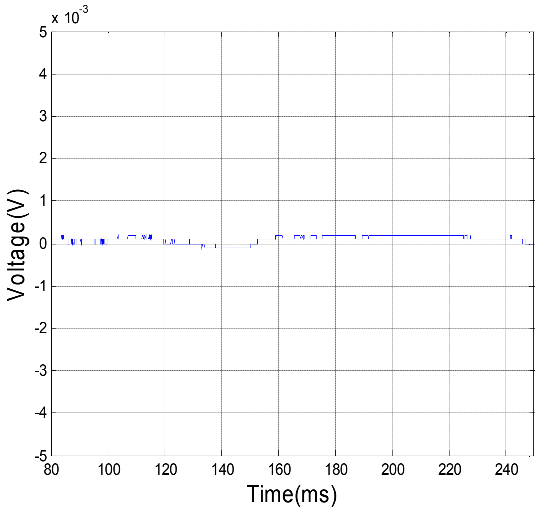

Fig. 7 Residual error

There is a convergence process in the Kalman filtering, and the convergent time is about 80 milliseconds via vast observe of the experiment. The scope of the deviation stays in -1～+1mV, close to the theoretical value. Although delay exists in the filtering, result in longer adjust time of the control system, the signal's precision and stability enhance greatly after Kalman filtering. The delay has no influence actual operation while the request of adjust time is 5 seconds, so it is feasible for Kalman filtering applying in the active support control system theoretically.

Applying the Kalman filtering to the active support control system as the algorithm handling the feedback sample signal, the PI arithmetic as its control algorithm. The output signal is shown in Fig. 8, while the set is -166.67N. Due to 800 groups data before remain stable, we choose the 800th record as the current true value coupling back to the system. See in the Fig. 8, a convergent time also exists in the output control signal, the adjust span of the force is -166.2433～-166.3463N, deviating -0.3976N～0.9033N from the set.

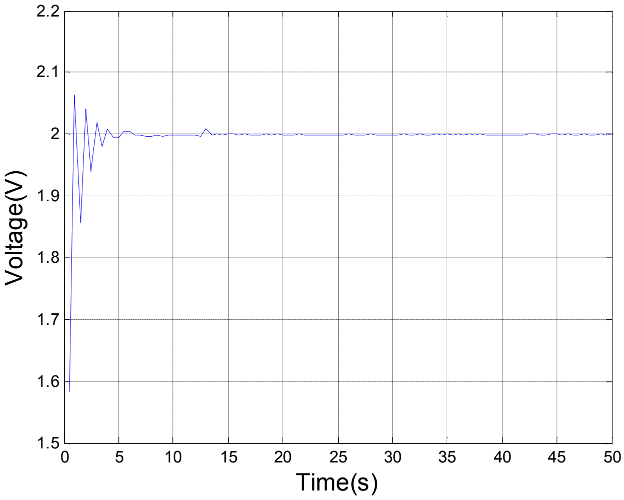

Fig. 8 Control signal

The continuous adjust output in the span is shown in Fig. 9, the control systyem stay stable after 3 seconds, its deviation remain in -1～+1mV. The force offset precision of the system is requested in -1.5～+1.5N, while adjust time in 5 seconds. So, although delays exist applying Kalman filtering, it is obvious advancing the force control precision, the adjust time is also in request, that would achieve the avtive support system's task effectively.

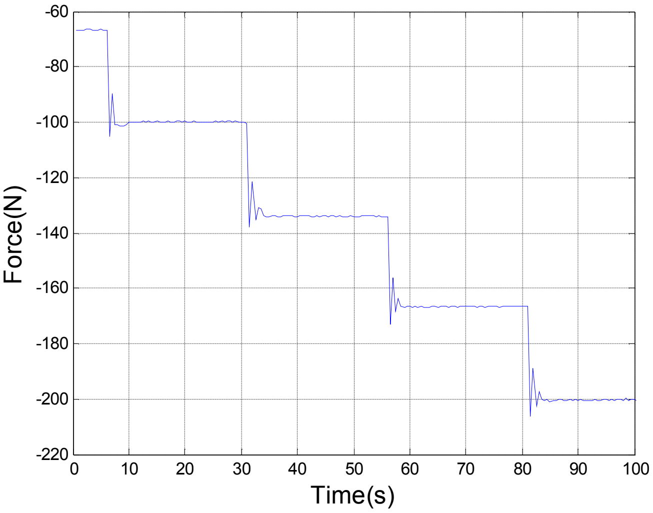

Fig. 9 Continuous output in the span

Conclusions

This document presents the means of conducting the sample signal of force transducer, establishs its mathematical model via Kalman filter's design, proves the applicability of the Kalman filter through vast experiments, reaches the conclusion that Kalman filtering could achieve the force's high-precision control in active support control system and has a great modify of mirror surface shape.

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